

Not to be cited without
permission of the authors¹

Ne pas citer sans
autorisation des auteurs¹

Canadian Atlantic Fisheries
Scientific Advisory Committee

Comité scientifique consultatif
des pêches canadiennes dans
l'Atlantique

CAFSAC Research Document 89/79

CSCPCA Document de Recherche 89/79

**Fluctuations in Mating, Reproduction and Recruitment
of the Snow Crab Population in Bonne Bay: Implications to Fisheries
Management**

by

M. Comeau, G. Y. Conan and D. A. Jones

Science Branch
Department of Fisheries and Oceans
Marine Biology Research Laboratory
Campus de l'Université de Moncton
Moncton, N.B.
E1A 3E9

¹ This series documents the scientific basis for fisheries management advice in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the Research Documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

¹ Cette série documente les bases scientifiques des conseils de gestion des pêches sur la côte Atlantique du Canada. Comme telle, elle couvre les problèmes actuels selon les échéanciers voulus et les Documents de Recherche qu'elle contient ne doivent pas être considérés comme des énoncés finals sur les sujets traités mais plutôt comme des rapports d'étape sur les études en cours.

Research Documents are produced in the official language in which they are provided to the Secretariat by the authors.

Les Documents de recherche sont publiés dans la langue officielle utilisée par les auteurs dans le manuscrit envoyé au secrétariat.

ABSTRACT

Snow crab couples were caught using SCUBA and tanglenets at depths ranging from 20 to 120 m in Bonne Bay, Newfoundland. The mean size of sexually coupled males decreased from 116.0 mm CW in 1984 to 109.1 mm CW in 1987 and to 85.2 mm CW in 1988. During the same period the percentage of clean carapace males increased from 0% in 1984 and 1987 to 34% in 1988. Female CW decreased from a mean of 71.1 mm in 1987 to 64.7 mm in 1988. Females with clean carapace increased from 0% in 1987 to 52.3% in 1988. The percentage of primiparous females also increased from 0% to 39.7% between 1987 and 1988. The percentage of juvenile males in couples remained low from 1984 (0%) to 1988 (less than 3%).

Trawl survey data in 1985 showed three major modes at 22 mm, 31 mm and 44 mm CW composed of juvenile males. In 1988, modes were observed at 60 mm and 80 mm CW for the juvenile males and, at 74 mm and 100 mm CW for the morphometrically mature males. This gives a growth per molt of 40.9% (22 mm to 31 mm CW), 41.9% (31 mm to 44 mm CW), 36.4% (44 mm to 60 mm CW) and 33.3% (60 mm to 80 mm CW) for juvenile males molting to another juvenile group. Growth into terminal molt gave an increase of 23.3% (60 mm to 74 mm CW) and 25% (80 mm to 100 mm CW).

Three major modes observed in 1985 were not observed in the 1988 trawl survey data, where only a few crabs could be observed at 30 mm CW and within the 40 mm CW group indicating a recruitment failure of certain year classes. Radioelement dating showed a maximum carapace age for mature males and females of approximately 3 years, indicating that most of the larger males in terminal molt captured in 1985 would have died prior to 1988 by natural mortality independently of any fishing effort.

The changes observed in Bonne Bay since 1984 can be explained by the combined effect of recruitment fluctuations and a high incidence of natural mortality among crabs morphometrically mature for more than 3 years. The undocumented illegal fishery may have had a lower than first assumed effect on the population. It may not be opportune to start a commercial fishery for experimental purposes while a natural population has been monitored successfully over several years.

RÉSUMÉ

Des couples de crabes des neiges ont été capturés par plongée et par filets maillants à des profondeurs variant entre 20 et 120 m à Bonne Bay, Terre-Neuve. La taille moyenne des mâles en couple a diminué de 116,0 mm LAC en 1984 à 109,1 mm LAC en 1987 et à 85,2 mm LAC en 1988. Parallèlement, le pourcentage de mâles à carapace propre a augmenté de 0% en 1984 et 1987 à 34% en 1988. La LAC chez les femelles a diminué d'une moyenne de 71,1 mm en 1987 à 64,7 mm en 1988. Le pourcentage de femelles primipares a aussi

augmenté de 0% à 39,7% entre 1987 et 1988. Le pourcentage de mâles juvéniles dans les couples est demeuré bas de 1984 (0%) à 1988 (moins que 3%).

Les données du chalutage effectué en 1985 démontrent trois modes à 22 mm, 31 mm et 44 mm LAC composés de mâles juvéniles. En 1988, des modes à 60 mm et 80 mm LAC ont été observés pour les individus mâles juvéniles et des modes à 74 mm et 100 mm LAC pour des individus mâles morphométriquement matures. Les augmentations de tailles à la mue sont de 40,9% (22 mm à 31 mm LAC), 41,9 % (31 mm à 44 mm LAC), 36,4% (44 mm à 60 mm LAC) et 33,3% (60 mm à 80 mm LAC) pour les individus mâles juvéniles ayant mué dans un autre groupe juvénile. La croissance à la mue terminale donne une augmentation de 23,3 % (60 mm à 74 mm LAC) et 25% (80 mm à 100 mm LAC).

Les trois modes observés en 1985 n'ont pas été observés dans les données de chalutage en 1988, où seulement quelques crabes ont été observés à 30 mm LAC et dans le mode situé à 40 mm LAC indiquant un manque dans le recrutement de certaines classes d'âge. La datation des carapaces par radioéléments a démontré que l'âge maximum des carapaces d'individus mâles et femelles morphométriquement matures était d'approximativement 3 ans, indiquant que la plupart des mâles de grandes tailles en mue terminale capturés en 1985 seraient morts avant 1988 par mortalité naturelle indépendamment de tout effort de pêche.

Les changements observés à Bonne Bay depuis 1984 peuvent être expliqués par les effets combinés des fluctuations dans le recrutement annuel et un taux élevé de mortalité naturelle pour les crabes morphométriquement matures depuis plus de trois ans. Il est suggéré que le braconnage non documenté exercé sur la population à Bonne Bay à un effet moindre qu'on ne l'avait anticipé par le passé. Il ne serait pas opportun d'initier une pêche commerciale à Bonne Bay présentement à des fins expérimentales alors que la population naturelle a été suivie depuis plusieurs années.

INTRODUCTION

The snow crab population in Bonne Bay has been studied since 1982 (Taylor *et al.* 1985, Hooper, 1986) with *in situ* observations on mating behavior. Mating couples from 1982 to 1984 were reported to be typically large dirty carapace males paired with multiparous females (Taylor *et al.* 1985). Since 1984, decreases in size and abundance of snow crab couples were reported primarily in 1986 and 1987 (Ennis *et al.* 1988b). Although abundance increased to the 1984 level in 1988, the size was still small and the incidence of newly molted males with clean carapaces had increased (Ennis *et al.* 1989). Trap data show the same reduction in abundance of large crabs since 1984 (Ennis *et al.* 1988a and 1989). Ennis *et al.* (1988a and 1989) stated that these significant changes have been related to the rapid development of an illegal fishery in Bonne Bay after 1984.

The purpose of this paper is to present the results of ongoing research started in 1984. These findings are preliminary and contribute to a data base from which the overall understanding of this snow crab population may be achieved.

MATERIALS AND METHODS

Snow crab couples were sampled using SCUBA at depths ranging from 20 to 55 m. Samples were obtained during the mating period for 1984, 1987 and 1988 with dives starting on May 24, May 11 and May 20 respectively. Couples were placed in separate mesh dive bags to prevent mixing of partners.

A tanglenet was used to capture crabs at depths ranging from 25 to 120 m. The tanglenet proved to be efficient in capturing solitary crabs as well as couples due to the possessive nature of the male snow crab holding his mate.

Trap surveys were conducted in 1985 (May), 1987 (May and June) and 1988 (April to August) in Bonne Bay. Small conical traps (base width: 115 cm; height: 62 cm; opening: 51 cm) doubled with 20 mm mesh were used at depths ranging from 30 to 120 m. Trawl surveys were conducted in 1985 (July, August and October) and in 1988 (July). A Bay of Biscay *Nephrops* otter trawl, with a 20 m opening designed for capturing semiburied crustaceans, was used at depths ranging from 120 to 140 m.

Measurements of carapace width (CW), absence of limbs and carapace condition were obtained from all crabs. Additional data were obtained on claw height (CH) for male crabs, and width of 5th abdominal segment, presence/color of egg mass, and the presence of old and new grasping marks, made during the mating embrace, for females. All measurements were done to the nearest 0.1 mm using calipers.

To identify male morphometric maturity, the methodology recommended by Conan and Comeau (1986) was used. The CH was plotted against CW on a logarithmic scale. A chi-square test was used to compare proportion between groups of crabs caught at different depth.

Oceanographic data obtained in 1988 included water temperature, dissolved oxygen, salinity, turbidity and particulate organic carbon. Water samples were obtained using a water sampling bottle. Surface and bottom temperatures were determined using a digital locking thermometer Vemco Ltd. attached to the water sampling bottle. This arrangement allowed water temperature to be taken at the depth of the water sample. Temperature profiles for the entire water column were obtained using an expendable bathythermograph (XBT Sippican Ltd. model MK-9). A dissolved oxygen meter was used to measure oxygen concentrations in surface and bottom water samples. Salinity of the water samples was determined in the laboratory using a hydrometer. One liter samples of sea water, obtained with the water sampling bottle were filtered, using microfiltering techniques to determine the particulate

organic carbon content (POC). Amounts of POC were determined following the procedures outlined by Strickland and Parsons (1972).

Plankton sampling was carried out in order to better understand the planktonic stages and distribution of the snow crab larvae. The plankton sampling device consisted of a 0.5 m diameter metal ring with a three point towing bridal, a flowmeter (General Oceanic Model 2030) and a conical plankton net (500 μ m) with a cod end bottle. A 0.25 m V-fin depressor, attached 5 m below the net was used to maintain the plankton net at the required depth. Depth of the net was determined using an ultra-sonic pressure transmitter (Vemco Ltd. model VR-60) attached to the ring of the plankton sampling apparatus.

RESULTS

Couples Captured using SCUBA and Tanglenet

In 1984, a total of 19 mating couples were collected (Table 1) by diving. The mean size of the males was 116 mm CW with size ranging from 97 mm to 134 mm CW. All sexually paired males were observed to be over 95 mm CW and had old shells.

In 1987 a total of 36 mating couples were collected (Table 1). Of that total, 28 were caught by diving and 8 by tanglenet. Sexually paired males collected by diving had a mean CW of 109.6 mm ranging in size from 85.8 to 122.6 mm CW. Sexually paired males caught in the tanglenet had a mean CW of 107.1 mm and ranged in size from 85.4 to 122.0 mm CW. Paired males under 95 mm CW made up 7.1% (2) of the couples caught by diving and 25.0% (2) of the couples caught by tanglenet. No sexually paired males caught in the tanglenet had clean carapaces, however 3.6% (1) of the diving sample did.

Sexually paired females caught by diving in 1987 had a mean CW of 70.6 mm and ranged in size from 59.2 to 84.3 mm CW (Table 1). Females which were brought up by males in the tanglenet, had a mean carapace width of 72.8 mm. None of the sexually paired females were primiparous and all had dirty carapaces.

The mean CW of all sexually paired males caught by diving and by tanglenet in 1987 was 109.1 mm and ranged in size from 85.4 to 122.6 mm CW (Table 1). The percentage of males under 95 mm CW was 9% with 2.3% (1) of those having clean carapaces. The mean size of all sexually paired females caught in 1987 by diving and tanglenet was 71.1 mm CW and ranged in size from 59.2 to 84.3 mm CW. Coupled females caught in 1987 were all multiparous.

In 1988 a total of 86 mating couples were collected (Table 1). Of that total, 44 were caught by diving and 42 by tanglenet. The sexually paired males

collected by diving had a mean CW of 80.9 mm and ranged in size from 56.9 to 126.8 mm CW. The males caught with the tanglenet had a mean CW of 89.6 mm and ranged in size from 60.6 to 125.9 mm CW. Paired males under 95 mm CW made up 86.4% (38) of the males caught by diving and 69.0% of those caught by tanglenet. Males with clean carapaces made up 54.5% (24) of those caught by diving and 14.3% (6) of the tanglenet sample.

Sexually paired females caught by diving in 1988 had a mean CW of 64.2 mm and ranged in size from 52.1 to 76.4 mm CW (Table 1). Females that were brought up by the males in the tanglenet had a mean CW of 65.2 mm and ranged in size from 48.5 to 79.7 mm CW. Clean carapace females made up 81.8% (36) of the females caught by diving and 21.4% (9) of those caught by tanglenet. The percentage of primiparous females caught by diving increased from 0% in 1987 to 77.2% (34) in 1988. No primiparous females were caught by tanglenet in 1987 or 1988.

The mean CW of all sexually paired males caught by diving and tanglenet in 1988 was 85.2 mm and ranged in size from 56.9 to 126.8 mm CW (Table 1). The percentage of males under 95 mm was 77.9% (67) with 34.9% (30) of them having clean carapace. The mean size of all the females was 64.7 mm CW and ranged in size from 48.5 to 79.7 mm CW. The percentage of primiparous females caught by diving in 1988 was 39.5% (34) and 52.3% (45) of all females caught had clean carapaces.

The allometric relationship of the CH vs CW plotted on a logarithmic scale shows a high percentage of morphometrically mature males in the couples. In 1984, all of the males sampled using SCUBA were morphometrically mature. The percentage of morphometrically mature males identified by a strong upper cloud of points in the allometric relationship remained high at 97.2% (35/36) in 1987 (Fig. 1) and 98.8% (85/86) in 1988 (Fig. 2).

The relationship of female CW vs male CW shows the presence of two clouds in this couple size ratio plot (Fig. 3a). The two clouds represent two groups of individuals separated by carapace condition (i.e. dirty and clean; Fig. 3b, c). The upper cloud is composed of dirty (larger) carapace males coupled with larger females. The lower cloud represents males with clean (smaller) carapaces coupled with smaller females. Male CW ranged from 90 mm to 130 mm and female CW ranged from 63 mm to 83 mm in the upper cloud. The CW's observed in the lower cloud were somewhat smaller, ranging from 58 mm to 100 mm for the males and from 49 mm to 75 mm for the females.

By combining male carapace condition of the dive sample and the tanglenet sample, two distinct groups appear as a function of depth. The two groups of sexually paired males, found at depths <40 m, were composed of an equal number (24) of crabs with dirty carapaces and crabs with clean carapaces. At depths greater than 40 m, the number of dirty males is 4.5X greater than clean carapace males (18 dirty, 4 clean). A significant difference ($p= 0.0116$) was found when comparing these two groups with a chi-square test.

Tanglenet Data

A total of 353 crabs were caught by tanglenet at depths ranging from 25 to 120 m in 1988. A histogram showing the multimodal distribution is observed for the males (Fig. 4) and the females (Fig. 5). The size distribution for the males ranged from 48 mm to 125 mm CW, with a mean size of 79 mm CW, and from 48 mm to 82 mm CW, with a mean size of 67 mm CW, for the females.

Trap Surveys

A total of 160 males were caught by trapping in 1985 (Fig. 6). The size distribution ranged from 81 mm to 134 mm CW with a mean size at 111 mm CW.

In 1987, 264 males were caught by trapping during the months of May and June and 1190 during the months of April to August in 1988. The histograms show multimodal size distributions ranging from 60 mm to 137 mm CW in 1987 (Fig. 7) and from 52 mm to 140 mm CW in 1988 (Fig. 8). The mean size dropped from 107 mm CW in 1987 to 89 mm CW in 1988. The graph of the CH vs CW plotted on a logarithmic scale shows an incidence of only 1.5% (4/265) juvenile males in 1987 (Fig. 9) compared to 5.2% in 1988 (Fig. 10).

A total of 51 females were caught by trapping in 1987 (Fig. 11), compared to 1962 in 1988 (Fig. 12). The size frequencies ranged from 59 mm to 83 mm CW and from 43 mm to 91 mm CW, for 1987 and 1988 respectively, with a major mode at 70 mm CW, in both cases. The mean sizes were at 72 mm CW in 1987 and 70 mm CW in 1988.

Trawl Surveys

A total of 2044 males were caught by trawling during the months of July, August and October in 1985 compared to 340 during the July 1988 trawl survey. The histograms show multimodal size distributions ranging from 14 mm to 132 mm CW, with major modes at 22 mm CW, 31 mm CW and 44 mm CW, in 1985 (Fig. 13) and ranging from 27 mm to 130 mm CW in 1988 (Fig. 14). The allometric relationships of the CH vs CW plotted on a logarithmic scale show a small overlap (55 mm to 60 mm CW) of morphometrically mature males (upper cloud) and juvenile males (lower cloud) in 1985 (Fig. 15) compared to 1988 (Fig. 16), where the overlap of the two clouds ranged from 55 to 103 mm CW. The size distributions of the juvenile males ranged from 14 mm to 60 mm CW, with three modes at 22 mm CW, 31 mm CW and 44 mm CW, in 1985 (Fig. 17) and from 27 mm to 103 mm CW, with modes at approximately 60 mm CW and the 80 mm CW, in 1988 (Fig. 18). The range in size distribution for the morphometrically mature males did not change between 1985 and 1988. However, within the size distribution a decrease in the number of males larger than 120 mm CW was observed in 1985 (Fig. 19) and an increase of smaller males (with modes at approximately 74 mm CW and 100 mm CW) was observed in 1988 (Fig. 20).

Trawling data indicates a change in the female component of the population between 1985 and 1988. A total of 3049 females were caught during the months of July, August and October in 1985 and 275 in July 1988. The size ranged from 12 mm to 86 mm CW with modes at 22 mm CW, 30 mm CW, 44 mm CW and 70 mm CW in 1985 (Fig. 21). Females pertaining to the modes below 55 mm CW were immature (82%) and all females with size greater than 55 mm CW (18%) were dirty multiparous females with orange eggs. The size range observed for the females caught in July 1988 (Fig. 22) varied from 28 mm to 78 mm CW. The histogram indicates a mode between 50 mm and 60 mm CW, and another at 67 mm CW. The percentage of multiparous females increased from 18% in 1985 to 45% in 1988. The percentage of immature females decreased from 82% in 1985 to 26% in 1988. Primiparous females, completely absent from the 1985 trawling sample, constitute 29% of the sample in 1988.

The ratio of large males (CW > 90 mm) vs mature females decreased from 1985 to 1988. The sex ratio was 1:9.5 (56:503) in 1985 compared to 1:3.6 (57/204) in 1988. A chi-square indicates a significant difference ($p < 0,001$) between these two sex ratios.

Oceanographic Parameters

Consecutive water temperature profiles for May to August show the formation of a thermocline between 10 to 50 m (Fig. 23). Temperatures below 80 m remain within the narrow range of 1.1^o to 1.3^o C. On May 25, temperatures within the thermocline ranged from 6.2^o C at 10 m to 0.8^o C at 50 m. The thermocline became more defined as the summer progressed, staying within the 10 to 50 m depth range. Similar temperature profiles were obtained from shallower depths (i.e. closer to shore) indicating that the temperature zones are fairly uniform and that a corresponding depth on the slope would be at the same temperature as in the profile in the water column.

Readings of dissolved oxygen at the surface ranged from 10.2 to 16.4 µg/ml with a mean at 13.1 µg/ml. At 120 m, mean dissolved oxygen was 10.0 µg/ml and ranged from 7.8 to 13.2 µg/ml. Dissolved oxygen levels for both surface and bottom samples followed the same trends indicating that oxygen profiles were relatively homogeneous from surface to bottom.

Salinity profiles indicate a higher salinity (33 o/oo) on the bottom compared to the surface (27 o/oo) (Fig. 24). Bottom salinity fluctuated between 32.4 to 33.4 o/oo. Surface salinity fluctuated greatly with the net influx of fresh water run off and tidal exchanges (15.8 to 31.5 o/oo).

Turbidity between April 25 and May 2 increased, reducing visibility from 10 to 4 m (Fig. 25). After May 2, the trend in turbidity was negative (less turbid) with improved surface visibility. Small reductions in surface visibility were noted on May 6, 12, 14 and 17. Turbidity followed a decreasing trend until June 4 where surface visibility reached 13.5 m and then followed an increasing trend into August with a drop to 9.0 m in surface visibility on August 23.

POC analyses revealed pulses of organic matter at various depth intervals in the water column. A representative bar graph from July 15 indicates a pulse at 10, 40 and 100 m (Fig. 26).

Larval Study

Chionoecetes opilio zoe 1 larvae were first observed in a vertical tow on April 25, 1988 and were found in abundance (237/4 tows) on May 24, 1988. *Hyas sp.* zoe 1 larvae were found in abundance (122/19 tows) between June 11-14, 1988. *Cancer irroratus* zoe larvae were present in great numbers (800/10 tows) on July 16 and 18, 1988. This order of events also seems to indicate the heat tolerance of each species. *C. opilio* larvae were found in surface samples with temperatures up to 9.3°C. *Hyas sp.* larvae were sampled in surface waters up to 12.9°C and *C. irroratus* zoe larvae were obtained from temperatures reaching 16.2°C. It would appear that *C. opilio* zoe 1 larvae remain within ranges of temperatures within the ranges of 0.6 - 3.3°C. *Hyas sp.* larvae were present in abundance between 0.6 - 5.8°C. *C. irroratus* seemed to thrive well at higher temperatures ranging between 12 - 12.3°C. These could reveal temperature limitations or depths at which other conditions were optimal (e.g. food availability and light intensity). The occurrences of *C. opilio* zoe 2 was limited to a single observation on June 14 at 40 m. *C. opilio* larvae in the megalops stage were not found in the plankton samples over the entire sampling period (April to August). A single zoe 2 (at 20 m) and 5 megalops (between 30 and 40 m) larvae were observed for *Hyas sp.* during the sampling period. *C. irroratus* megalops larvae were abundant (230/1 tow) on August 24, 1988 in the warmer surface waters.

DISCUSSION

Results show remarkable changes in composition of the Bonne Bay snow crab population since 1984. Similar changes were reported by Ennis *et al.* (1988a, b and 1989), who attributed these changes to a considerable reduction in the abundance of large commercial size (> 95 mm CW) males by the rapid development of an illegal fishery after 1984 (Ennis *et al.* 1988a). It was assumed that prior to 1985, the snow crab population in Bonne Bay was virgin (Taylor *et al.* 1985). However, our information from local fishermen indicates that there has always been a traditional, albeit non-legalized, snow crab fishery in Bonne Bay.

The recent changes observed in the mating couples included a net decrease in the mean CW and the percentage of old carapace crabs for both male and female. At the same time, the percentage of males under 95 mm CW increased from 0% in 1984 to 77.9% in 1988. Two distinct groups of mating couples are now being identified after these changes. Mating couples caught using SCUBA were originally composed exclusively of large (>95 mm CW) dirty shell males frequently having missing limbs, and mating with large dirty shell

females in similar condition. Couples are now composed of 1.) large dirty carapace males mating with large dirty shell females and 2.) small males with clean carapaces, mating with smaller clean shell females. The two types of males clearly segregate into different groups with little intermixing (Fig. 3). We interpret these facts by the occurrence of a pulse of recruitment into the reproduction component of the population.

Our observations on mating couples in Bonne Bay are similar to Ennis *et al.* (1988a, b and 1989), although our interpretation of facts may differ. Ennis *et al.* (1989) data shows 80% of clean carapace for both males and females, compared to our estimates of 34.9% for males and 52.3% for females, as shown in Table 1. We attribute these differences to our use of a tanglenet which allowed us to capture couples in deeper water (down to 120 m) inaccessible to divers. The tanglenet enabled the capture of couples below the lower limit of the thermocline at 40 m (Fig. 23). Water temperatures below the thermocline remained fairly constant, ranging from 0.5° to 1°C (Fig. 23). Paired male crabs caught deeper than 40 m were mostly dirty crab (82%) compared to the cleaner ones caught at depths less than 40 m (50%). The carapace condition of paired males, caught by tanglenet at depths greater than 40 m (below the thermocline) is significantly different ($p < 0.05$) from the carapace condition of paired males caught by diving and tanglenet at depths above 40 m, indicating a segregation of the couples by temperature or bathymetry on the very steep slope. We believe that the vertical movement of couples is not a breeding migration, as stated by Hooper (1986), but a competitive territorial exclusion of inferior males by dominant males. The mating movement observed in Bonne Bay is not directly related to mating but is a combination of 1.) exclusion by competition (during mating) of inferior male towards less favorable grounds by the dominant male (larger, old dirty males) and 2.) the geomorphology of the bay, which limits the horizontal movement of inferior males. Prior to the recruitment pulse, males with missing legs or claws were abundant within diving range.

Thus, inferior males, either old "amputees" or small clean males, tend to concentrate in shallower depths, while dominant males occupy the better niche at greater depths. Our experiments using sonic tags also show strong sedentary behavior for large, old shell males and active movements for small clean shell males (Maynard, unpubl. data). A reduction in crab abundance, either by natural mortality or illegal fishing, will reduce competition during mating, and explain the low number of couples collected by diving in 1986 and 1987 by Ennis *et al.* (1988b).

It is not clear yet what factors initiate mating activity in Bonne Bay. However, it was observed that the occurrence of couples on the slopes up to diving range always took place after a heavy phytoplankton bloom (G. Conan pers. obs.). The couples can actually be seen moving up into shallower water immediately after the first phytoplankton spring bloom. This behavior is presently being monitored by secchi disk, time/depth profiles and POC in the water column. Although a few couples can be found in deep water (120 m) prior to the bloom, the 1988 data partially showed that the particulate carbon,

resulting from the first bloom, reached depths of 120 m within a few days and appears to activate mating activity of morphometrically mature individuals.

All males in couples encountered in Bonne Bay can be identified as morphometrically mature. This characteristic remained constant since 1984. Conan and Comeau (1986) observed in the field that among morphometrically mature animals, only the larger ones (approximately 95 mm and more) were functionally mature, i.e. apt to grab a female, carry her around (precopulatory embrace) and mate. Part of this statement may be updated based on recent observations. Our data collected on couples suggested that size (<95 mm CW) does not prevent males from mating and corroborate statements by Ennis *et al.* (1988a, b and 1989). However, this appears to be a very marginal participation to reproduction. Small morphometrically mature males only mate with smaller females and appear to be competitively excluded from mating as a function of size as anticipated by Conan and Comeau (1986). In stable populations, with sufficient presence of large males, all males < 95 mm CW, are excluded from mating and most likely physically eliminated (killed) by the larger males. Very few small morphometrically mature, if any, are found on the fishing grounds. Diving observations on couples produce biased estimates on the importance of the participation of small males to mating because only a marginal part of the population comprising mostly handicapped males is sampled.

The statement indicating that males have to be morphometrically mature to mate (Conan and Comeau 1986) has remained unchanged and is reinforced by our observations on mating couples and those by Ennis *et al.* (1989). The discriminant function identifies that the reproductive component of the population was composed entirely of morphometrically mature males in 1984, 97.2% in 1987 and 98.8% in 1988. These departures are within the range of the discriminant power of the tool. Figure 1 in Ennis *et al.* (1989) shows one point outside of the allometric curve, making up 0.5% (1/203) of juvenile crabs. This percentage agrees totally with our findings. The existing data from the Bonne Bay snow crab population supports the statement that mating so far observed in nature occurs exclusively between mature females and morphometrically mature males.

The high incidence of morphometrically mature males in couples should be anticipated due to the timing of molting and mating. Molting occurs generally prior to the mating period implying that terminal molt males would not be affected by post-molting soft shell condition compared to the juvenile males that molted. During the mating period the juvenile males and the newly terminal molt males can not compete with the terminal molt males for females and are excluded from mating due to their soft shell condition. Thus, the ability for male to proceed with the precopulatory embrace and the mating will be determined by molt stage and carapace condition rather than size.

Mating involving juvenile males in nature is so far inconclusive. Moriyasu and Conan (1988) reported the mating of juvenile males with primiparous females in aquaria. This mating was observed a month before morphometrically mature males mated with multiparous females. The presence

of a large amount of primiparous females having recently molted (identified by radioelement dating of carapace) and bearing orange (recently spawned) eggs at the very beginning of the mating season of morphometrically mature couples in Bonne Bay, may indicate that primiparous females mate earlier in nature out of the range of divers, using a different mating strategy. The participation of such females in the actual reproduction of a stable population may be extremely limited. Trawl surveys in the Gulf identified only 2% of primiparous females within the egg bearing category.

In identified locations, the percentage of juvenile males captured by trapping was low (5.2% for CW > 55 mm), compared to trawling where 70% of the males >55 mm CW were identified as juvenile. Traps seem to be more selective toward catching morphometrically mature crabs which have reached terminal molt, this may naturally enhance yield by protecting individuals still able to grow. It is the percentage of crabs reaching morphometric maturity as a function of size which now appears to be determinant for yield predictions. So far, no observations are available on this due to selective depletion of morphometrically mature populations by heavy trap fishing in the Gulf of St Lawrence. By following the recruitment pulse through time in Bonne Bay, an area protected from fishing, such information could be provided. The *Nephrops* trawl has now been used by several authors (Comeau, 1985, Conan and Comeau, 1986, Comeau, 1987, Mallet *et al.* 1988 and 1989) to study snow crab populations and is less selective toward juvenile and post molt crabs. Interpretations of snow crab population structure, and particularly recruitment, should be based on trawl data rather than trap data.

The histograms plotted from the trawl survey data give good indications on growth for the snow crab populations in Bonne Bay. In 1985, three major modes were observed giving a growth per molt for males (in nature) of 40.9% (22 mm to 31 mm CW) and 41.9% (31 mm to 44 mm CW). These growth per molt are approximately 10% higher than laboratory data on carapace width increments found by Miller and Watson (1976) for small crabs from the Gulf of St. Lawrence. However, Miller and Watson (1976) did not differentiate between terminal molt and non terminal molt in their data. Furthermore, carapace ageing using a radioelement technique, described by Le Foll *et al.* (1989), indicates that the inter-molt period (time between molt) for small males in the 30 and 40 mm CW group is approximately one year (Conan *et al.* in prep.). We may quite reasonably assume, as a first approximation, that each mode represents one year class, molting once a year over the range of sizes studied.

The juvenile and mature males have to be interpreted separately for the 1988 trawl data due to a difference in growth rate of juvenile males at the terminal molt (Moriyasu *et al.* 1987). Data on juvenile males in 1985 (Fig. 17), showed the absence of age groups which should have recruited over the past years. Data over the same size ranges in 1988 (Fig. 18) shows the presence of well represented age groups over the whole range of sizes. Morphometrically mature males in 1988 were composed of clean carapace individuals with smaller CW compared to 1985 (Fig. 19 and 20), indicating the initiation of a pulse of recruitment into that group from the juvenile males. The pulse is

expected to last over several years and reach sizes greater than 120 mm CW presently depleted.

In 1988 data, the percentage of growth from the mode at 44 mm CW (Fig. 13) to the mode at 60 mm CW (Fig. 18) was approximately 36.4%. The growth rate to the next mode (from 60 mm to 80 mm CW) was approximately 33.3%. Molt to maturity was partially achieved from modes at approximately 60 mm CW and 80 mm CW. The percentage of CW increase for the individuals molting to maturity was 23.3% (60 mm molting to 74 mm CW) and 25% (80 mm molting to 100 mm CW). Percentage of CW increments was less for the molt to maturity as anticipated. These findings on the molt to maturity agree with the size increment presented by Miller and Watson (1976) for larger crabs, although these authors did not segregate individuals molting to morphometric maturity.

Fluctuations in abundance of larger terminal molt males in Bonne Bay can be due partially to the illegal fishery as stated by Ennis *et al.* (1989), although no data on that fishery are available to support it. However, these fluctuations could have been predicted without referring to poaching simply from the recruitment fluctuations observed in the 1985 data. Data from the 1988 trawl survey shows changes in the population structure from 1985. The overall size ranges varied slightly from 1985 (14 mm to 132 mm CW) to 1988 (27 mm to 130 mm CW), but the relative importance of modal groups along those size ranges varied considerably. Three major modes observed in 1985 (Fig. 13) were practically non-existent in the 1988 trawl survey data (Fig. 14), where only few crabs can be observed at 30 mm CW and within the 40 mm CW group. High percentages of crabs were found at sizes > 50 mm CW in 1988. These shifts in the population structure are probably due to the recruitment failure of certain year classes. An incidence of recruitment failure was indicated by a lack of males > 50 mm CW in 1985. Growth of individuals in the three major modes < 50 mm CW (recruitment pulses) in 1985 contributed to the large number of crabs > 50 mm CW observed in 1988 and should continue to do so for several years. Nevertheless, very few modes < 50 mm CW were observed in 1988, indicating another recruitment failure of those year classes.

The recruitment failure observed in Bonne Bay seems to take place at the larval stage. A monitoring for the presence of larvae initiated in 1988 indicates a good incidence of snow crab zoe 1 larvae just below the thermocline in May and early June. The transition from zoe 1 to zoe 2 in June, as observed by Lanteigne (1985) in the baie des Chaleurs, was never observed in Bonne Bay. The zoe 2 and the megalop stages were not present in the subsequent tows in June, July and August, indicating a high mortality at the larval stage or a net outflux (flushing) of larvae from the bay, during zoe 1 stage. The high mortality rate seems to be caused by the warmer supra thermocline water temperatures experienced in Bonne Bay during the summer of 1988, which were more suitable for larval species with warmer water tolerances (i.e. *C. irroratus*).

Natural mortality seems to have also played an important role in the fluctuations in abundance of large terminal molt males. The ageing of carapaces by radioelement dating showed a maximum carapace age for mature

males and females of approximately 3 years (Conan *et al.* in prep.). At this age, the carapace is fairly decalcified by bacterial or fungal action and limbs are missing (non-regenerated). This new finding indicates that most of the larger males in terminal molt captured in 1985 would have died prior to 1988 by natural mortality, independently of any fishing effort. This high natural mortality coupled with a lack of recruitment into the terminal molt male group in 1985 and 1986 would explain the low number of large males observed in mating pairs and trap samples by Ennis *et al.* (1988a, b and 1989).

Another observation supporting natural mortality, as one of the two major factors (the other being recruitment fluctuation) for the fluctuations in abundance of large terminal molt males, is the sex ratio of males with CW > 90 mm vs females in terminal molt. An increase in the sex ratio would have been expected from the pressure of an illegal fishery focussing only on large males (> 90 mm CW). Instead, trawl data from 1985 and 1988 shows a significant ($p < 0,001$) decrease in sex ratio, which dropped from 1:9.5 in 1985 to 1:3.6 in 1988. This data shows that natural mortality is high among crabs in terminal molt and may indicate that the effect of an illegal fishery on the relative abundance of crabs in the Bonne Bay snow crab population may be much lower than first thought.

The growth pattern of the Bonne Bay snow crab population based on data collected since 1985 can be described as follows (Fig. 27):

The population structure in 1985 was composed of small juvenile males and large dirty males in terminal molt. The juvenile males are the dynamic component of the population and will molt once a year. Males in the 22 mm CW mode grew to 31 mm CW (40.9% CW increase) in 1986, to 44 mm CW (41.9% CW increase) in 1987, and finally to 60 mm CW (36.4% CW increase) in 1988. Males in the 31 mm CW mode and the 44 mm CW mode reached the 60 mm CW mode in 1987 and 1986, respectively. The growths mentioned above are from juvenile crabs molting to another juvenile size group. No molt to maturity was achieved until 1987, which means a considerable reduction in the abundance of large dirty crabs primarily by natural mortality (for terminal molt males reaching 3 years of age, this is shown by the fact that trends in numbers are similar for males and for females, the latter not being fished) and fishing effort. The net reduction in terminal molt male crab was due to: 1) recruitment failure of the age groups preceding the 1980's recruitment pulse (modes observed at 22 mm CW, 31 mm CW and 44 mm CW in 1985) and 2) mortality (primarily natural mortality) among terminal molt males.

Males from the 44 mm CW mode in 1985 grew to maturity in 1987. A portion of the males at 60 mm CW (1986) grew to another juvenile size group at 80 mm CW (33.3% CW increase) and the other portion grew to maturity at 74 mm CW (23.3% CW increase). Thus, the first recruitment pulse into the terminal molt male group in 1987 was composed of small (74 mm CW) males. In 1988, another pulse of recruitment into the terminal molt group came from: 1) the 1987 mode at 60 mm CW that grew to 74 mm CW mode and 2) the 1987 mode at 80 mm CW that grew to 100 mm CW mode (25% CW increase). It seems that the growth from the 1987 mode at 60 mm CW went partially to the mode at 80

mm CW and to terminal molt mode at 74 mm CW. The males of the 1987 mode at 80 mm CW grew almost entirely to the terminal molt mode at 100 mm CW. The molt to maturity seems to be density-dependent. This assumption is based on the fact that no recruitment pulse could have increased the number of males for the past three years and the low abundance may have triggered the molt to maturity. It does not at this time seem to be genetically induced for a specific age group. The individuals of the recruitment pulse to the terminal molt group can also be observed in the mating couples.

Based on the observations mentioned above, the following pattern should be observed in the future (Fig. 27):

In order to simplify the discussion, we will start with the mode at 80 mm CW (1988) and then follow with the mode at 60 mm CW (1988). The mode observed at 44 mm CW in 1985 is composed almost entirely of terminal molt males in 1988. In 1989, some males of the 80 mm CW mode will molt to maturity at 100 mm CW and the others will molt to another juvenile group arbitrarily set at 104 mm CW (30% CW increase). Males from the mode at 104 mm CW will grow to maturity in 1990, reaching approximately 125 mm CW (20% CW increase based on Fig. 19). The third and final recruitment pulse into the terminal molt group, from the three original modes observed in 1985, will start in 1989. Some males will molt to the mode at 80 mm CW and the others to the mode at 74 mm CW in 1989. In 1990, some males will molt to 104 mm CW and the others 100 mm CW and finally in 1991, to the last molt at 125 mm CW. Some males may remain juvenile up to a carapace size of 120 mm CW and will molt to maturity at carapace sizes greater than 135 mm CW.

Small changes should be observed in Bonne Bay during 1989. Bigger changes should be anticipated in 1990, when the first of two recruitment pulses arrive contributing to the large males (> 120 mm CW) in the terminal molt male group. A positive trend in the occurrence of large males in the mating couples and trap samples should take place in 1990 due to: 1) the arrival of large (> 120 mm CW) terminal molt males into the population and 2) the natural death of the first small terminal molt male mode (74 mm CW) from 1987. The following year (1991), this phenomena should be more acute as: 1) the males from the two recruitment pulses (79 mm CW and 100 mm CW) in 1988 die, and 2) another recruitment pulse of large terminal molt males (> 120 mm CW) enters into the population. The abundance of small dirty males should decrease during the following years (1992 and 1993) due to natural mortality. No major recruitment pulse into the terminal male group should be anticipated before 1993, according to Figure 18. A recruitment failure, similar to the one observed in the years preceding the present recruitment pulse (mode 22 mm CW, 31 mm CW and 44 mm CW from 1985), should be observed in the successive years following it. By 1992, the population structure should be similar to the one observed in 1984. Thus, the Bonne Bay snow crab population may have an 8 year cycle. This actually corroborates the beliefs of fishermen in the southern Gulf.

The population structure hypothesized above is based on observations made since 1984 and reflect a possible scenario, if no changes are made to the

present status of that stock. The establishment of a commercial fishery in Bonne Bay would mean a significant increase in fishing mortality (incomparable to the rather traditional cottage industry paralegal fishery) and a net loss for possible future biological research. Many aspects of the life cycle of the snow crab are still not fully understood, for instance, the proportion of an age group recruiting to terminal molt as a function of size and abundance of large morphometrically mature males which is essential for the elaboration of a yield-per-recruit model for snow crab. The life cycle of the snow crab is complex and Bonne Bay, in its present state, offers a well defined low exploited population close to shore where biological studies may be conveniently carried out.

In conclusion, the changes observed in Bonne Bay since 1984 can be explained by the combined effect of recruitment fluctuations and the high incidence of natural mortality. We believe that the undocumented paralegal fishery may have had a lower than first assumed effect on the population and that it may not be an opportune time to start a commercial fishery. A commercial fishery would prevent us from observing the progression of the new recruiting males into the morphometrically mature/immature categories and subsequently calculating the probabilities of molting to morphometric maturity as a function of size. This information is required for the growth component in yield-per-recruit estimates.

ACKNOWLEDGMENTS

The authors wish to thank the following people for their assistance in the field:

Randy Angus, Michel Biron, Roland Cormier, Ted Currie, André Doiron, Daniel Ferron, Steve Hamet, Wade Landsburg, Marc Lanteigne, Don Maynard, Denis Poirier, Robert Rioux, and Andrew Ross.

Special thanks are provided to Guy Robichaud for his dedicated assistance in the plankton studies, and Mrs. Fernande Robichaud-Savoie for the typing.

REFERENCES

- Comeau, M., 1987. Maturité gonadique et mue pré-pubérale chez le crabe des neiges, *Chionoecetes opilio*, (O. Fabricius). Thèse de Maîtrise, Université de Moncton, Moncton, N.-B., 145 p.
- Conan, G.Y., and M. Comeau. 1986. Functional Maturity and terminal molt of male snow crab, *Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 43: 1710-1719.
- Ennis, G. P., R. G. Hooper, and D.M. Taylor. 1988a. Changes in size composition of male crabs (*Chionoecetes opilio*) participating in the annual breeding migration in Bonne Bay, Newfoundland. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/2: 14 p.
- 1988b. Functional maturity in small male snow crabs (*Chionoecetes opilio*). Can. J. Fish. Aquat. Sci. 45: 2106 - 2109.
1989. Changes in size composition of snow crab (*Chionoecetes opilio*) participating in the 1988 breeding migration in Bonne Bay. Can. Atl. Fish. Sci. Adv. Comm. Research Document 89/10, 16 p.
- Hooper, R. G. 1986. A spring breeding migration of the snow crab, *Chionoecetes opilio* (O. Fabr.) into shallow water in Newfoundland. Crustaceana 50: 257-264.
- Lanteigne, M., 1985. Distribution spatio-temporelle des larves de crabe appartenant aux genres *Chionoecetes* et *Hyas*, dans la baie des Chaleurs, Canada. Thèse de Maîtrise, Université de Moncton, Moncton, N.-B., 161 p.
- Le Foll, D., E. Brichet, J.L. Reyss, C. Lalou and D. Latrouite. 1989. Age determination of the spider crab *Maia squinado* and the European lobster *Homarus gammarus* by $^{228}\text{Th}/^{228}\text{Ra}$ chronology: possible extension to other crustaceans. Can. J. Fish. Aquat. Sci. 46: 720-724.
- Mallet, P., Y. Chiasson and M. Moriyasu, 1988. A review of catch, fishing effort and biological trends for the 1987 southwestern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery. CAFSAC Research Document, 88/32, 39 p.
- Mallet, P.E. Wade, Y. Chiasson, P. Degrâce, G. Conan et M. Moriyasu, 1989. La pêche du crabe des neiges (*Chionoecetes opilio*) dans le sud-ouest du golfe St. Laurent, en 1988: L'analyse des prises, de l'effort de pêche, et l'estimation de la biomasse. CSCPCA Document de recherche 89/25, 59 p.
- Miller, R.J., and J. Watson, 1976. Growth per molt and limb regeneration in the spider crab, *Chionoecetes opilio*. J. Fish. Res. Board Can. 33: 1644-1649.

- Moriyasu, M. and G.Y. Conan, 1988. Aquarium observation on mating behavior of snow crab, *Chionoecetes opilio* . ICES C.M. 1988/K:9.
- Moriyasu, M., G.Y. Conan, P. Mallet, Y.J. Chiasson and H. Lacroix, 1987. Growth at molt, molting season and mating of snow crab (*Chionoecetes opilio*) in relation to functional and morphometric maturity. C.M. 1987/K14, 22 p.
- Strickland, J. D. H and T. R. Parsons, 1972. A practical handbook of sea water analysis. Fish. Res. Bd. Canada Bulletin No. 167, 310 p.
- Taylor, D.M., R.G. Hooper, and G.P. Ennis. 1985. Biological aspects of the spring breeding migration of snow crabs, *Chionoecetes opilio*, in Bonne Bay, Newfoundland (Canada). Fish. Bull. U.S. 83: 707-711.

Table 1: Summary of snow crab characteristics for couples caught in Bonne Bay during the 1984, 1987 and 1988 spring mating season.

Year		N	Mean CW (mm)	Range (mm)	% Clean Carapace	%<95mm CW (Males) % Primiparous (Females)
1984	Males Diving	19	116.0	97.0-134.0	0	0
	Females Diving	-	-	-	-	-
	Males Tanglenet*	-	-	-	-	-
	Females Tanglenet*	-	-	-	-	-
	Males Total	19	116.0	97.0-134.0	0	0
	Females Total	-	-	-	-	-
1987	Males Diving	28	109.6	85.8-122.6	3.6	7.1
	Females Diving	28	70.6	59.2- 84.3	0	0
	Males Tanglenet	8	107.1	85.4-122.0	0	25.0
	Females Tanglenet	8	72.8	65.0- 81.4	0	0
	Males Total	36	109.1	85.4-122.6	2.3	9.0
	Females Total	36	71.1	59.2- 84.3	0	0
1988	Males Diving	44	80.9	56.9-126.8	54.5	86.4
	Females Diving	44	64.2	52.1- 76.4	81.8	77.2
	Males Tanglenet	42	89.6	60.6-125.9	14.3	69.0
	Females Tanglenet	42	65.2	48.5- 79.7	21.4	0
	Males Total	86	85.2	56.9-126.8	34.9	77.9
	Females Total	86	64.7	48.5- 79.7	52.3	39.5

*Tanglenet was not used

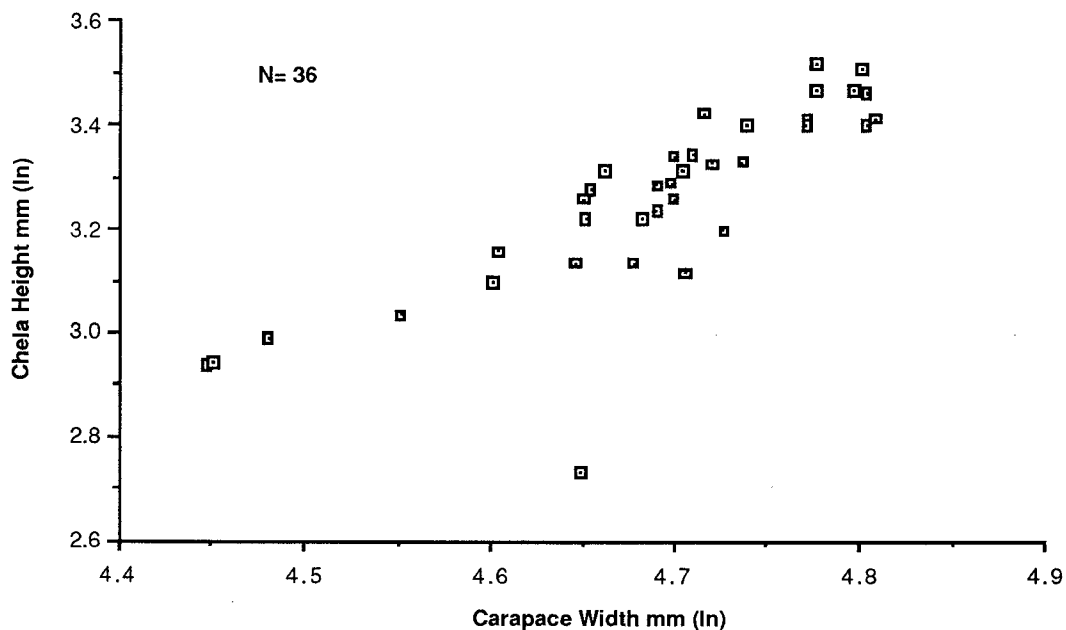


Figure 1. Chela Height vs Carapace Width plotted on a logarithmic scale for all sexually paired males *C. opilio* caught in Bonne Bay, 1987

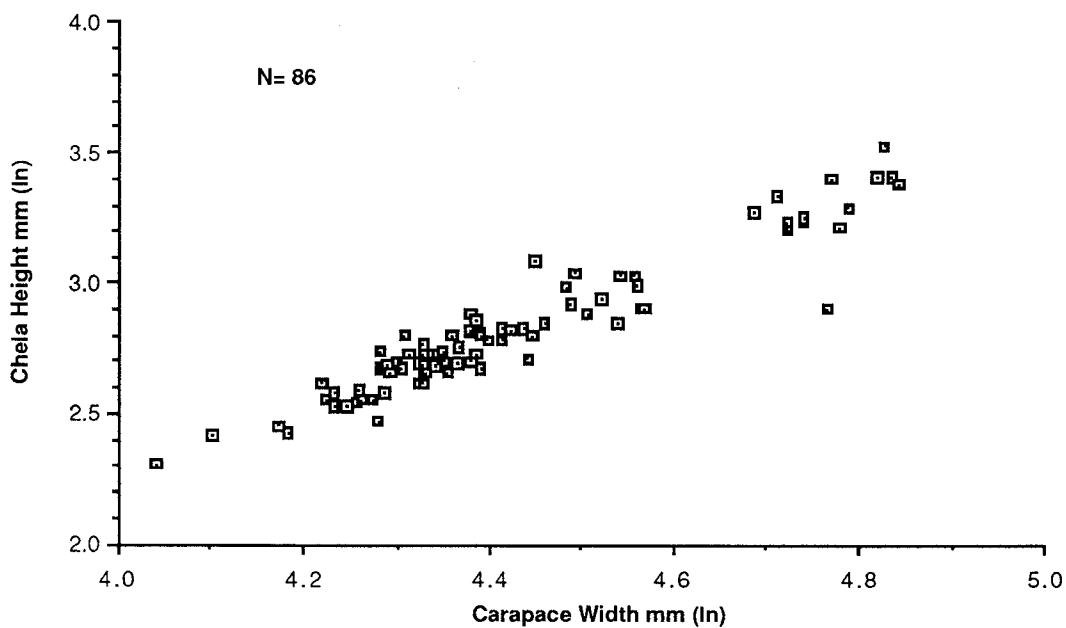


Figure 2. Chela Height vs Carapace Width plotted on a logarithmic scale for all sexually paired males *C. opilio* caught in Bonne Bay, 1988

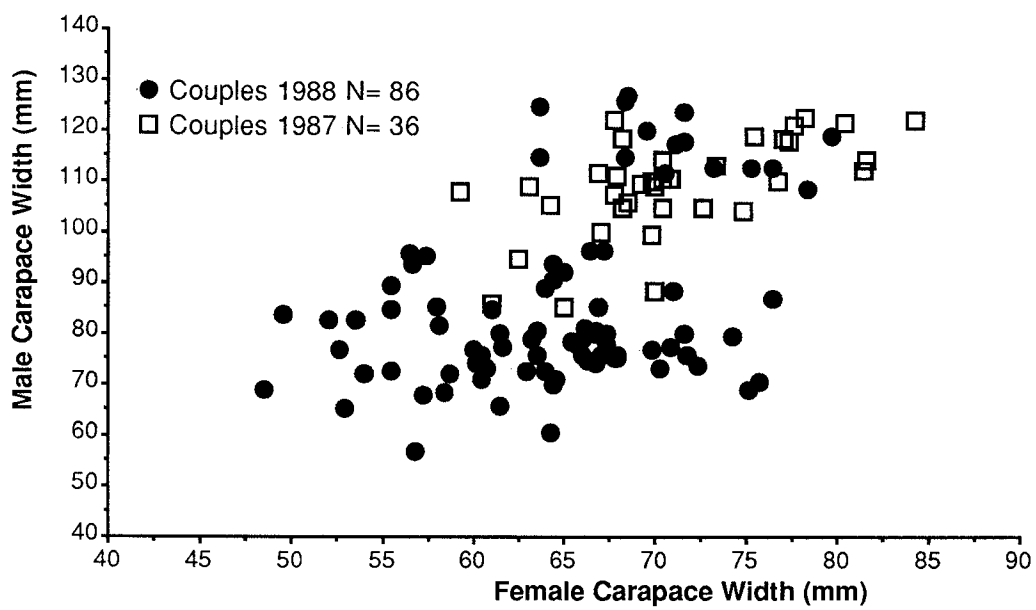


Figure 3a. Couple Ratios for all sexually paired snow crab collected in Bonne Bay, 1987-1988.

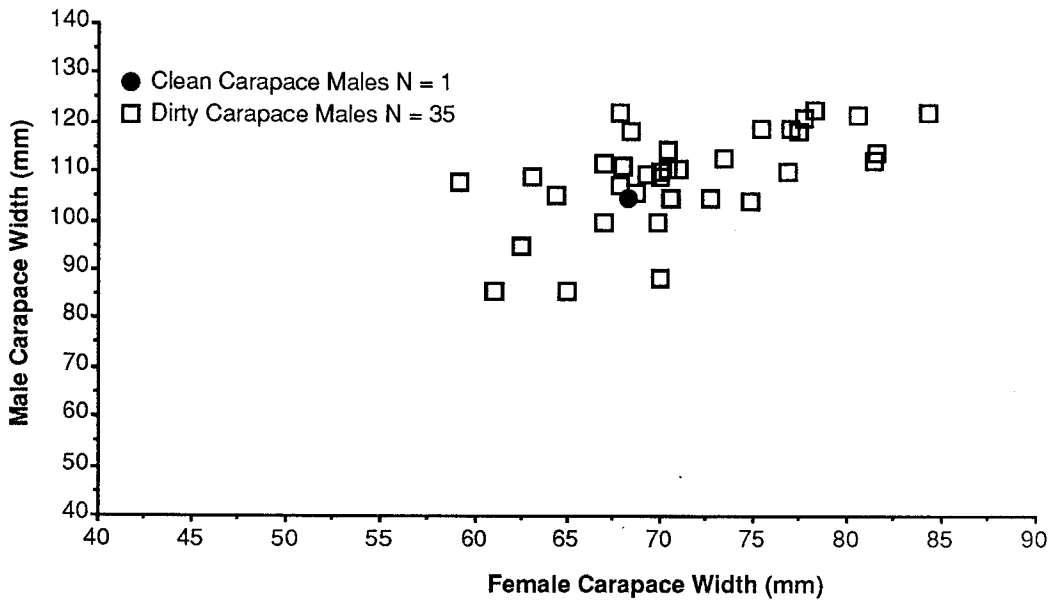


Figure 3b. Couple ratio for sexually paired snow crab showing carapace condition of male, Bonne Bay 1987.

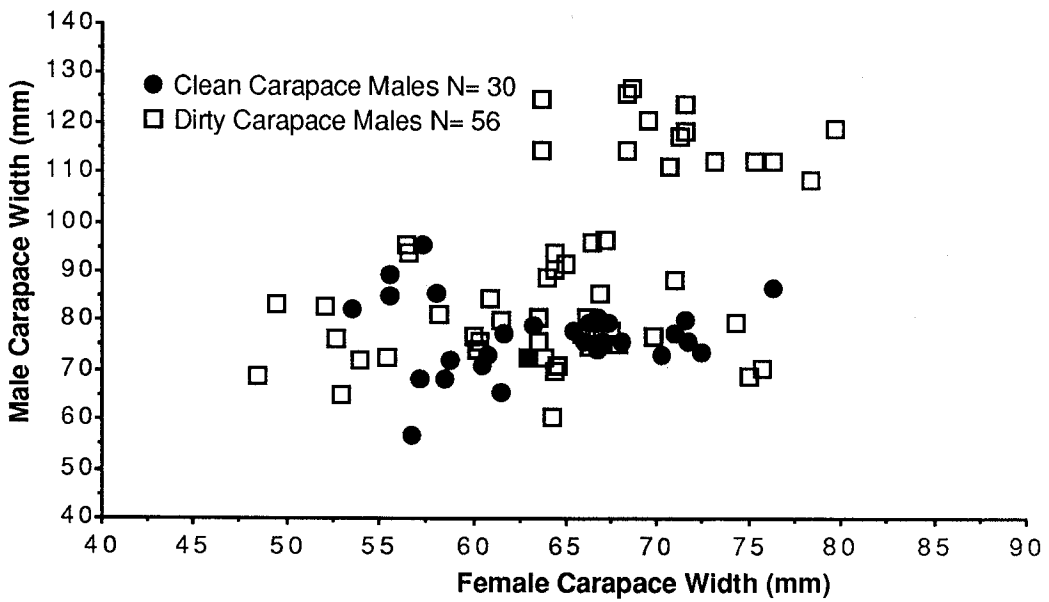


Figure 3c. Couple ratio for sexually paired snow crab showing carapace condition of male, Bonne Bay 1988.

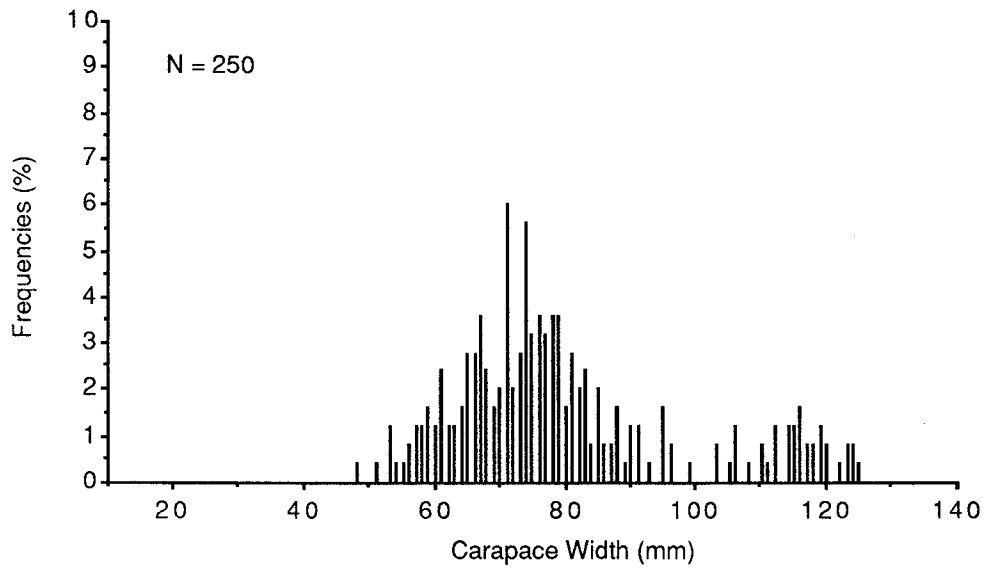


Figure 4. Size frequency distribution for male *C. opilio* caught by tanglenet in Bonne Bay, 1988.

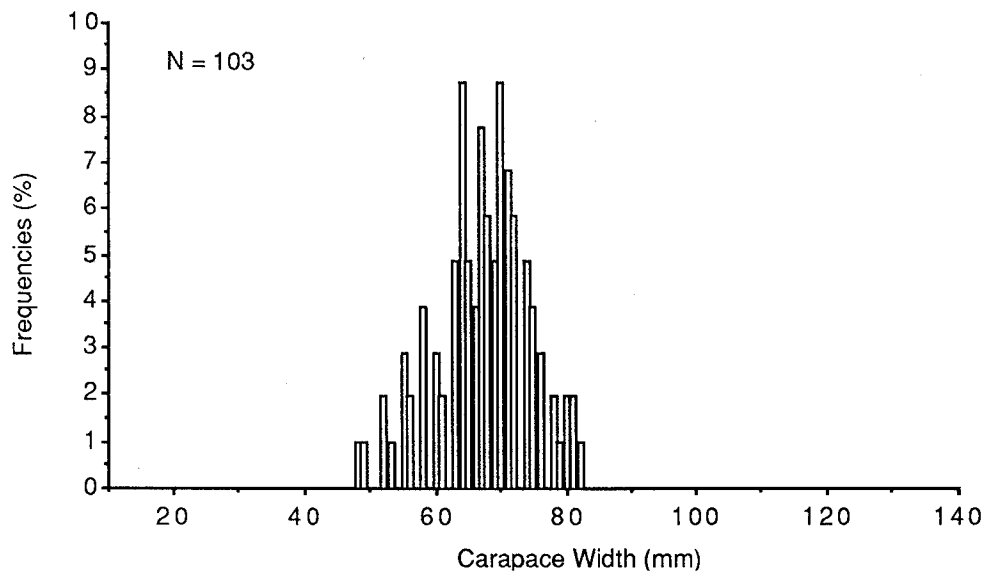


Figure 5. Size frequency distribution for female *C. opilio* caught by tanglenet in Bonne Bay.

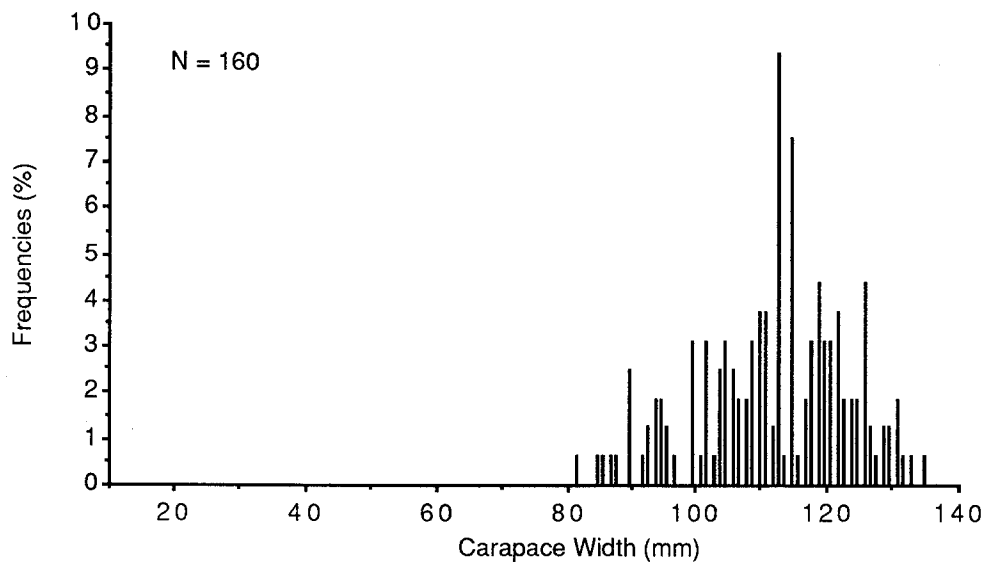


Figure 6. Size frequency distribution for male *C. opilio* caught by trap, Bonne Bay 1985.

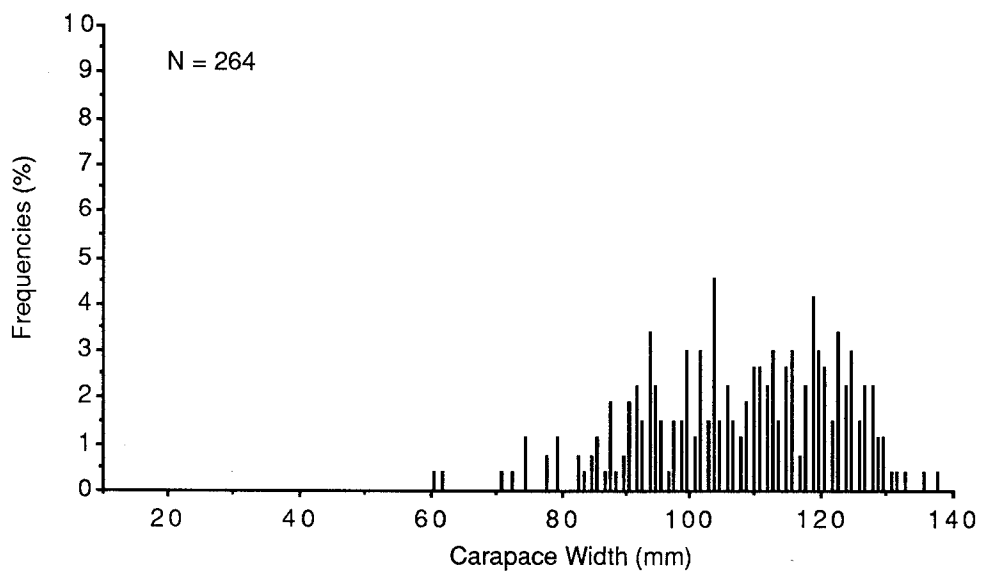


Figure 7. Size frequency distribution for male *C. opilio* caught by trap, Bonne Bay 1987.

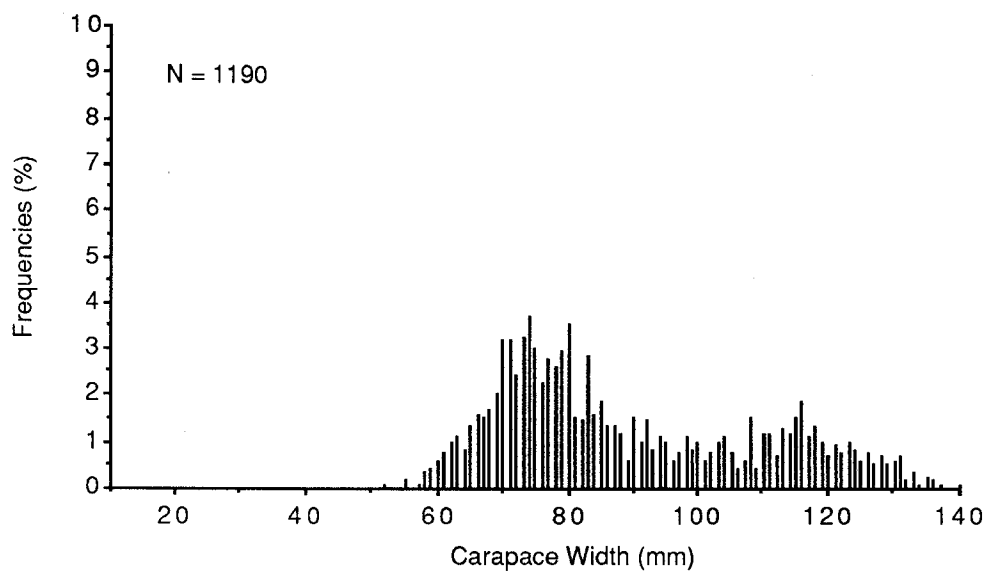


Figure 8. Size frequency distribution for male *C. opilio* caught by trap, Bonne Bay 1988.

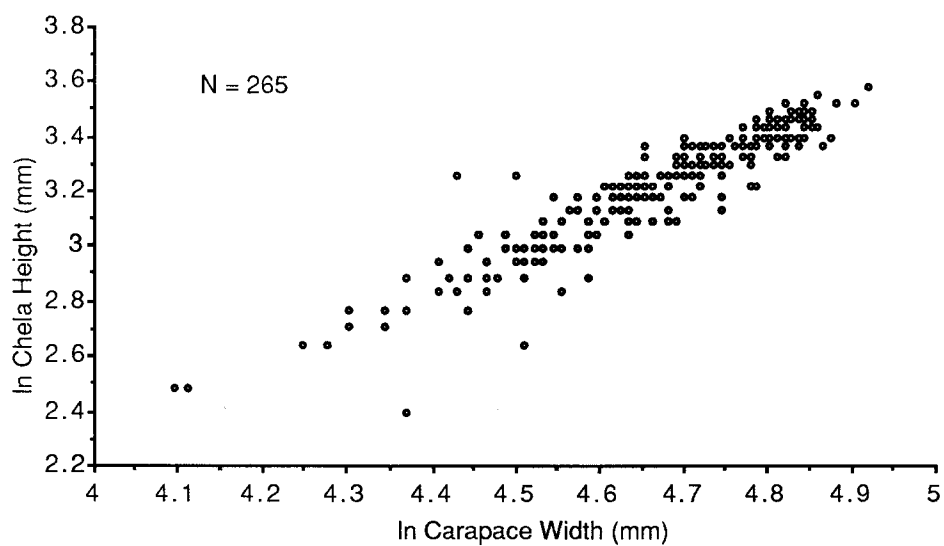


Figure 9. Chela Height vs Carapace Width plotted on a logarithmic scale for male *C. opilio* caught by trap, Bonne Bay 1987.

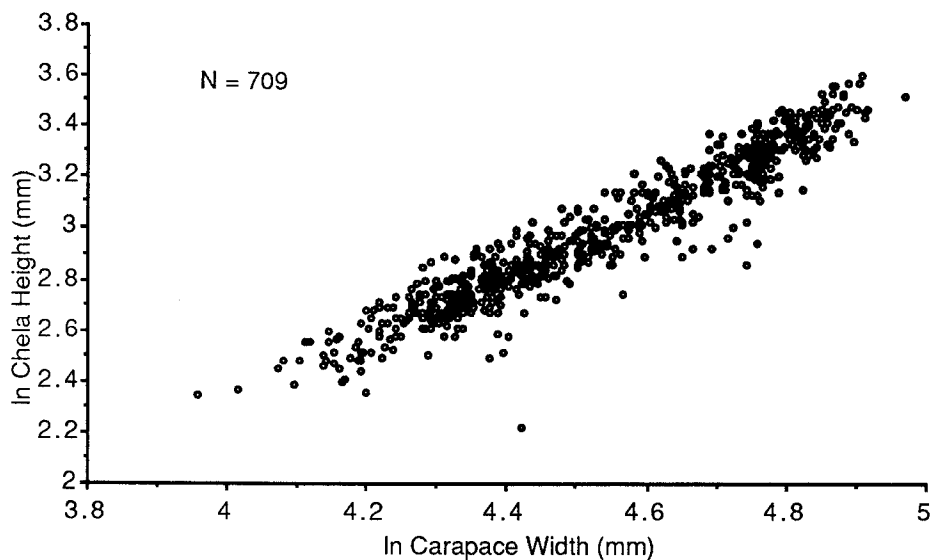


Figure 10. Chela Height vs Carapace Width plotted on a logarithmic scale for male *C. opilio* caught by trap, Bonne Bay 1988.

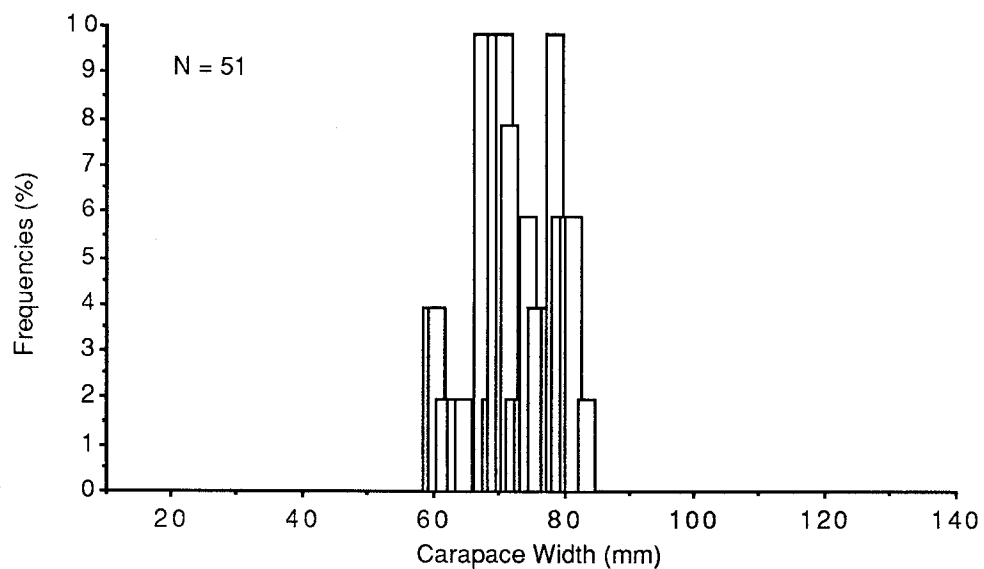


Figure 11. Size frequency distribution for female *C. opilio* caught by trap, Bonne Bay 1987.

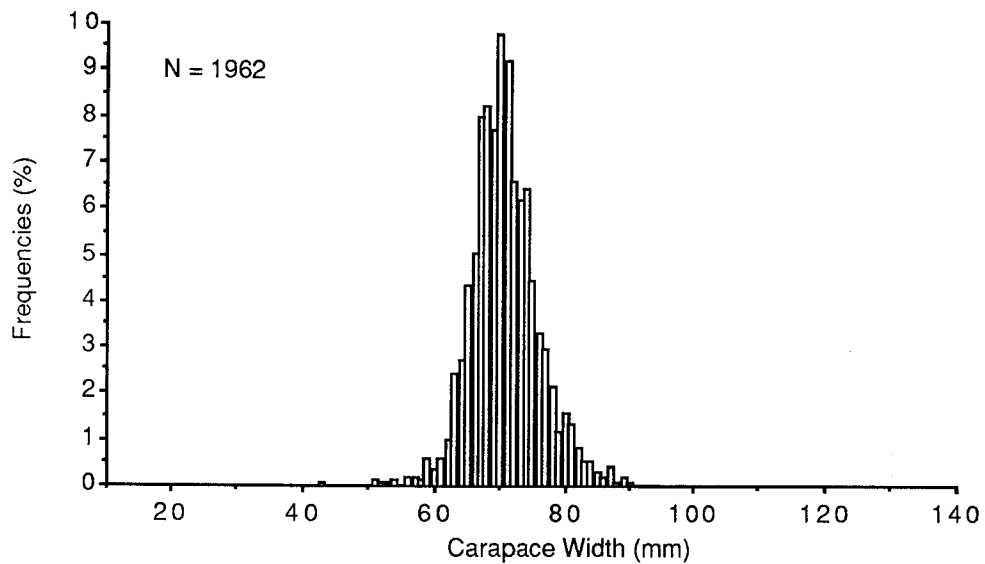


Figure 12. Size frequency distribution for female *C. opilio* caught by trap, Bonne Bay 1988.

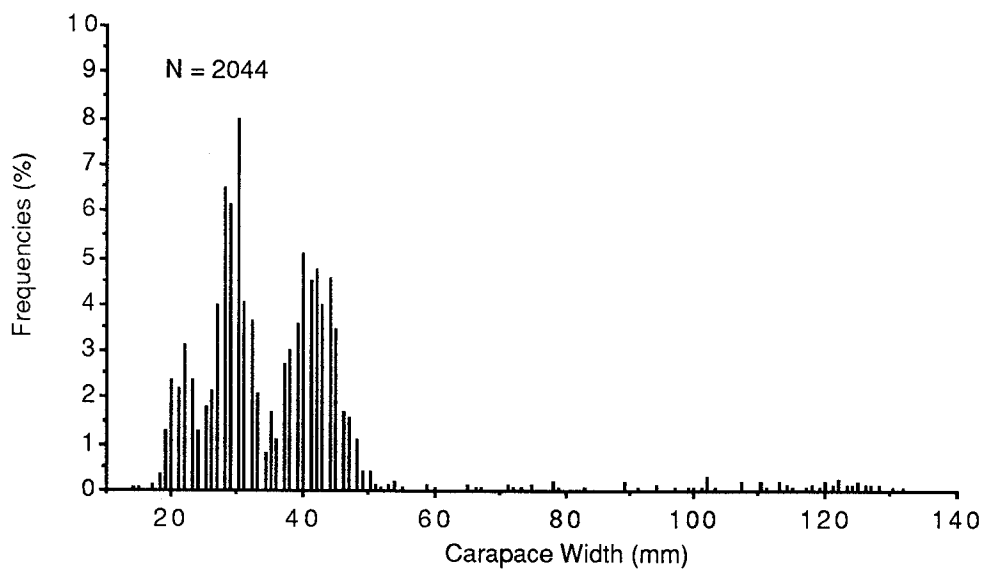


Figure 13. Size frequency distribution for male *C. opilio* caught by trawl, Bonne Bay 1985.

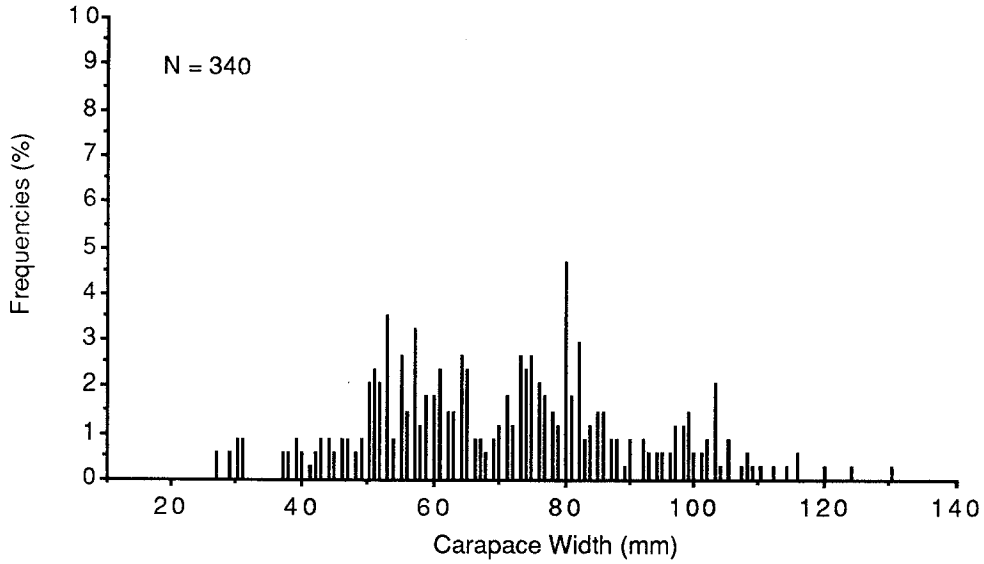


Figure 14. Size frequency distribution for male *C. opilio* caught by trawl, Bonne Bay 1988.

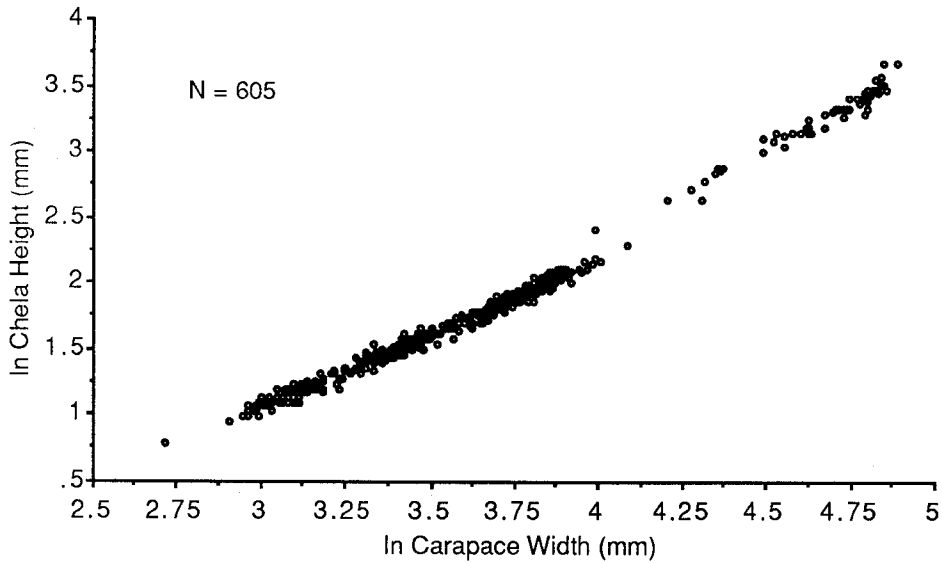


Figure 15. Chela Height vs Carapace Width plotted on a logarithmic scale for male *C. opilio* caught by trawl, Bonne Bay 1985.

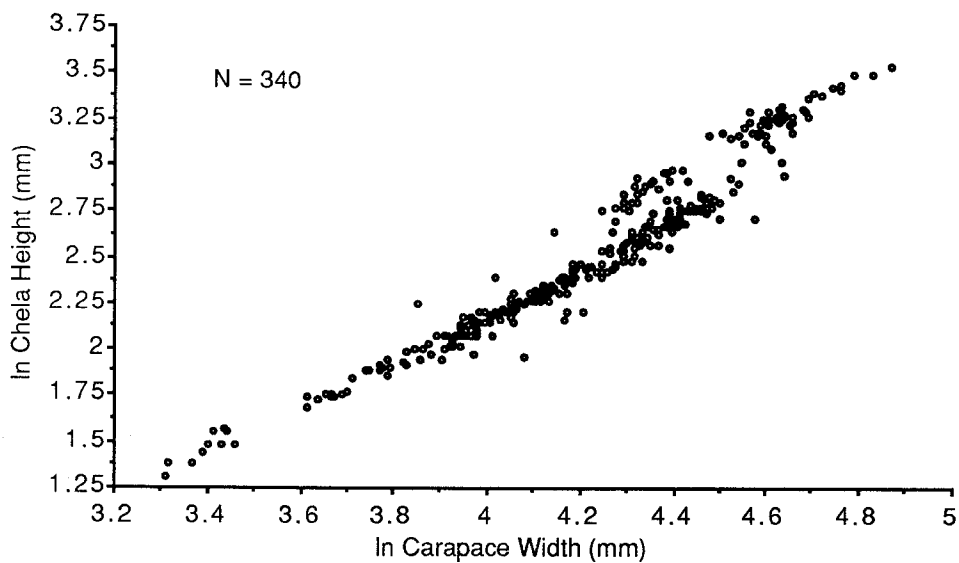


Figure 16. Chela Height vs Carapace Width plotted on a logarithmic scale for male *C. opilio* caught by trawl, Bonne Bay 1988.

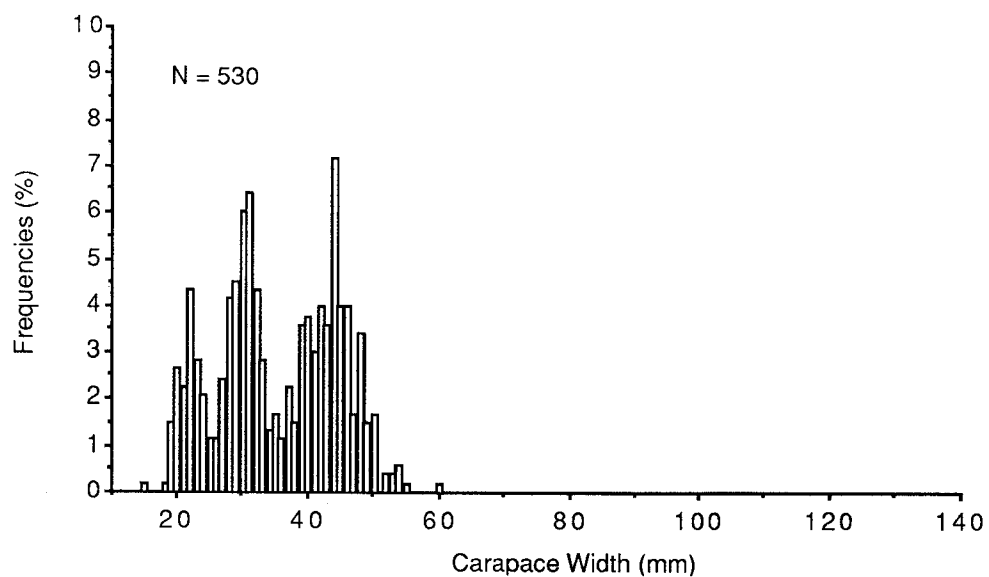


Figure 17. Size frequency distribution for morphometrically immature male *C. opilio* caught by trawl, Bonne Bay 1985.

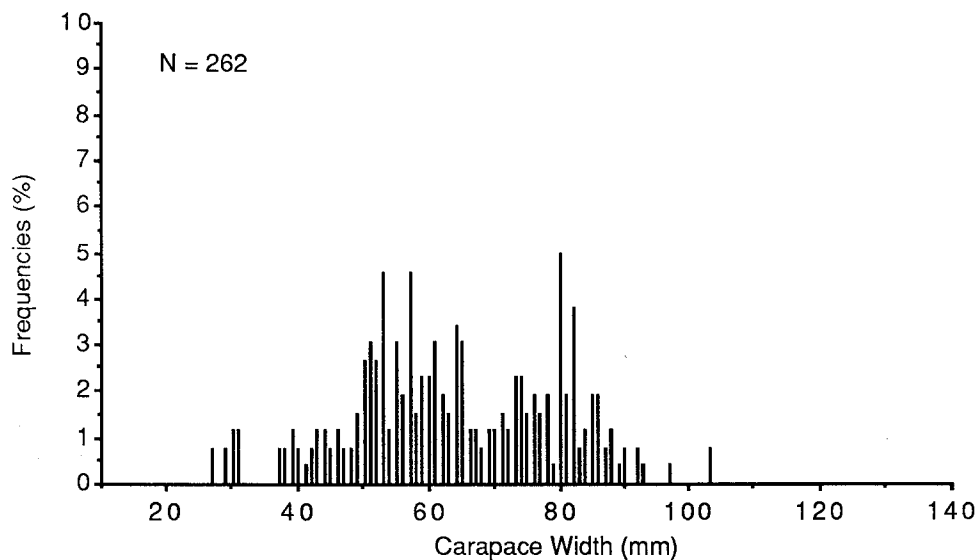


Figure 18. Size frequency distribution for morphometrically immature male *C. opilio* caught by trawl, Bonne Bay 1988.

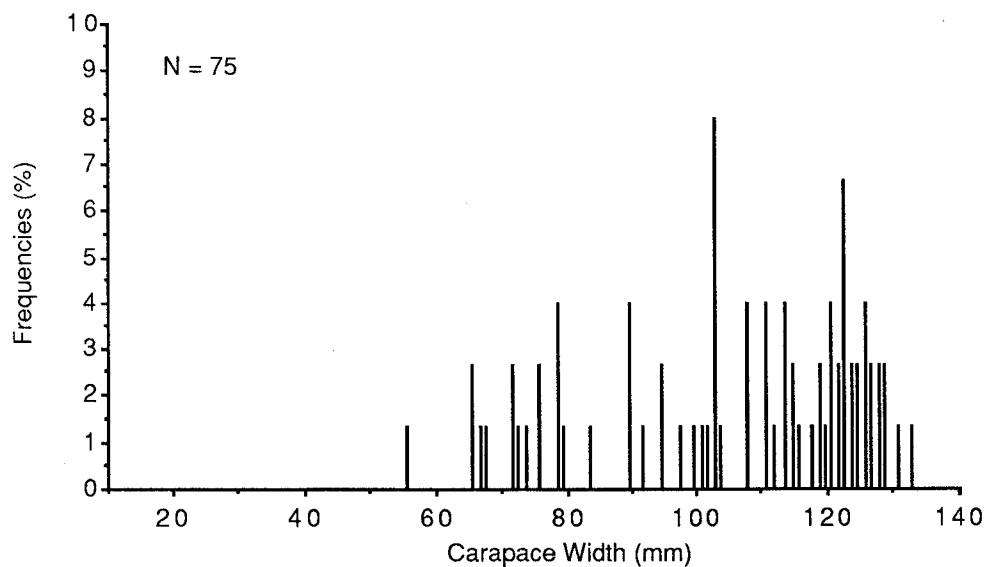


Figure 19. Size frequency distribution for morphometrically mature male *C. opilio* caught by trawl, Bonne Bay 1985.

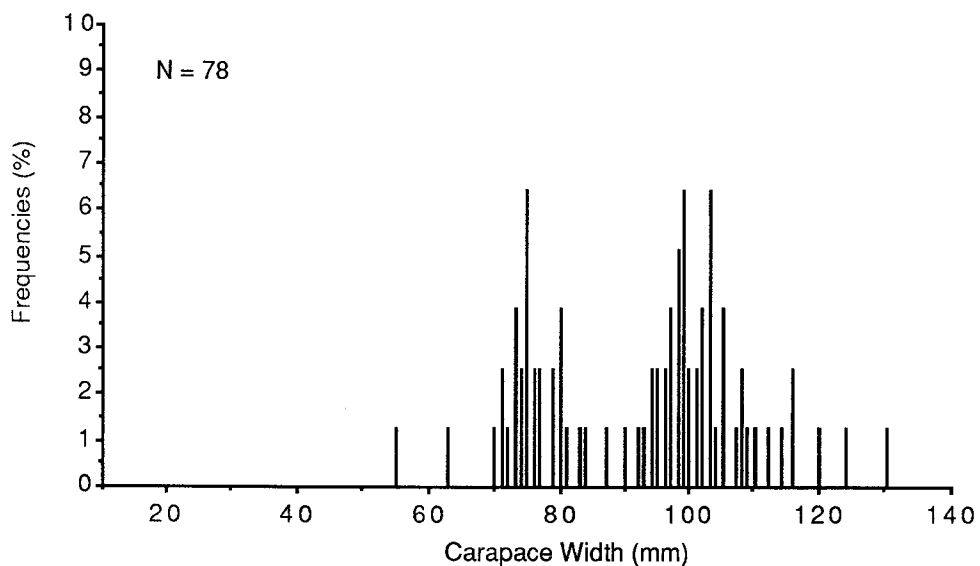


Figure 20. Size frequency distribution for morphometrically mature male *C. opilio* caught by trawl, Bonne Bay 1988.

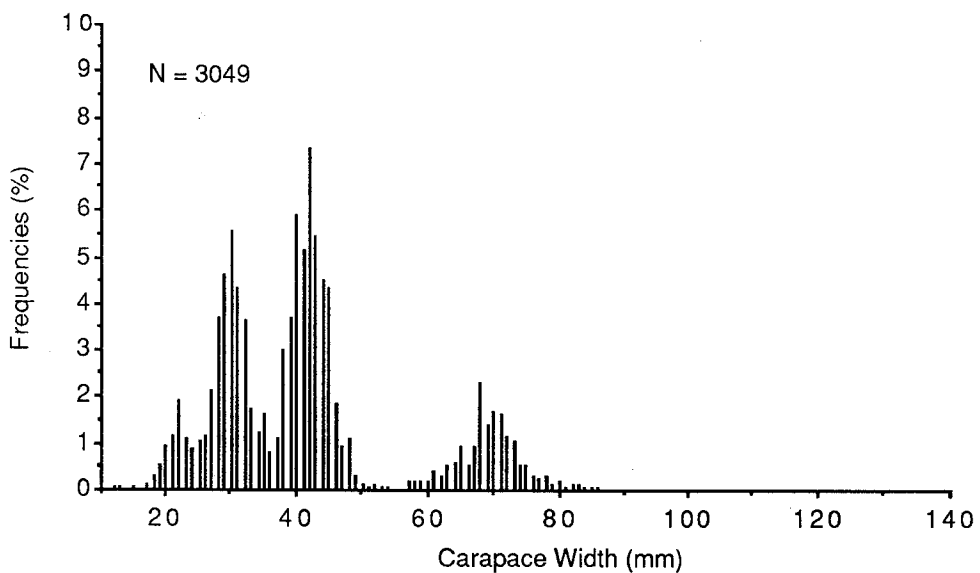


Figure 21. Size frequency distribution for female *C. opilio* caught by trawl, Bonne Bay 1985.

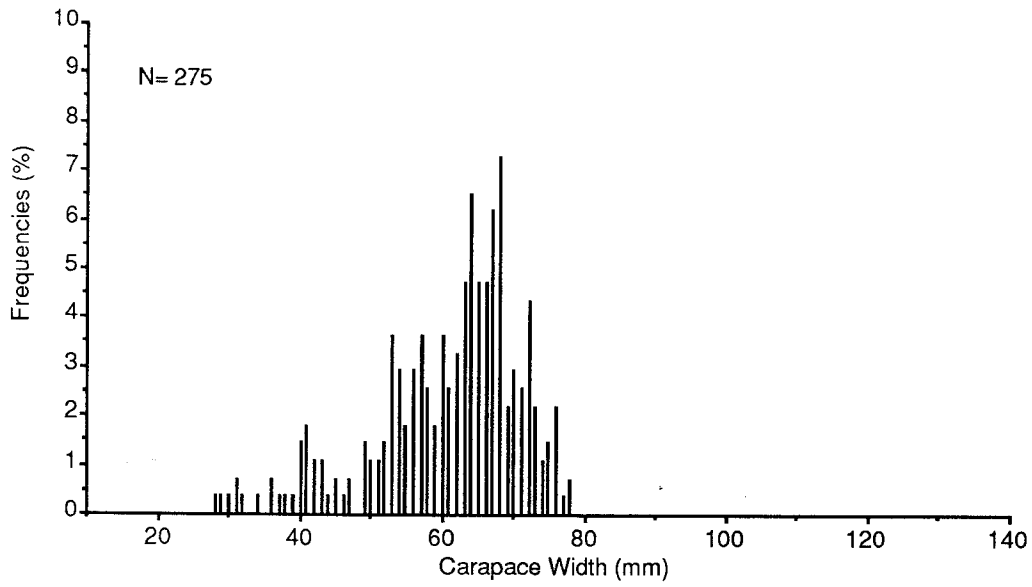


Figure 22. Size frequency distribution for female *C. opilio* caught by trawl, Bonne Bay 1988.

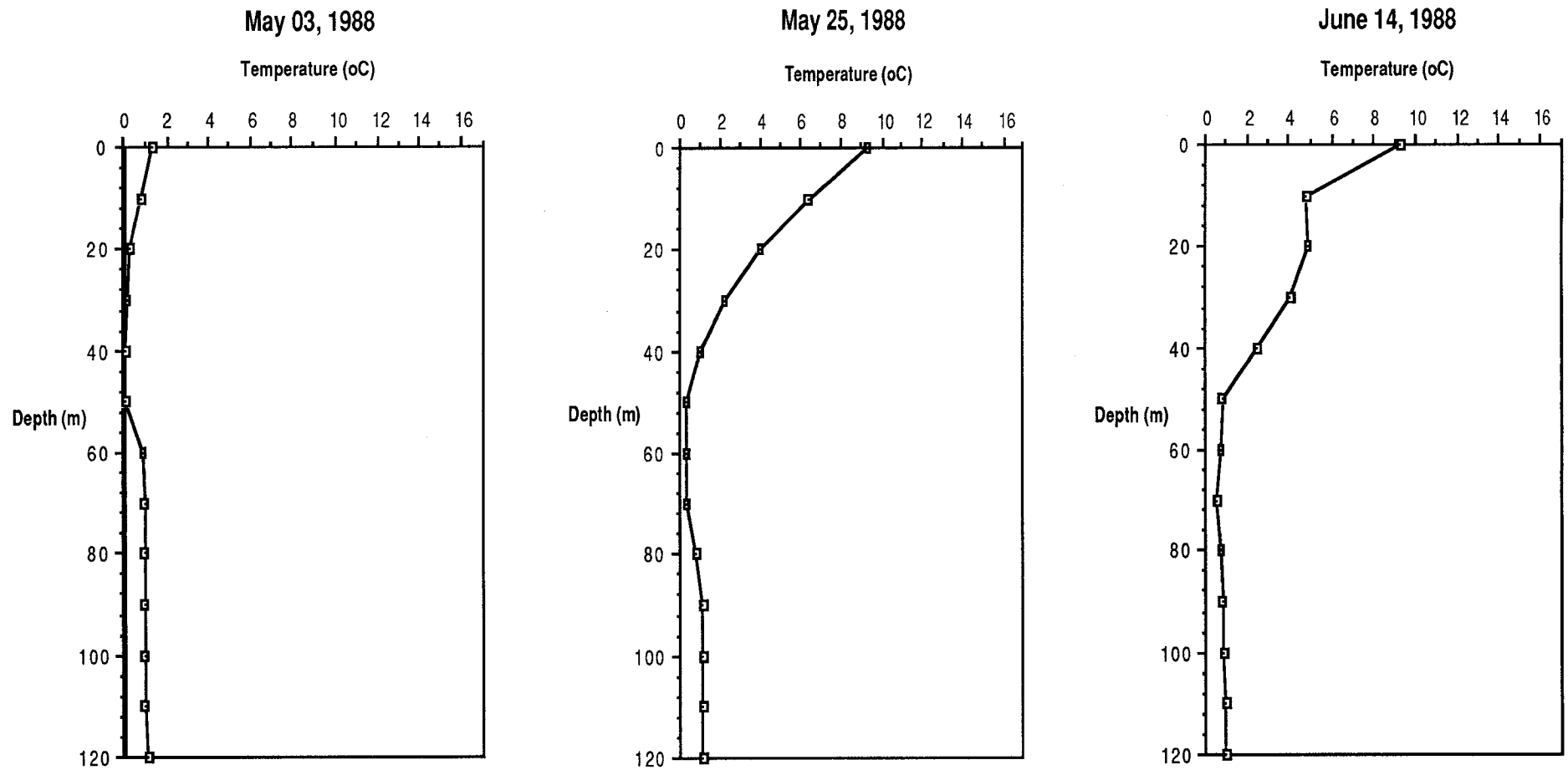


Figure 23. Temperature profiles obtained between May and August 1988 in Bonne Bay.

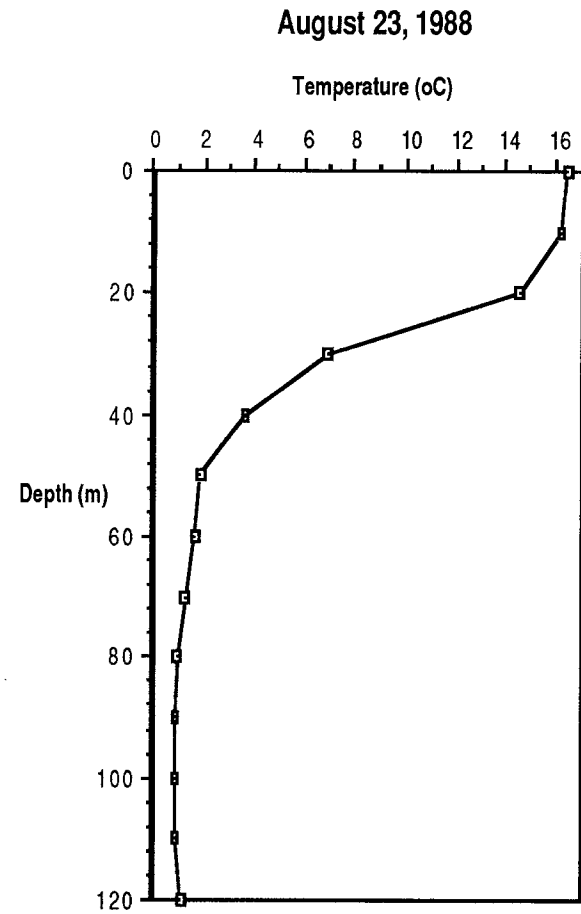
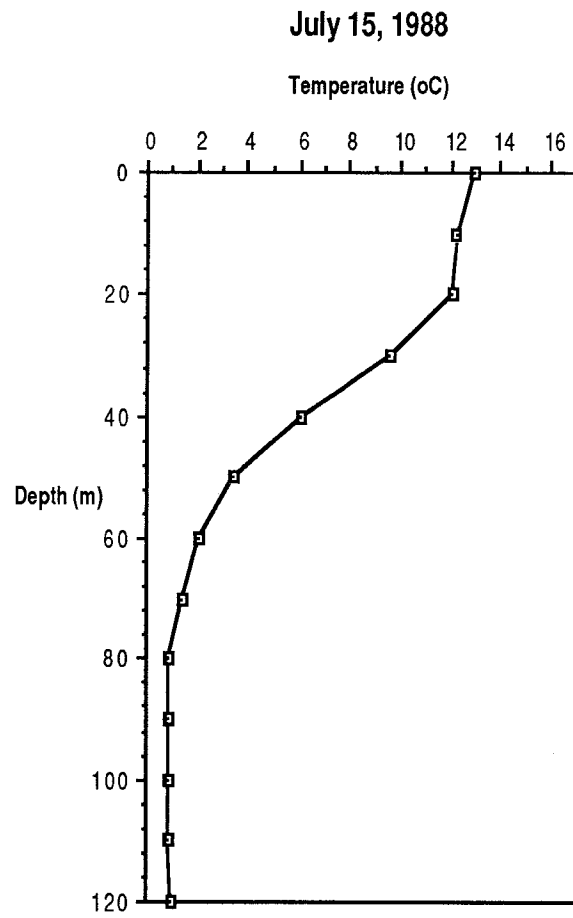
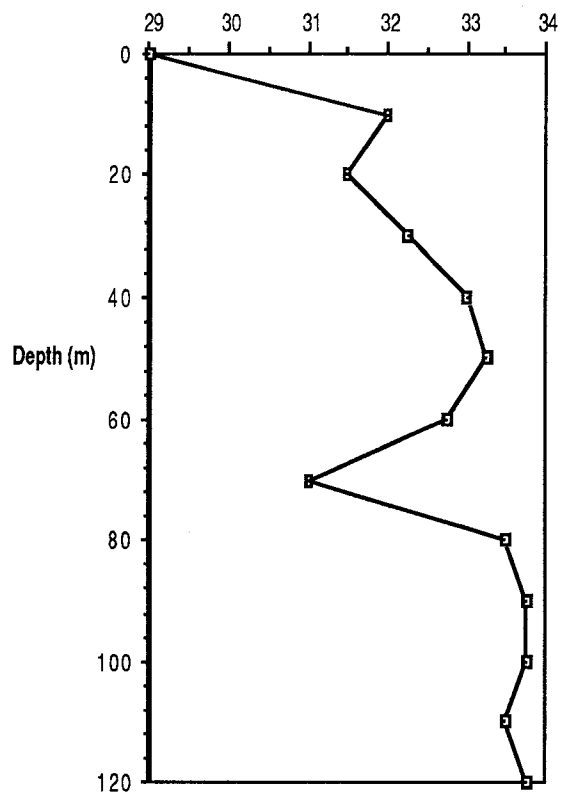


Figure 23. (cont.)

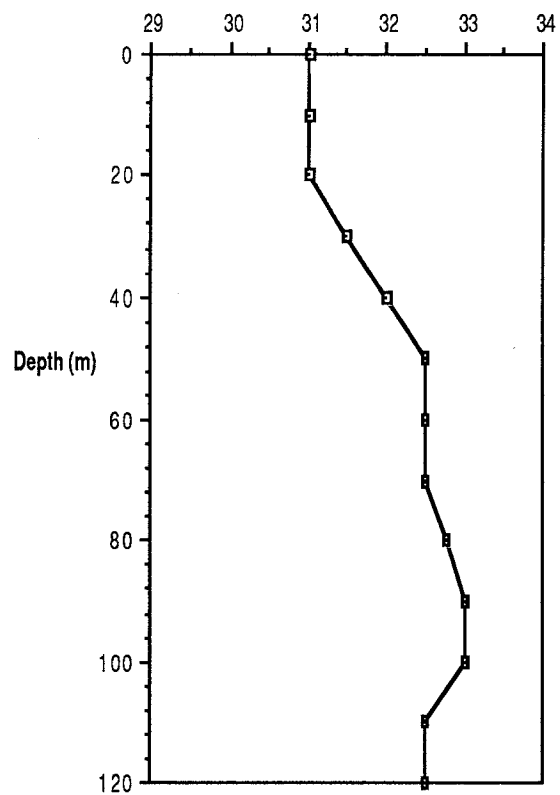
June 14, 1988

Salinity (o/oo)



July 15, 1988

Salinity (o/oo)



August 23, 1988

Salinity (o/oo)

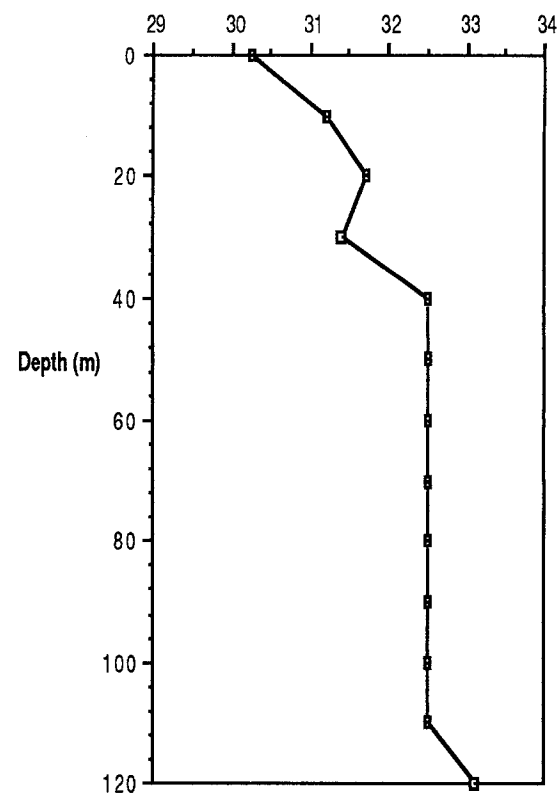


Figure 24. Salinity profiles obtained between June and August 1988 in Bonne Bay.

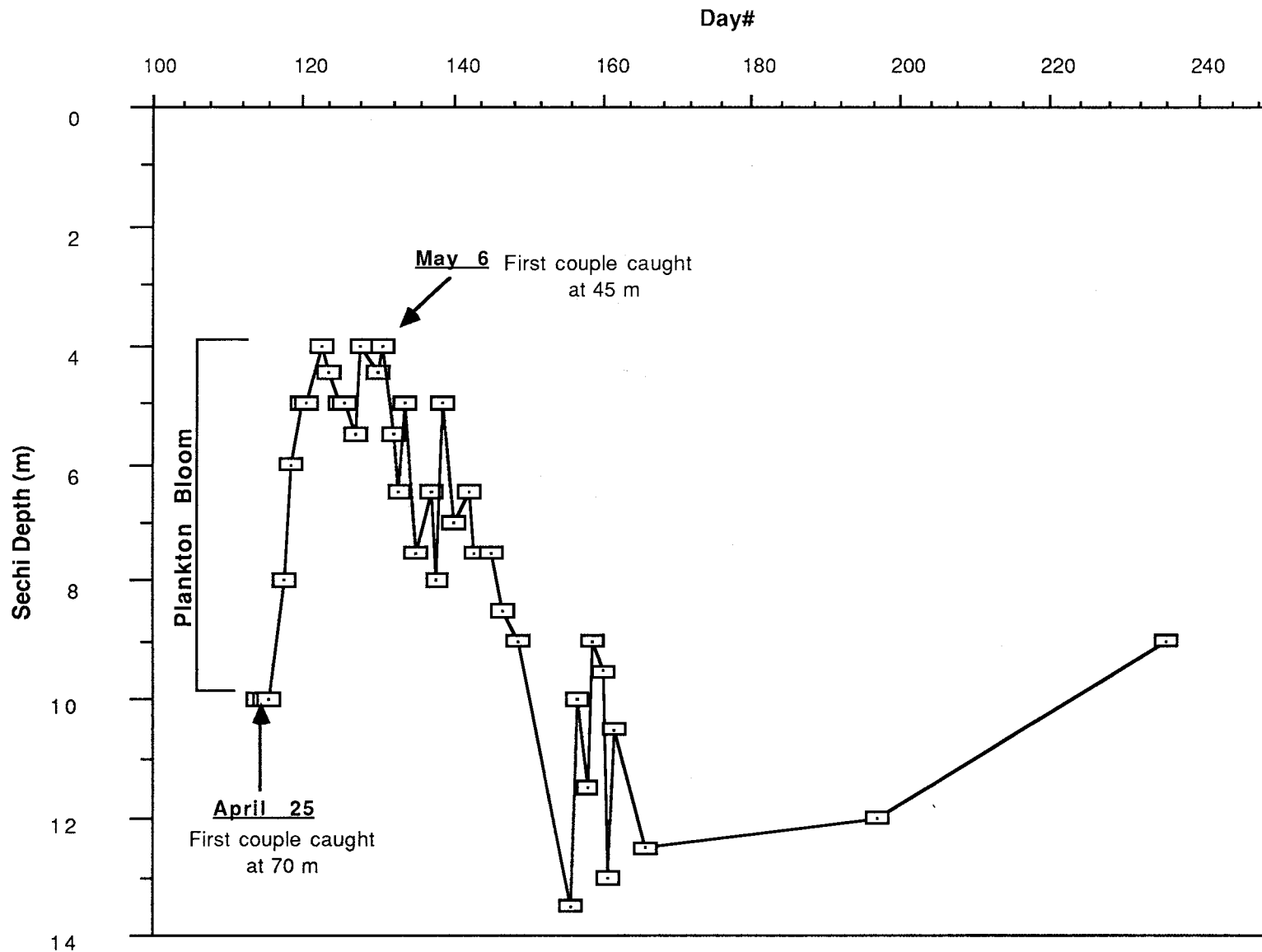


Figure 25. Secchi disk readings between April and August 1988 in Bonne Bay. The appearance of the first couples at depth of 70m and 45m are indicated.

Particulate Organic Carbon on July 15, 1988

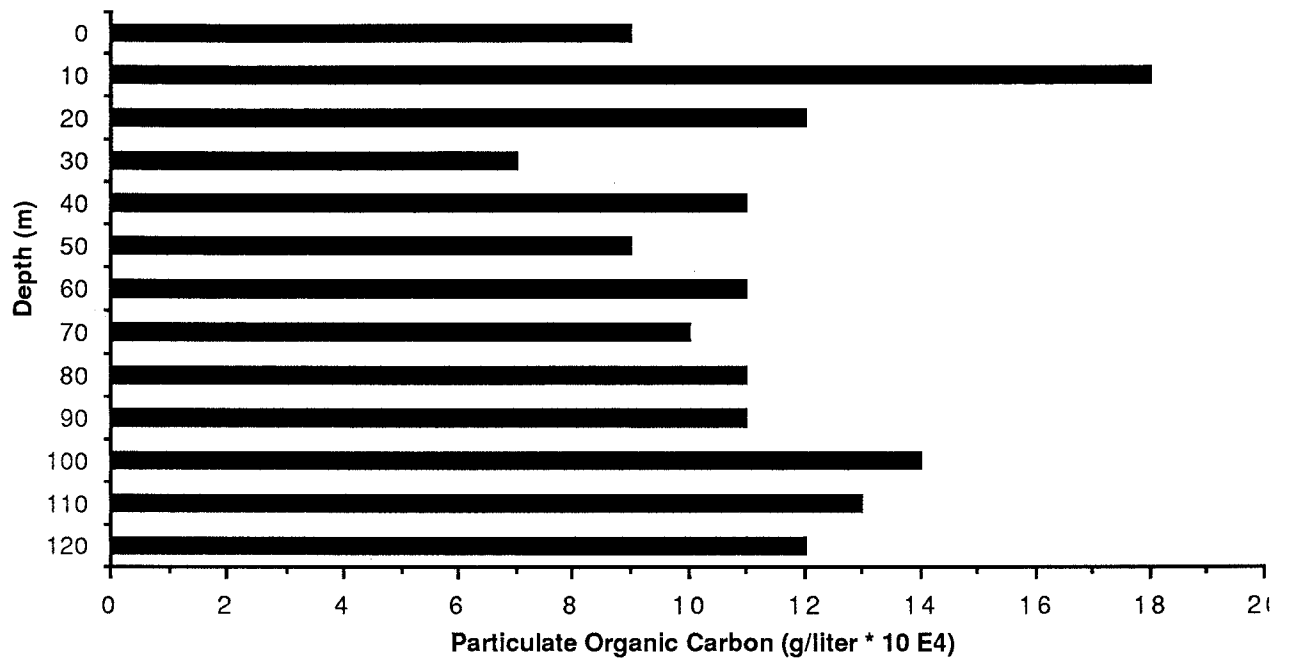


Figure 26. Bar chart showing amounts of particulate organic carbon at each 10 m depth interval on July 15 1989 in Bonne Bay.

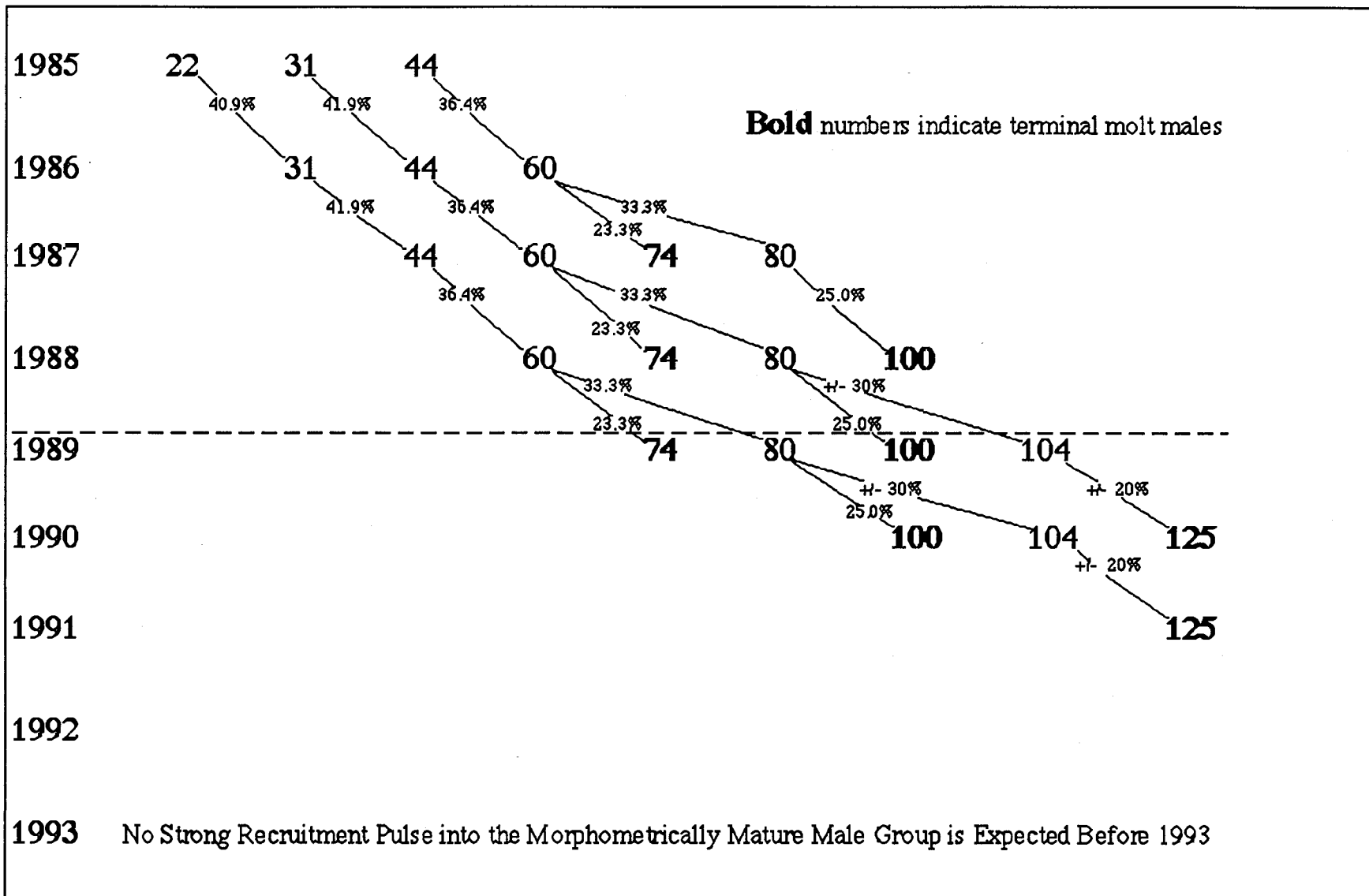


Figure 27. A schematic representation of the modal movements and percentage carapace width increase of molting male snow crab in Bonne Bay