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Observations on the efficacy of the minimum legal size for Atlantic snow crab, *Chionoecetes opilio*

by

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Abstract

Female snow crab attain a terminal molt to maturity below the current minimum legal size of 95 mm carapace width, and are thus barred from commercial exploitation. As males attain sexual maturity at least 1 yr prior to recruitment into the fishery, the reproductive potential of the resource has been generally accepted as being at pre-fishery levels. In this paper, we examine the rationale for, and the possible effects of, the minimum legal size in the Atlantic snow crab fishery. Supporting data are presented on female size at maturity, ovigerous female incidence and the size frequency of mature females from Cape Breton Island.

Although there appears to have been a ~10% reduction in Area 5 during 1983, ovigerous female incidence has remained close to 100%, and invariably above 90%. A literature review reveals major inconsistencies in our understanding of snow crab reproduction and growth that should be addressed before a more thorough understanding of long-term effects of the current minimum size limit on the resource can be adequately assessed. In the meantime, we recommend that monitoring the incidence of ovigerous females should continue as a means of providing warning of reduced egg production.

Résumé

Les crabes des neiges femelles atteignent leur dernière mue avant la maturité à une taille inférieure à la limite légale minimale de 95 mm de largeur de carapace, et de ce fait échappent à l'exploitation commerciale. Comme les mâles atteignent la maturité sexuelle au moins 1 an avant de rallier le stock pêchable, on accepte généralement le potentiel reproducteur de la ressource aux niveaux d'avant l'exploitation par la pêche. Nous analysons dans le présent travail le pourquoi et les effets possibles d'une taille légale minimale dans la pêche du crabe des neiges dans l'Atlantique. On y présente les données à l'appui de la taille des femelles à la maturité, sur l'occurrence des femelles ovigères et sur la fréquence de tailles des femelles matures au Cap-Breton.

Bien qu'il semble y avoir eu une diminution de ~10 % dans la Zone 5 en 1983, l'occurrence de femelles ovigères s'est maintenue à près de 100 % et toujours au-dessus de 90 %. Une revue des travaux publiés révèle d'importantes contradictions dans notre compréhension de la reproduction et de la croissance du crabe des neiges, auxquelles il faudrait remédier avant de pouvoir évaluer adéquatement l'analyse en profondeur des effets à long terme de la limite de taille minimale actuelle sur la ressource. Entre-temps, nous recommandons que l'on continue à suivre l'occurrence des femelles ovigères, afin d'être prévenus d'une diminution de production d'oeufs.

Introduction

The exploitation of snow crab, Chionoecetes opilio, in Atlantic Canada started in 1960 when landings took place in the Gaspé area of Quebec. Up until 1966, snow crab landings were the result of incidental by-catches by groundfish draggers and totaled only a few thousand kilograms annually. However, since the inception of a directed trap fishery in 1966, after exploratory vessels located abundant stocks in the Gulf of St. Lawrence, annual landings have increased rapidly (Table 1). In 1978, 21,936 metric tons (MT), representing 20% of the world catch of Chionoecetes sp., was landed. In 1979 and 1981, landings were worth over $20 million to the fishermen and the species ranked sixth in value on the Atlantic coast behind cod, lobster, scallops, herring, and flatfishes. Snow crab landings in 1982 of 47,275 MT were the highest recorded and considerably exceeded the forecasted sustainable yield of 20,000-32,000 MT.

In the early stages of the fishery, no size limit was enforced and processors voluntarily agreed to accept only crabs over 4 in. (102 mm) carapace width (CW). The size limit was selected prior to any knowledge on sizes at maturity or the reproductive capabilities of the various stocks. No information was available on the minimum sizes at which snow crabs could mate successfully.

Since about 1973, a minimum legal size of 95 mm CW has been enforced throughout the Atlantic snow crab fishery; apparently, this size represented the smallest crab that Industry felt was economical to process, as well as reflecting snow crab size at maturity and mating observations made by Powles (1968) and Watson (1970, 1972).

Both the 102-mm and the 95-mm minimum sizes had similar biological implications: Most apparently, the fishery became based exclusively on mature male snow crabs. The vast majority of females are smaller than 95 mm CW and are thus effectively barred from commercial exploitation. Female snow crabs undergo a terminal molt to maturity and attain a maximum size of 47-95 mm CW (Watson 1970). Males attain maturity between 51 and 72 mm CW (Watson 1970) and are presumed able to mate in the intervening years before they recruit into the fishery. The lack of barren females and the large numbers of eggs produced by each female has, hitherto, allayed fears of a reduction in recruitment due to a lack of fertilized females. Thus, the 95-mm CW minimum size limit has been widely accepted as having made the reproductive potential of the various snow crab stocks inviolate.

The following review of published research on reproduction in the genus Chionoecetes and supporting field data from the Cape Breton Island snow crab fishery is a re-examination of the various premises relevant to the issue of snow crab minimum size in Atlantic Canada.

Cape Breton Island Field Observations on Female Snow Crabs

The snow crab grounds around Cape Breton Island are divided into seven management areas (Fig. 1). Since 1977, at-sea sampling of female snow crabs has been carried out intermittently, in most management areas, from traps and danish-seines fished by commercial vessels and beam trawls during research surveys. Parameters recorded from female snow crabs are: carapace width, maturity (based on abdomen width (Watson 1970)), presence or absence of extruded eggs, and egg development stage.

Our sampling for female snow crabs has been intermittent and sample sizes relatively small because:

1) During the July-September snow crab season around Cape Breton Island females are found in aggregations on the fishing grounds. These aggregations are avoided by experienced fishermen because of the labor of culling large numbers of females and the almost total absence of males of commercial size.
2) Mesh size regulations for commercial snow crab traps are such that most females and sublegal males are able to escape.

Records of size at maturity, the incidence of mature females caught with extruded eggs, and the size frequencies of ovigerous and non-ovigerous females are presented in Fig. 2, 3, 4, 5, 6, and 7. Egg extrusion for both primiparous and multiparous females occurs in May; there is usually less than 3 d between mating and egg extrusion, and approximately 2 wk between hatching of old eggs and extrusion of a new egg mass (Watson 1972).

All females we sampled >53 mm CW appeared mature (Fig. 2). Comparison of the incidence of ovigerous females (Fig. 3b) reveals a sudden increase in the number of barren mature females in Area 5 in 1983. However, while Watson (1969) found less than 1% barren mature females in samples from the Gulf of St. Lawrence in June 1968, Powles (1968) recorded 7% barren mature females (>60 mm CW) in his Gulf of St. Lawrence samples during July/August 1966. Hence, the recent barren female trends for Area 5 are not markedly different from trends recorded in the early days of the fishery, before a marked reduction in the density of mature males could have taken place.

In summary, field observations indicate that snow crab reproductive effort around Cape Breton Island remains high and close to historical pre-fishery levels. Nevertheless, a cautious monitoring of barren female levels for Cape Breton Island should probably continue. The snow crab grounds on the Atlantic side of Cape Breton Island have experienced a stock collapse since 1980 (Elner and Robichaud 1983) and (while the collapse is probably not correlated to a dearth of egg production) are the most likely of any to show the first indications of lowered fecundity due to a lack of mature males. Thus, the Atlantic side of Cape Breton Island could be viewed as an "oracle" for the remainder of the Atlantic fishery as far as the long-term effects of high fishing pressure on male snow crabs are concerned.

Literature Review

Mating behavior

The behavioral sequences of *Chionoecetes opilio* mating observed by Watson (1970, 1972) in the laboratory are the most detailed account of the process and have remained unsurpassed.

During the week-long precopulatory embrace, the hard-shelled mature male holds the female and drives away intruding males. Before a 45-min copulation period, the male assists the female in ecdysis. The male continues to embrace the female for approximately 8 h after copulation. Egg extrusion usually occurs within 72 h of mating.

Watson (1972) reported that hard-shelled mature females were incapable of mating and observed that hard-shelled mature females, without contact with males, could produce fertile eggs within 2 wk of releasing larvae. Although such subsequent egg batches must be fertilized from spermatophores stored in the female's spermathecae, there is no information on the number of egg extrusions that can occur from a single mating. Eggs are extruded by female snow crabs around Cape Breton Island in May and are generally observed to hatch approximately 12 mo later (Elner, pers. obs.).

Snow crab males are polygamous as shown by Watson (1972); in experiments, a 98.2-mm CW male mated successfully with six females in a 1-mo period. Males below the current legal minimum size of 95 mm CW are capable of mating with larger females. Watson (1972) documented a successful mating between a 60.8-mm CW male and a female, which, after molting, increased from 63.9 to 73.7 mm CW.

In examining the possibility that in areas of heavy exploitation males could be reduced to such a low density that some females might not be fertilized immediately after molting to maturity, Watson (1972) noted that three females mated successfully 27, 53, and 95 h after molting.

Although Watson's (1970, 1972) papers have generally remained unchallenged, there has been speculation that mating can occur between hard-shelled males and hard-shelled female *C. opilio*. Hartnoll (1969) noted that females of the Majidae do sometimes mate in the hard-shelled condition, and observed that *Hyas coarctatus* females mated in both hard- and soft-shelled conditions. Paul (1982) reported that 98% of multiparous female *Chionoecetes bairdi* captured near Kodiak, Alaska, had grasping marks as a result of mating in a hard-shelled condition. Supporting evidence for *C. bairdi* re-mating has been provided by laboratory and field observations (Adams 1982; Somerton 1981a). Somerton (1981a, 1982), from a study of ontogenetic migration patterns, suggested that bipartite breeding occurs in *C. opilio elongatus*, *C. tanneri*, and *C. bairdi*. Essentially, Somerton proposed that mating occurs amongst two distinct life history groups: one composed of primiparous females and recently matured males, and the other composed of multiparous females and large mature males. Although there is no published evidence for multiparous female matings in Atlantic populations of *C. opilio*, the fact that there appears to be spatial segregation of recently matured males and females from larger males would tend to support a portion of Somerton's hypothesis.

Adams (1982), in documenting the mating behavior of *C. bairdi*, observed that: 1) very small males grasped newly molted females and mated precociously without subsequent production of viable zygotes; and 2) 28 primiparous females, which had been isolated from males, extruded unfertilized, inviable eggs of the normal orange color. In 33 cases, the eggs produced by unmated primiparous females were resorbed rather than extruded.

Fecundity

There have been numerous studies of the fecundity of snow crabs (Brunel 1962; Ito 1963; Kon 1974; Haynes et al. 1976; Jewett 1981; Davidson 1983) and include comparisons between widely separated populations and latitudinal gradients in fecundity. Davidson (1983), in a study of snow crab from four areas of Atlantic Canada, found high correlations between carapace width and total egg weight (mean egg weight did not correlate with female CW or area of origin). Total egg weight for any given CW was found to vary significantly between areas, with areas, grouped from highest to lowest total egg weight, as follows: Newfoundland, Gabarus (N.S.), Pleasant Bay (N.S.), Anticosti. The results supported those of Haynes et al. (1976) in showing that Atlantic female snow crab have a higher fecundity for a given carapace width than females from the Bering Sea. Estimates of total fecundity and regression equations of fecundity against carapace width for snow crab from various areas are shown in Table 2. (It should be noted that the number of eggs carried has been reported to decrease by approximately 50% from time of egg extrusion to the time of hatching (Brunel 1962; Kon 1976). Presumably this egg loss is due to predation, unfertilization, abrasion, and/or abnormalities.)

Recently, Somerton and Meyers (1983) demonstrated that primiparous female *C. bairdi* from the eastern Bering Sea are only approximately 70% as fecund as equivalent-sized multiparous females. Since primiparous females molt and grow before extruding eggs, whereas multiparous females do not grow, the lesser fecundity of primiparous females may be due to either the energetic cost of growth or to their having a smaller volume within the exoskeleton available for ovarian tissue at the premolt size. A relationship between fecundity and multi- and primiparous spawners is a distinct possibility for *C. opilio* but has yet to be researched. Paul (1982) determined that, although the majority of multiparous *C. bairdi* females will mate again if given the opportunity, a lack of males does not hinder egg production. The majority of females isolated from males could rely on sperm stored in their spermathecae from a previous mating to fertilize at least one egg clutch of normal size. Only approximately 3% of the multiparous *C. bairdi* must copulate to obtain sperm to fertilize new eggs or remain barren.

Changes in the proportion of egg-bearing females in a population may indicate that fishing pressure is too great or that the animals are under environmental stress. Studies on *C. opilio* in the Bering Sea and Chukchi Sea, in areas where no commercial exploitation of the species occurs, have shown only 3.3% of females of egg-bearing size to be ovigerous (Jewett 1981). Further examination revealed that 97% of females $>$40 mm CW had advanced ovarian development. No further information is available as to the cause of the relatively low fecundity in the area.

Growth and size at maturity

Miller and Watson (1976) document laboratory data on carapace width increases per molt for Atlantic snow crab. Fitting least squares regressions to percentage increase of CW per molt (Y) to premolt CW (X in mm) gave the following equations:

		Mean % growth increment
Immature males:	Y = 40.7 - 0.363X	29.8
Immature females:	Y = 45.3 - 0.444X	32.0
Mature males:	Y = 14.2 + 0.051X	18.4
Mature females:	Y = 14.0 - 0.014X	14.8

Growth per molt decreased with sexual maturity for both sexes and was significantly less for females molting to maturity than for mature males of the same size. Growth per molt for immature females was significantly greater than for immature males, but the difference was slight. These observations are in agreement with other studies on snow crab growth.

Information on molting frequency is lacking. Tagging studies (Elner and Robichaud, unpubl. data) suggest that "skip-molting" is prevalent and that many males attain a terminal molt well below the postulated maximum possible size in the Gulf of St. Lawrence of 160 mm CW (R. Bailey, unpubl.). Watson (1969) suggested that annual molting normally occurs in males between 65-90 mm CW.

There is only one published report that challenges the premise that the female molt to maturity is a terminal molt: Ito and Kobayashi (1967) recorded a mature female crab of 83 mm CW undergoing ecdysis to 89 mm CW (a 7.2% growth increment).

Watson (1970) determined that, for the Gaspé area of the Gulf of St. Lawrence, 50% of females at 50 mm CW were mature and that, effectively, all females >60 mm CW were mature (maturity based on abdomen and pleopod morphology as well as ovary condition and the presence of extruded eggs). Squires (1965) found 50% maturity of female _C. opilio_ from the Newfoundland/Labrador area to occur at 35 mm CL, equivalent to 40 mm CW. Our data from Cape Breton Island (Area 1), suggesting 50% maturity for females at around 51 mm CW, are in good agreement with Watson (1970).

The high proportion of females >70 mm CW in our samples casts doubt on one or more of the assumptions regarding size at maturity, growth increment and female terminal molt; given 100% maturity is presumed to occur at 60 mm CW and mean terminal growth is 14.8%, then females should attain a maximum size no larger than 69 mm CW.

Based on morphometric measurements and gonad examinations, Watson (1970) showed that 50% maturity in male _C. opilio_ from the Gaspé area occurred at about 57 mm CW, with a minimum size at 51 mm CW. All males above 80 mm CW appeared mature.

Somerton (1981 b) has demonstrated regional variation in the size of maturity for both sexes of _C. bairdi_ and _C. opilio_ in the eastern Bering Sea; the existence of similar variation for Atlantic _C. opilio_ has yet to be examined. Based on his data, Somerton (1981 b) advocated changes in management areas and argued that the size of 50% maturity for females is a less useful measure of the size of maturity than is the mean size of adult females.

Considering available information on growth rates and size at maturity, it is possible to estimate the time available to a mature male to mate before it recruits into the fishery at 95 mm CW. In the 'best' case, a male becoming mature at 51 mm would have to molt four times (51 mm to 60 mm to 71 mm to 84 mm to 99.5 mm) to recruit into the fishery and would, thus, have 4 yr in which to mate. In the 'worst' case, a male becoming mature at 80 mm CW would have 12 mo available for mating before molting to 95 mm CW.

Although 'skip-molting' might increase time at large considerably, there is the possibility that part of the stock of mature females are accessible to large males only; thus, even an excess of small mature males might not guarantee fertilization for all females. On the other hand, given CAFSAC advised exploitation rates of 50-60%, enough males should escape the fishery to ensure that a large number of females are mated.

Discussion

As the unpredictable trends in the Atlantic snow crab fishery (Bailey 1982; Elner 1982a, b; Waiwood and Elner 1982) demonstrate, the relationships between stock and recruitment are not clear. Nevertheless, preserving full reproductive potential or maximizing egg production is, in most fisheries, a desirable management objective. Methods to achieve this objective in crab fisheries include prohibiting the harvest of females and restricting harvested males to individuals above some minimum size (Miller 1976). The minimum size is most commonly set at the mean size of males 1 or 2 yr after maturity, with the rationale that all males have at least one opportunity to mate and that most females will be mated even when the exploitation rate is high.

Yield-per-recruit considerations are probably secondary to egg production considerations, although yield-per-recruit analyses by Bailey (unpubl.) tend to support the current 95-mm CW minimum size limit and suggest that a minimum size below 90 mm CW would tend to decrease yield.

Detailed examination of the logic on which the current 95-mm minimum size limit is based indicates no compelling reason why the limit should be changed. The bottom line remains that high egg production appears to be being maintained. Nevertheless, it appears prudent that monitoring of ovigerous females should continue on a regular basis in selected areas of the Atlantic fishery, with a particular emphasis around Cape Breton Island, and the following specifics: 1) proportion of mature females with external eggs; 2) egg mass condition, egg development stage and viability; 3) proportion of mature females with sperm in spermathecae and description of sperm mass; 4) shell condition of females sampled, including 'grasping marks', as indication of multiparous mating.

If egg production is demonstrated to be declining, then size-limit rationale should be rapidly re-assessed. Furthermore, from a literature review, it is evident that many premises regarding snow crab reproduction and growth should be questioned. The following are among the most obvious areas that require research before a more in-depth appreciation of the long-term effects of the current size limit can be elucidated:

1) the maximum reproductive lifespan of females;

2) the existence and importance of multiparous female mating;

3) the number of times egg extrusion can occur after a single primiparous mating;

4) the proportion of females that can be fertilized by: 1) sublegal males, and 2) the legal males that escape harvesting;

5) the relationship between egg production and subsequent recruitment into the fishery (implies a knowledge of stock-recruitment relationships);

6) the migration and spatial segregation of C. opilio life-history stage;

7) the natural growth rate of male (and female) C. opilio.

Intensive tagging studies appear the best tool to investigate many of the above.

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Table 1. Snow crab landings and landed values for the Atlantic coast of Canada, 1966-81.

Year	Gulf of St. Lawrence (P.E.I., N.B., Quebec) (kg)	Cape Breton Island (N.S.) (kg)	Newfoundland (kg)	Atlantic Canada total (kg)	Landed values ($000)	Average price to fishermen (¢/kg)
1966	30,098	-	-	30,098	5	17
1967	255,508	240,934	-	496,442	84	17
1968	4,223,190	712,882	93,000	5,029,072	1,005	20
1969	7,805,782	98,120	319,000	8,222,902	1,664	20
1970	6,552,539	90,488	891,000	7,534,027	1,582	21
1971	5,405,510	-	1,380,000	6,785,510	1,221	18
1972	5,182,047	51,456	1,484,000	6,717,503	1,948	29
1973	6,804,416	121,881	2,622,370	9,548,667	3,724	39
1974	6,725,221	216,907	3,103,434	10,045,562	3,817	38
1975	4,650,429	378,883	1,820,099	6,849,411	2,397	35
1976	7,603,795	489,490	2,406,343	10,499,628	4,619	44
1977	9,411,948	936,297	3,750,806	14,099,051	7,331	52
1978	11,319,594	3,189,061	7,427,591	21,936,246	12,503	57
1979	16,260,927	3,224,849	11,195,000	30,680,776	20,556	67
1980	16,727,872	2,499,533	9,311,230	28,538,635	16,838	59
1981	21,967,499	1,615,406	12,607,710	36,190,615	20,991	58
1982	31,585,000	2,190,000	13,500,000	47,275,000	39,348	83

Table 2. Estimates of total fecundity and regressions of fecundity (Y) with carapace width (X) for female snow crabs, *Chionoecetes opilio*, from Atlantic Canada and the Bering Sea.

Sample area	No. of females sampled	Fecundity regressions	Corr. coef.	Mean fecundity	Range
Newfoundland[1]	51	$Y = 6.4080X^{2.169}$	0.7767*	52,000	37,900- 81,200
Eastern Cape Breton Island[1]	115	$Y = 14.7361X^{1.9859}$	0.6598*	80,100	42,300-120,400
Western Cape Breton Island[1]	98	$Y = 38.4554X^{1.7649}$	0.6347*	74,500	32,600-128,400
Western Gulf of St. Lawrence[1]	98	$Y = 13.2530X^{1.9922}$	0.7472*	58,800	12,100-122,900
All four of the above areas[1]	361	$Y = 9.2490X^{2.0893}$	0.7694*	66,300	12,100-128,400
Southeastern Bering Sea[2]	42	$Y = 0.4905X^{2.7206}$	0.7329	36,300	- -
Gulf of St. Lawrence[2]	99	$Y = 0.0012X^{4.200}$	0.8086	-	20,000- 40,000[3]

[1]From present study.
[2]From Haynes et al. (1976).
[3]From Watson (1969).
*Significant at $P < 0.0001$.

Re Table 2

N.B.: Results of Haynes et al. (1976) differ from those of Davidson (1983) by indicating a more exponential relationship between carapace width (CW) and fecundity for female crabs from the western Gulf of St. Lawrence. This may be due to two factors: Firstly, the females used by Haynes et al. (1976) were collected in May and June when the eggs would have been freshly extruded. Hence, there would have been little egg loss compared to the females collected by Davidson (1983) in July and August. Secondly, Haynes et al. (1976) used blotted wet weights of the egg masses when calculating fecundity. Since a higher percentage of water can be easily blotted from a small egg mass than a large one, Haynes et al.'s (1976) method would tend to overestimate the fecundity of females with large egg masses and may underestimate the fecundity of females with small egg masses.

Fig. 1. Snow crab management areas around Cape Breton Island.

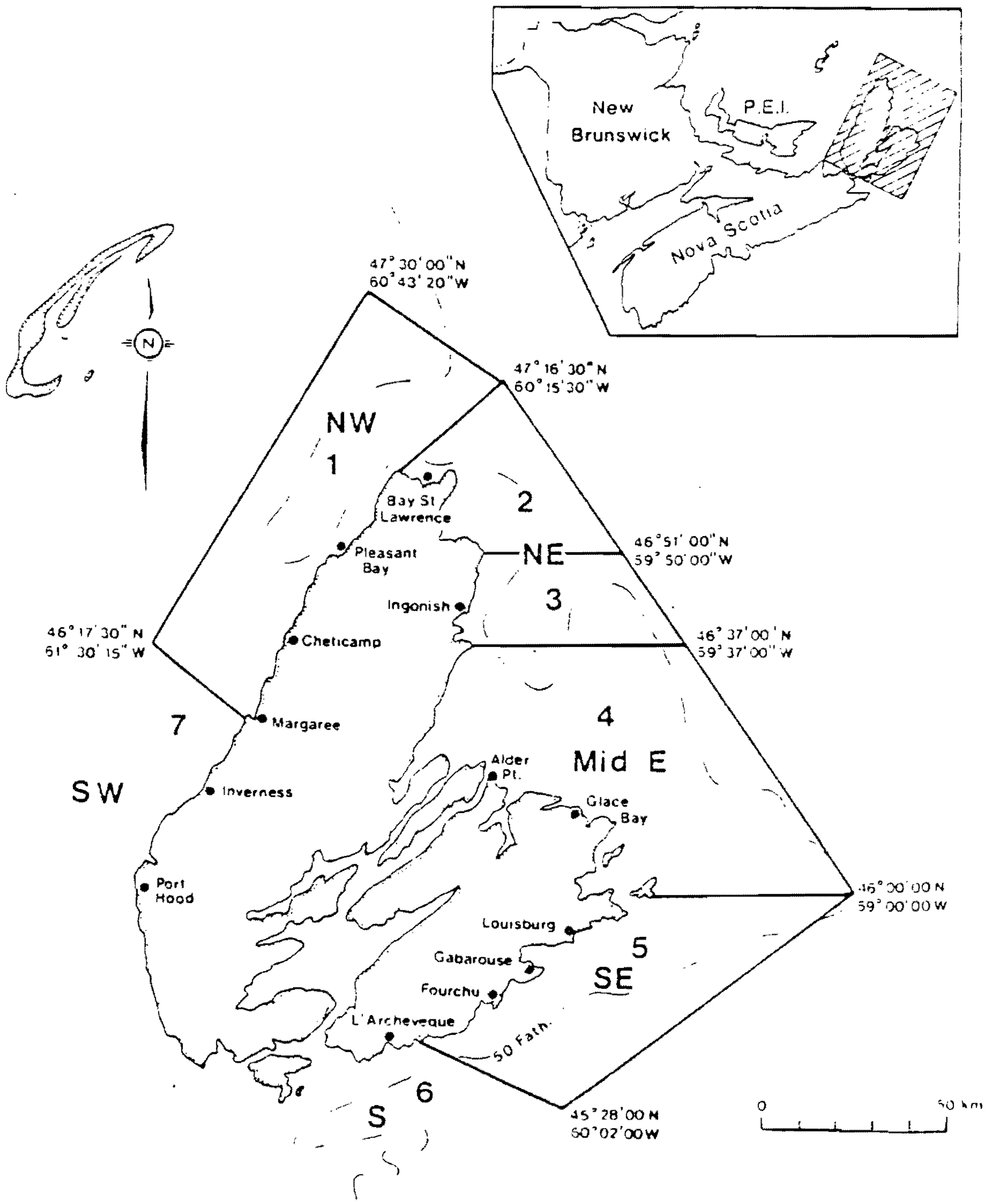

Fig. 2. Relationship between percent maturity and carapace width in female <u>C. opilio</u> from 1981-82. Obtained from beam trawling in Area 1.

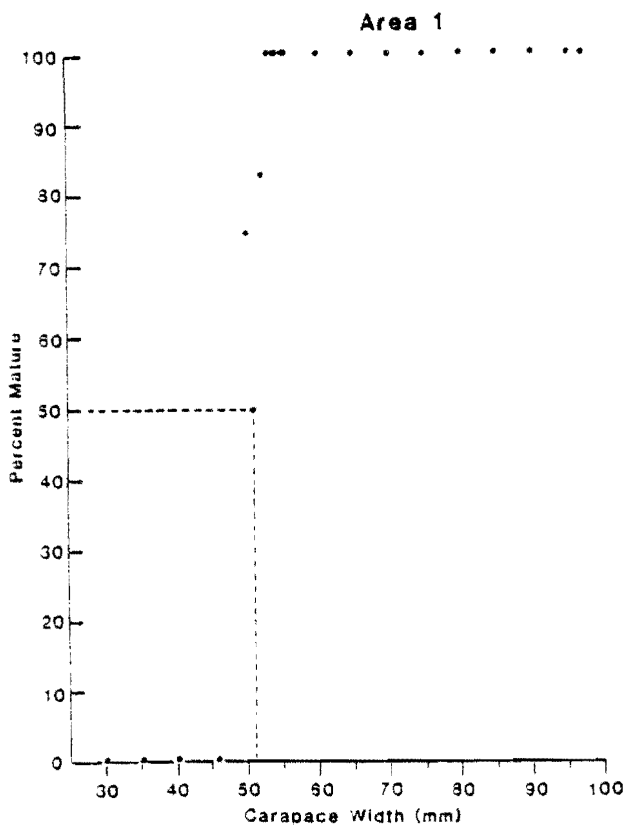

Fig. 3a. Percentage of ovigerous female C. opilio by monthly periods for Areas 1 and 7 from 1977-82.

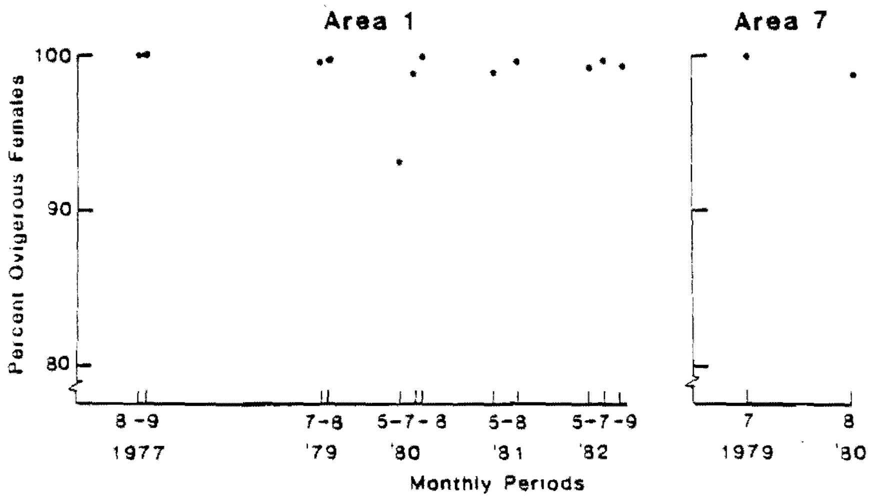

Fig. 3b. Percentage of ovigerous female *C. opilio* by monthly periods for Areas 3, 4, and 5 from 1977-83.

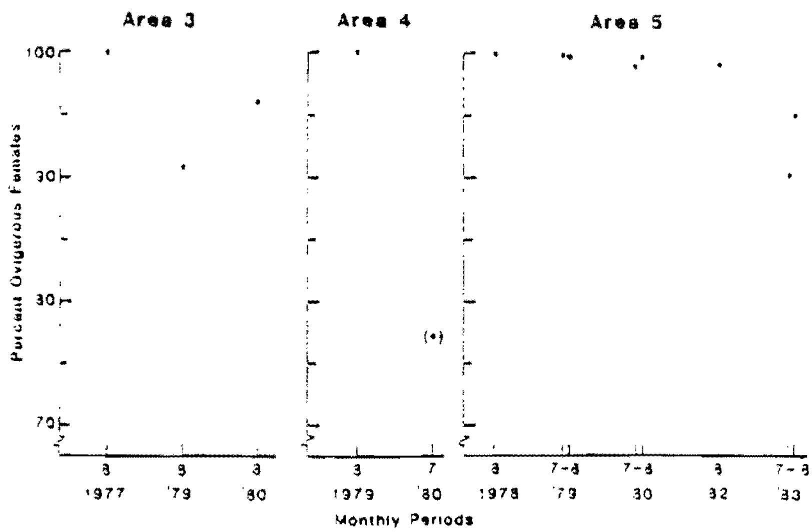

Fig. 4a. Size-frequency histograms for ovigerous female snow crab captured during sea sampling on commercial boats in Area 1 from 1977-81.

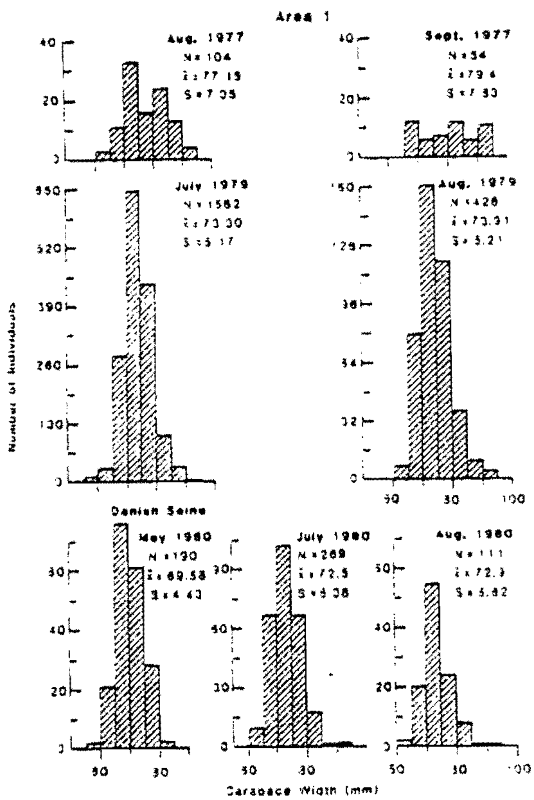

Fig. 4a. (continued)

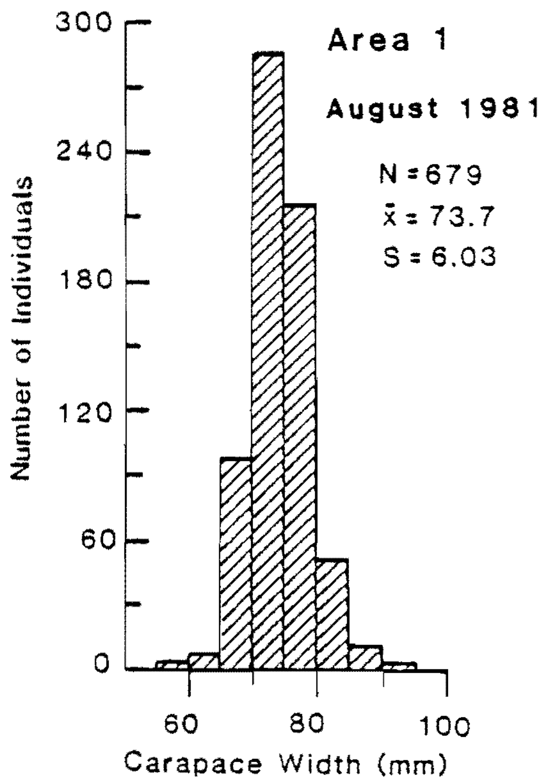

Fig. 4b. Size-frequency histograms for ovigerous female snow crab captured during sea sampling on commercial boats in Area 7 from 1979-80.

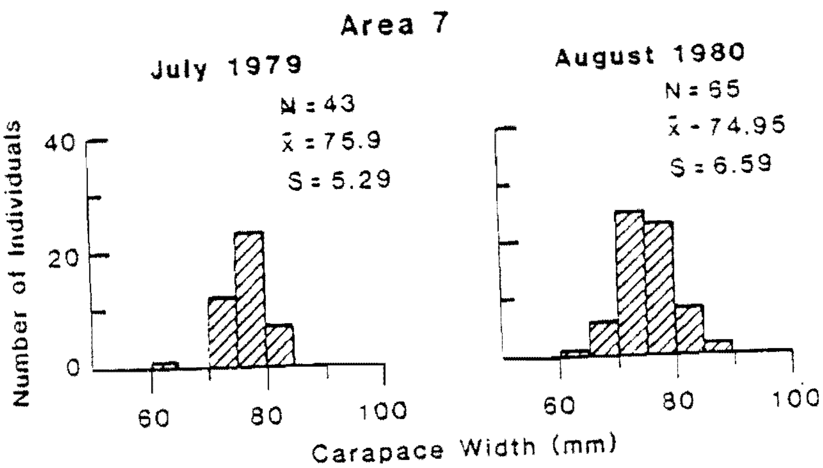

Fig. 4c. Size-frequency histograms for ovigerous female snow crab captured by beam trawling in Area 1 during 1981 and 1982.

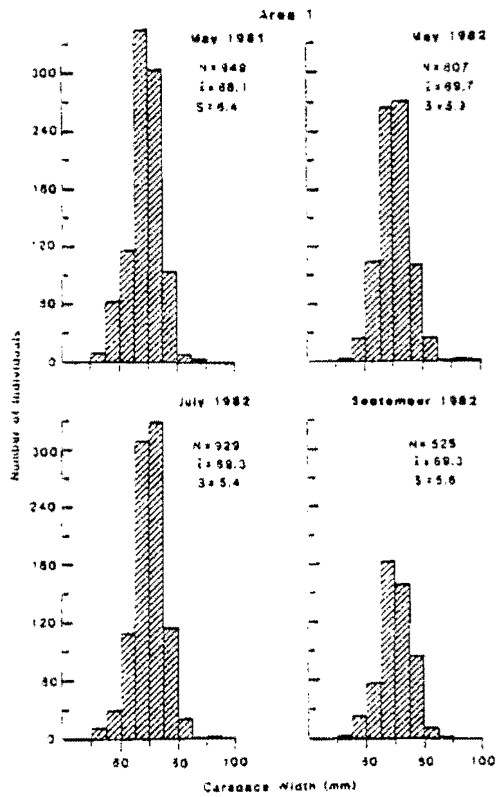

Fig. 5a. Size-frequency histograms for ovigerous female snow crab captured during sea sampling on commercial boats in Area 5 from 1978-80.

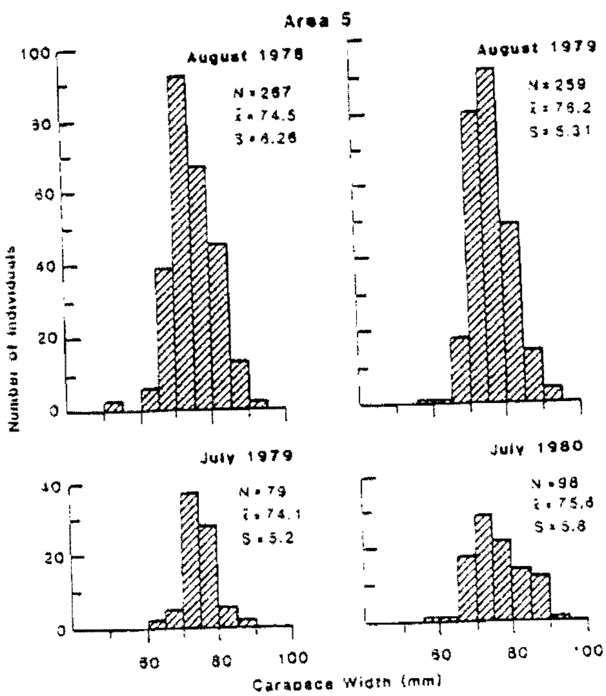

Fig. 5b. Size-frequency histograms for ovigerous female snow crab captured during sea sampling on commercial boats in Area 5 from 1980-83.

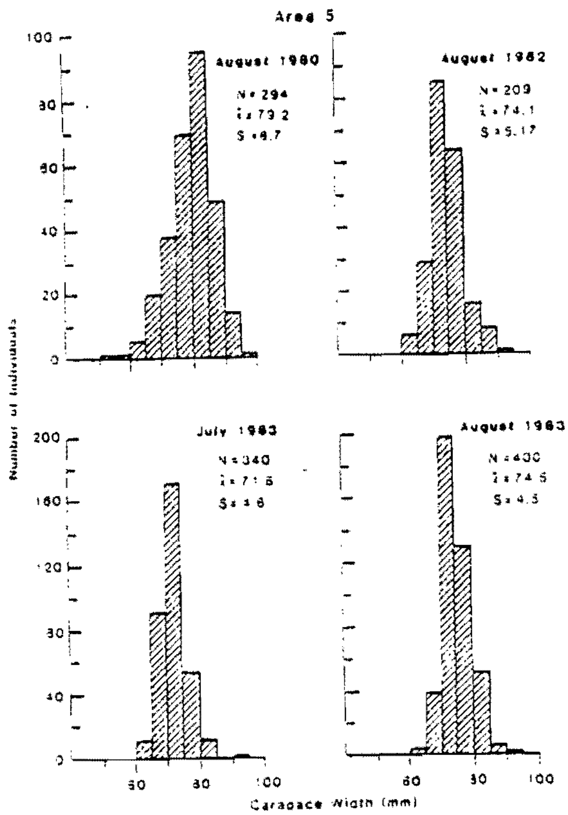

Fig. 6. Size-frequency histograms for ovigerous female snow crab captured during sea sampling on commercial boats in Areas 3 and 4 from 1977-80.

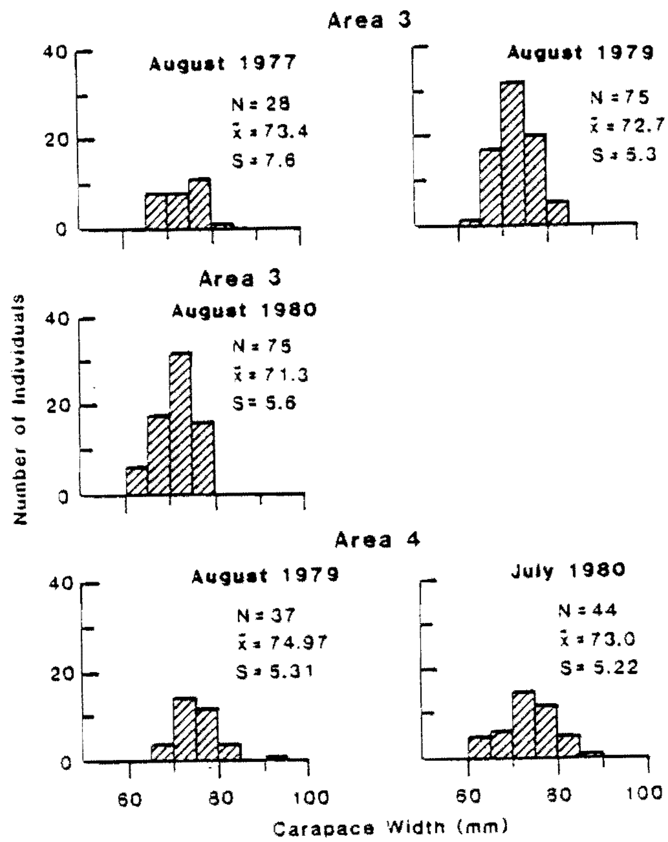

Fig. 7. Size-frequency histograms for non-ovigerous mature female snow crab for Areas 1 and 5 from 1981-83.