Assessment of snow crab (*Chionoecetes opilio*) catchability by Japanese trap

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

RÉSUMÉ

Sainte-Marie, B. et C. Turcotte. 2003. Évaluation de la capturabilité du crabe des neiges (*Chionoecetes opilio*) par le casier japonais. Rapp. tech. can. sci. halieut. aquat. 2508E : vii + 21 p.

Des expériences ont été réalisées à l'été 1992 sur la rive sud de l'estuaire du Saint-Laurent afin de déterminer la capturabilité du crabe des neiges par le casier japonais. La capturabilité, ou surface effective de pêche d'un casier, est le quotient du nombre moyen d'individus capturés par un casier et de la densité de ces individus sur le fond. La capturabilité s'exprime en mètres carrés. Nous avons évalué la densité de crabes sur le fond à l'aide d'un chalut à perche. La capturabilité a été déterminée pour les mâles de différentes catégories de maturité (adolescent versus adulte), d'âge relatif (temps écoulé depuis la dernière mue) et de taille. De plus, nous avons mesuré les effets sur le rendement et la composition des prises d'une occupation préalable des casiers japonais par un ou plusieurs crabes des neiges vivants, soit des mâles adolescents à carapace dure, des mâles adultes à carapace molle (récemment mués) ou des mâles adultes à carapace dure. Les casiers japonais se sont avérés très sélectifs pour les mâles adultes de taille légale (≥ 95 mm de largeur de carapace, LC) à carapace intermédiaire (âgés d'environ 2 à 3 ans depuis la mue terminale). Ceux-ci avaient une capturabilité 1000 fois supérieure (environ 63 000 m^2) à celle des mâles adultes de taille légale mués depuis quelques semaines et 10 fois supérieure à celle des mâles adultes de taille légale à vieille carapace (âgés d'environ 5 à 6 ans depuis la mue terminale). Les mâles adolescents de taille légale étaient 30 fois moins capturables que les mâles adultes de taille légale à carapace intermédiaire. La relation entre la capturabilité et la taille des mâles adultes à carapace intermédiaire avait la forme d'une cloche, les mâles de moins de 80 mm de LC comme ceux de plus de 135 mm de LC étant peu capturables. Les raisons pour les différences de capturabilité entre catégories de mâles sont discutées. De façon générale, l'occupation préalable par des mâles adultes à carapace dure a entraîné une baisse modérée du rendement du casier japonais, probablement en raison d'une intimidation des crabes à l'extérieur du casier. L'occupation préalable par des mâles adultes récemment mués a entraîné une baisse très importante du rendement du casier japonais. Cependant, cette baisse de rendement est attribuable à la forte mortalité des crabes récemment mués et à l'aversion du crabe des neiges pour ses congénères morts. Les résultats de la présente étude pourraient servir à ajuster les rendements des casiers japonais utilisés dans la pêche commerciale ou les relevés post-saison afin que les indices d'abondance qui en sont tirés soient plus représentatifs de la réalité démographique des populations échantillonnées.

ABSTRACT

Sainte-Marie, B. and C. Turcotte. 2003. Assessment of snow crab (*Chionoecetes opilio*) catchability by Japanese trap. Can. Tech. Rep. Fish. Aquat. Sci. 2508E: vii + 21 p.

Experiments were performed during the summer of 1992 on the southern shore of the St. Lawrence Estuary to determine the catchability of snow crab by Japanese traps. Catchability, also referred to as the effective fishing area of a trap, is the ratio of the mean number of individuals captured by a trap to the density of individuals present on the bottom. Catchability is expressed in square metres. Crab density on the sea bottom was assessed using a beam trawl. Catchability was determined for males in various categories of maturity (adolescent versus adult), relative age (time elapsed since the last moult) and size. Furthermore, we measured the effects on catch composition and yield of prior occupancy of Japanese traps by one or more live snow crabs, either hard-shell adolescent males, soft-shell (recently moulted) adult males or hard-shell adult males. Japanese traps were highly selective for adult males of legal size (≥ 95 mm carapace width [CW]) with an intermediate shell condition (about 2–3 years since the terminal moult). The catchability of these males was 1000 times greater (about 63,000 m^2) than that of legal-size adult males having moulted within a few weeks and 10 times greater than that of legal-size adult males bearing an old shell (about 5–6 years since terminal moult). Adolescent males of legal size were about 30 times less catchable than legal-size adult males with intermediate shell. The relationship between catchability and size of adult males with intermediate shell has a bell-shaped distribution, with males smaller than 80 mm CW and males larger than 135 mm CW having low catchability. The reasons for these differences in catchability among male categories are discussed. In general, prior occupancy by hard-shell adult males resulted in a moderate reduction of the yield of Japanese traps, probably because crabs outside the traps were intimidated. Prior occupancy of Japanese traps by soft-shell adult males caused a large reduction of yield. However, this decrease can be attributed to the high mortality of soft-shell crabs and the snow crab's aversion for dead conspecifics. The results of the present study could be used to adjust the yield data collected by Japanese traps employed by the commercial fishery or post-season trap surveys, so that derived abundance indices better reflect the demography of sampled populations.

1.0 INTRODUCTION

In Eastern Canada, the harvesting of snow crab (*Chionoecetes opilio*, Brachyura: Majoidea) began during the early 1960s but only became widespread and intensive around the beginning of the 1980s (Bailey, 1978; Hare and Dunn, 1993). In 2002, landings reached a peak of 105,700 tons, which corresponds to more than 411 million $CAN (É. Koulouris, DFO, Quebec Region, pers. comm.). The commercial fishery only targets the largest males since regulations impose a minimum size of 95 mm carapace width (CW) and a prohibition on female landings (Miller, 1976). Moreover, a TAC (total allowable catch) by area of fishery, a limited number of licences per area, a quota by licence and a limit on the number of traps per licence are used to control this fishery. The release at sea of crabs of legal size is generally prohibited, although exceptional measures are applied in some areas for males of legal size that are adolescent or that have recently moulted ("white" crabs). In several areas, the fishing season is of limited duration, and there are protocols for partial or complete closure of fishing areas when the proportion of recently moulted crabs found in catches exceeds a given threshold, generally 20% (Bailey and Elner, 1989).

In Canada, snow crabs are fished with baited traps. Several types of traps exist: Japanese, conical and rectangular models are most popular (Lafleur et al., 1983). However, the Japanese trap is still the main type used in the fishing areas of the Estuary and Northern Gulf of St. Lawrence (R. Dufour, DFO, Quebec Region, pers. comm.). This trap has the shape of a truncated cone, with a diameter of 1.22 m at the base and 0.71 m at the apex, and a height of 0.58 m. Its single entry, with a diameter of 0.51 m, is in apical position and is equipped with a rigid plastic skirt to reduce escapement (Lafleur et al., 1983). A mesh bag containing bait, usually thawed herring, is suspended inside the trap, close to the entrance. Some components of the bait diffuse or are washed out by water currents into the environment, forming a plume whose shape and spatial extent will depend on the size of the source as well as the speed and turbulence of the water (Okubo, 1980; Sainte-Marie and Hargrave, 1987; Moore et al., 1994). Like other carnivorous or necrophagous marine animals, the snow crab is attracted to baited traps by smell (McLeese, 1970; Mackie, 1973; Hancock, 1974) and will move toward the bait following a counter-current route (Karnofsky and Price, 1989; Lapointe and Sainte-Marie, 1992; Vienneau et al., 1993).

The coefficient of catchability (simply called catchability hereafter) is a measurement of a species' vulnerability to a given type of fishing gear. According to Morgan (1974), the most direct way to assess catchability is to simultaneously measure the catch per unit of effort (CPUE) of the fishing gear and the density of the target species. In the case of a benthic organism like the snow crab, catchability (q) by Japanese trap is calculated as follows:

$$q = \text{CPUE} \cdot \text{D}^{-1}$$

where D is the density of crabs on the bottom (Miller, 1990). The concept of catchability, when applied to a baited trap, is also referred to as the "effective fishing area of a trap" and is expressed as a unit area (e.g., m^2, hectare). Catchability is thus an estimate of the minimal bottom area influenced by the trap, based on the hypothesis that all individuals are available to the trap. Actually, the area of attraction of a baited trap—i.e., the actual bottom area over which the odour plume of the trap is perceptible by at least some animals—is larger than what is shown by the coefficient of catchability because individuals are not all attracted to the same extent by baited traps and are not all able to enter or all retained in the traps (Miller 1978a, 1978b, 1990; Lafleur et al., 1983; Brêthes et al., 1985; McQuinn et al., 1988; Cyr and Sainte-Marie, 1995).

The quality and quantity of bait, the availability of alternative sources of food, and the environment's physicochemical conditions such as light intensity, the velocity and turbulence of water flow, and the temperature, can have a significant influence on the number of animals a baited trap will attract as well as on catch composition (Morrissy, 1975; Sainte-Marie and Hargrave, 1987; Miller, 1990; Cyr and Sainte-Marie, 1995). However, according to Brêthes et al. (1985), the abundance and the biological parameters of a population may explain most of the variability of the CPUE. These parameters include sex, maturity, moult stage and size of crabs, among others, which may determine to a large extent the vulnerability of individuals to baited traps (Miller, 1990).

Three successive stages of maturity are used to describe male snow crabs—immature, adolescent and adult—and these stages are separated by moults considered as being "critical" (Comeau and Conan, 1992; Sainte-Marie et al., 1995). The moult at which immature crabs become adolescents is characterized by the beginning of sperm production and by a slight acceleration of claw growth compared to cephalothorax growth. During the second critical moult, which is a terminal moult, a strong and sudden increase occurs in the size of the claw compared to the cephalothorax. Adolescent males are less aggressive than adults (Conan and Comeau, 1986; Sainte-Marie et al., 1997) and may also be less vulnerable to baited traps (Hoenig and Dawe, 1991). It may thus be possible that the identity of crabs first entering a trap affects the subsequent "colonization" of this trap (see for example Addison and Bannister, 1998).

After moulting, male snow crabs do not feed for a period of time ranging from a few days to a few weeks (Watson, 1971; O'Halloran and O'Dor, 1988; Mayrand et al., 2000), and thus would not be very vulnerable to baited traps (Hoenig and Dawe, 1991). After a terminal moult, the shells of new adult males hardens and their flesh develops over a period of 1 to 2 years. They maintain an optimal condition for approximately two years and then gradually lose this condition as they age and accumulate wounds until death occurs, between 5 and 8 years after the moult (Sainte-Marie et al., 1995; B. Sainte-Marie and F. Hazel, unpublished data). The elapsed time since the last moult (or "relative age") of an adult crab can be established based on the aspect and hardness of the carapace. The vulnerability of an individual to baited traps probably depends on relative age, and senescent individuals are assumed to have a low catchability (B. Sainte-Marie, unpublished data).

The assessment of snow crab stocks is mainly based on indices of abundance that are derived from CPUEs of commercial fishery and research surveys with trawls or baited traps (Dufour and Dallaire, 1999). In the Estuary and the northern Gulf of St. Lawrence, surveys are made on a regular or intermittent basis using a beam trawl with a 3-m horizontal opening. However, the rugged bottoms do not allow complete coverage of this area with the beam trawl. Consequently, the Department of Fisheries and Oceans and fishermen associations jointly developed post-season surveys involving the use of baited traps in each fishing area. Variations in trap CPUE among areas or years are thought to mainly reflect variations in the abundance of the exploited population. However, little information is available on the vulnerability of males to traps according to their maturity, stage of moult, relative age or size. Such information is essential for modelling the abundance, production, exploitation rate and expected yield of populations based on trap fishery data (e.g., Zheng et al., 1996). The goal of this study is to fill these gaps, at least partially.

2.0 MATERIAL AND METHODS

2.1 EXPERIMENTAL PROTOCOL

2.1.1 Experimental site, fishing gears and characterization of crabs

Three experiments (Table 1) were carried out in 1992 off the southern shore of the St. Lawrence Estuary (approximately 48º38.5' N, 68º21.75' W), between Rimouski and Sainte-Luce, at depths ranging from 40 to 75 m. Bottoms in this area are composed of fine mud. Water flow, mainly influenced by the Gaspé and tidal currents, is nearly parallel to the coast. The study area is commercially exploited, but the fishery was finished before the experiments were carried out.

Table 1. Nature and dates of experiments on snow crab (*Chionoecetes opilio*) yields with Japanese traps made during experimental fisheries on the southern shore of the St. Lawrence Estuary in 1992.

Experiment	Dates	Treatments (number of traps per day)
Catchability	June 14–15	Herring bait only (20)
Prior occupancy	June 18–19	Herring bait + soft adult male (8), herring bait + hard adult male (8), herring bait only (8)
Prior occupancy	June 21–22	Herring bait + adolescent male (8), herring bait + hard adult male (8), herring bait only (8)

The first experiment was carried out to assess the catchability of snow crabs by Japanese traps according to the stage of maturity, relative age and size of males. The purpose of the second and third experiments was to measure the impact on the yields by prior occupancy of Japanese traps by one or more living male crabs with predetermined characteristics (hard adult versus soft adult and hard adolescent versus hard adult). Occupying crabs were obtained either using a beam trawl before beginning the experiment or from the contents of traps once the experiments were started. The number of occupants varied from 1 to 6 individuals per trap, and no occupying crab was used more than once.

The Japanese traps that were used had exactly the configuration described in the Introduction and were covered with 135-mm stretched mesh net. Each trap was baited with five herring (*Clupea harengus*) of approximately 200 g each contained in a 25-mm stretched mesh bag. Each trap had its own buoy and was independent from adjacent traps (not connected by a rope). The beam trawl used had a 3-m opening, ensuring an effective fishing width of 2.5 m. It was provided with chains to dislodge buried crabs, and the codend was lined with a 15-mm stretched mesh net.

All crabs captured by trap or trawl were counted and characterized in the following way. The sex was determined based on the form of the abdomen, which is suboval or circular in females, and triangular in males. Carapace width (CW) and claw height (CH), excluding spines in both cases, were measured with a vernier calliper with an accuracy of 0.1 mm. The maturity of males was established from the discriminating equation provided by Sainte-Marie and Hazel (1992):

$$\ln CH_{obs} - \ln CH_{exp}$$

$$\text{where } \ln CH_{exp} = -2.6077 + 1.2209 \cdot \ln CW_{obs}$$

according to which a male is considered to be an adolescent or an adult when the difference between observed CH (CH_{obs}) and expected CH (CH_{exp}) for an observed CW (CW_{obs}) is respectively < 0 or ≥ 0. The shell condition (SC) was described according to the following arbitrary scale: 1 = soft and clean; 2 = hard and clean; 3 = intermediate; 4 = hard and dirty; 5 = soft and dirty (see Sainte-Marie, 1993). However, no crab with a SC5 was captured during our study. The progression of SC1 to SC5 reflects a gradual temporal change in crab shell condition since the last moult. To meet the requirements of some analyses of this study, we grouped the SCs into three categories: N = 1 and 2 (New); I = 3 (Intermediate); O = 4 (Old).

2.1.2 Catchability of snow crab by Japanese trap

To calculate catchability, 20 traps were soaked on two occasions, equally distributed between four lines running nearly perpendicular to the coast. Lines 1 and 2 as well as lines 3 and 4 were 0.93 km (0.5 nautical mile) apart from each other, whereas lines 2 and 3 were 1.85 km (1 nautical mile) apart. The traps were deployed at 300-m intervals on the lines. After 17 to 27 hours of fishing, the traps were recovered, and their contents were counted and characterized as described above.

Crab density on the bottom was established using a beam trawl. On June 14, 1992, before the traps were soaked, two trawl tows were made west and east and in the centre of the anticipated positions of trap lines. On June 15, a trawl tow was made west and east of trap lines and two trawl tows were made in the centre of trap lines, just before the recovery of the traps soaked the day before. The beginning and ending positions of the tows were noted to calculate the swept area and estimate the density of crabs, based on the crab numbers for each tow. On average, the trawl was towed at 3.5–4 knots for 21.5 minutes and swept approximately 6,400 m^2 of bottom per tow.

2.1.3 Influence of prior occupancy

To measure the influence that one or more prior occupants could have on the number and the composition of captures, two successive two-day experiments were carried out. Every day, 24 traps were soaked, equally divided among three lines that were perpendicular to the coast. On each line, traps were deployed at 0.5 km intervals, and the lines were about 1.5 km apart.

In addition to the herring bait, a given type of occupying crab (Table 1) was randomly placed into the traps on each line. For each day of sampling in the first of these two experiments, eight traps were populated with one to six hard shell adult males (SC2 and SC3), eight traps with one to five recently moulted adult males (SC1), and eight traps were left unoccupied as control traps. The occupying crabs had a CW greater than 100 mm and were marked with a spaghetti tag bearing a unique number. This tag was tied around the cephalothorax of the occupying crabs so that they could be recognized when the traps were recovered. The second experiment to determine the influence of prior occupancy on the yield of traps was performed in the same manner, except that occupying crabs were adolescent or adult males with a hard shell (SC2 and SC3). The adults used had a CW greater than 100 mm, while the adolescent males had a CW between 60 and 80 mm. Following a soak period ranging from 17 to 27 hours, the mortality of occupants was noted, and catches were counted and characterized.

2.2 DATA PROCESSING

When traps were recovered, both in the experiment on catchability and in the experiments on impact of prior occupancy on Japanese trap yield, a certain number of traps were empty and had a side or part of the apex soiled with mud because they had tilted. All of these traps, i.e., 12.5% of the 136 traps soaked, were not considered in the analyses. The soak time, which was quite uniform, did not have any perceptible impact on trap yield according to a correlation analysis, and this variable was thus not considered in the analyses.

The ≥ 300-m interval we left between the traps on a same line was intentionally higher than the estimated radius of attraction of a baited Japanese trap, which is 140 m at the most according to Brêthes et al. (1985). Each trap was thus considered to be independent of other traps on the same line, as well as of other traps on adjacent lines because the distance between the lines exceeded the distance between traps on a same line. In order to verify this premise, we performed a single factor analysis of variance (ANOVA) on the yield of traps used in this catchability experiment based on their position on the lines, which was numbered from 1 (coast) to 5 (offshore). When there is interaction between traps on a same line, inner traps should have lower yields than the traps located at the ends of the line (Eggers et al., 1982; Gros and Santarelli, 1986).

For the 119 traps recovered and considered to be valid during these three experiments, females made up only 295 out of the total catch of 2,969 snow crabs, which is less than 9.9% of the catch. Because of the low representation of females in traps, only males were addressed in subsequent analyses.

Catchability was assessed for various classes of maturity and size of males. The approach we took was to calculate catchability from the average CPUE for a given male category in all traps of a same line and the average density of the crabs of this same category on bottoms directly adjacent to that line. Therefore, four catchability estimates were obtained for each male category.

Data processing was carried out using the STATGRAPHICS Plus software, Version 2.0. Data normality was assessed with the Kolmogorov-Smirnov test, while homogeneity of variance was verified with the Bartlett test. We used the Student's t-test or the analysis of variance to compare the CPUE, density, catchability, CW and the percentage of adult individuals between traps, lines or fishing gears. The percentages were first subjected to an arcsine transformation to ensure their normality. When data were not normally distributed or had heterogeneous variances that we were unable to correct by any transformation, we used the Kruskal-Wallis nonparametric test. Finally, we used the χ^2 test to compare size frequency distributions between fishing gears. The average values presented in this document are accompanied by their standard error.

3.0 RESULTS

3.1 INDEPENDENCE OF TRAPS ON A SAME LINE

The average yield of traps in the catchability experiment according to their position on lines is shown in Table 2. The position did not significantly affect trap yield (ANOVA: $F_{4,28} = 2.50$, $p = 0.065$). The highest average yields were obtained at positions 2 and 3, towards the centre of the line. The yields at the ends of the line were definitely lower, contrary to what would be expected if there had been interference between the traps. This analysis also suggests that yield was independent of the shallow depth gradient observed from the coast to offshore, since no yield gradient is perceptible according to trap position on the line. As the distance between the traps on a same line was even greater in the experiments on the impact of prior occupancy, we can suppose that each trap represented an independent sampling unit.

Table 2. Average yield (number of individuals ± standard error) of snow crab (*Chionoecetes opilio*) males captured by Japanese traps during the experiment on catchability according to the position of the trap on the lines. The traps are numbered from 1 (coast) to 5 (offshore).

	Position of the trap on the line				
	1	2	3	4	5
Average yield	23.9 ± 3.8	32.6 ± 4.2	31.7 ± 3.7	16.5 ± 5.0	23.7 ± 3.3
Number of valid traps	8	5	7	6	7

3.2 CATCHABILITY

Table 3 shows a summary of the abundance and characteristics of male snow crabs captured by the trawl and the traps during the experiment on catchability. The traps mostly captured adult males, whereas this category accounted for only 44.2% of the males sampled with the trawl, the others being immature or adolescent males. Generally, the males captured by the traps had an older shell and were bigger than the males captured by the trawl.

Table 3. Summary of average yields (number of individuals ± standard error) and characteristics (± standard error) of snow crab (*Chionoecetes opilio*) males captured during the experiment on catchability according to the fishing gear. N, number of traps or valid trawl tows; SC, shell condition; CW, carapace width, in mm.

Fishing gear	N	Yield	% of adults	SC	CW
Beam trawl	10	$2.8 \pm 0.8 \cdot 1000\ m^{-2}$	44.2 ± 0.1	1.9 ± 0.1	96.1 ± 1.9
Japanese trap	33	$25.3 \pm 0.7 \cdot trap^{-1}$	93.4 ± 0.1	3.0 ± 0.0	112.4 ± 0.5

The representation of males by shell condition and by fishing gear was further assessed (Fig. 1). Overall, a slight prevalence of individuals with new shell (66.1%) and a clear predominance of individuals with intermediate shell (88.1%) were noted in the trawl and the traps, respectively. Moreover, crabs with new shell were mainly clean and soft in the trawl (64.8% of all crabs with new shell had SC = 1), whereas they were rather clean and hard in traps (SC = 2 for 76.0% of individuals). Males with an old shell were very seldom (< 5%) captured with the two types of fishing gears. The distribution of all males by shell condition differed significantly between the trawl and the traps (Fig. 1; $\chi^2 = 208.42$, df = 2, $p < 0.001$). However, this general picture hides a clear divergence in the representation of shell conditions between pre-adult (immature and adolescent) and adult males for both fishing gears (Fig. 1). Thus, among pre-adult males, 81.2% had a new shell and 18.7% had an intermediate shell in the trawl, compared to 34.5% and 61.8%, respectively, in the traps. Fifty percent of adult males had a new shell, and 47.4% had an intermediate shell in the trawl compared to 3.2% and 90.1%, respectively, in the traps. Therefore, males with an intermediate shell were over-represented in the traps compared to their numbers on the bottom, both for pre-adult males and adult males.

With respect to the size of males, there also was as a strong and significant difference between the CW of all males captured by the trawl and the traps (Table 3; Kruskal-Wallis, H = 60.26, df = 1, $p < 0.001$), with males being definitely smaller in the trawl (96.1 mm) than in the traps (112.4 mm). The frequency distributions of the size of males (Fig. 2) differed between the trawl and the traps in a very significant fashion for pre-adults ($\chi^2 = 34.51$, df = 8, $p < 0.001$), but to a lesser extent for adults ($\chi^2 = 17.35$, df = 7, p = 0.015). The average CW of the pre-adult males captured by the trawl was much smaller than that of the pre-adult males captured by the traps (Kruskal-Wallis, H = 20.05, df = 1, $p < 0.001$) (Fig. 2). On the other hand, the average CW of the adult males captured by the trawl was slightly greater than that of the adult males captured by the traps (Kruskal-Wallis, H = 6.69, df = 1, p = 0.010) (Fig. 2). When the comparison is restricted to the adult males with an intermediate shell, the average CW is similar (Kruskal-Wallis, H = 0.67, df = 1, p = 0.414) for the individuals captured by the trawl (115.4 ± 2.2 mm) and the traps (114.3 ± 0.4 mm).

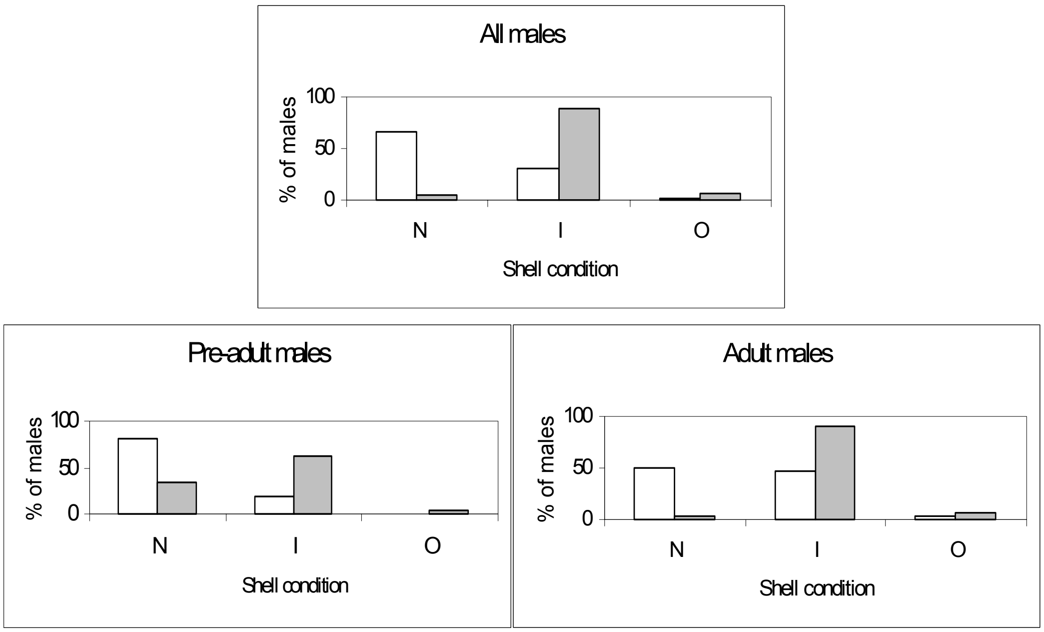

Figure 1. Distribution by shell condition of snow crab (*Chionoecetes opilio*) males as a whole, of pre-adult males and of adult males captured by the beam trawl (white bars) and Japanese traps (grey bars) during the experiment on catchability (N = new shell; I = intermediate shell; O = old shell). The total number of captured males was 96 pre-adults and 76 adults for the beam trawl and 55 pre-adults and 780 adults for Japanese traps.

Spatial heterogeneity of trap yield and density of snow crabs on the bottom was observed during the experiment on catchability (Table 4). The ANOVA shows that the localization of the trap line had a significant impact on the yield for adult males ($F_{3,29} = 4.82$, p = 0.008), but not on the yield for pre-adult males ($F_{3,29} = 0.21$, p = 0.886). The traps on the two central lines showed average adult crab yields superior to those of the traps on the two peripheral lines. On the contrary, the bottom density was heterogeneous for the pre-adult males ($F_{2,7} = 18.52$, p = 0.002), which were approximately 10 to 35 times more numerous in the centre of the experimental area than at its western or eastern periphery, whereas the density of adult males appeared more homogeneous ($F_{2,7} = 2.39$, p = 0.160).

Depending on the localization of the trap lines, the number of adult males was 8 to 24 times higher than the number of pre-adult males found in the traps (Table 4). The density of pre-adult males on the bottom, as estimated from trawl data, exceeded that of adult males in the centre of the experimental area, was equal in the east and was lower by a factor of 10 in the west (Table 4).

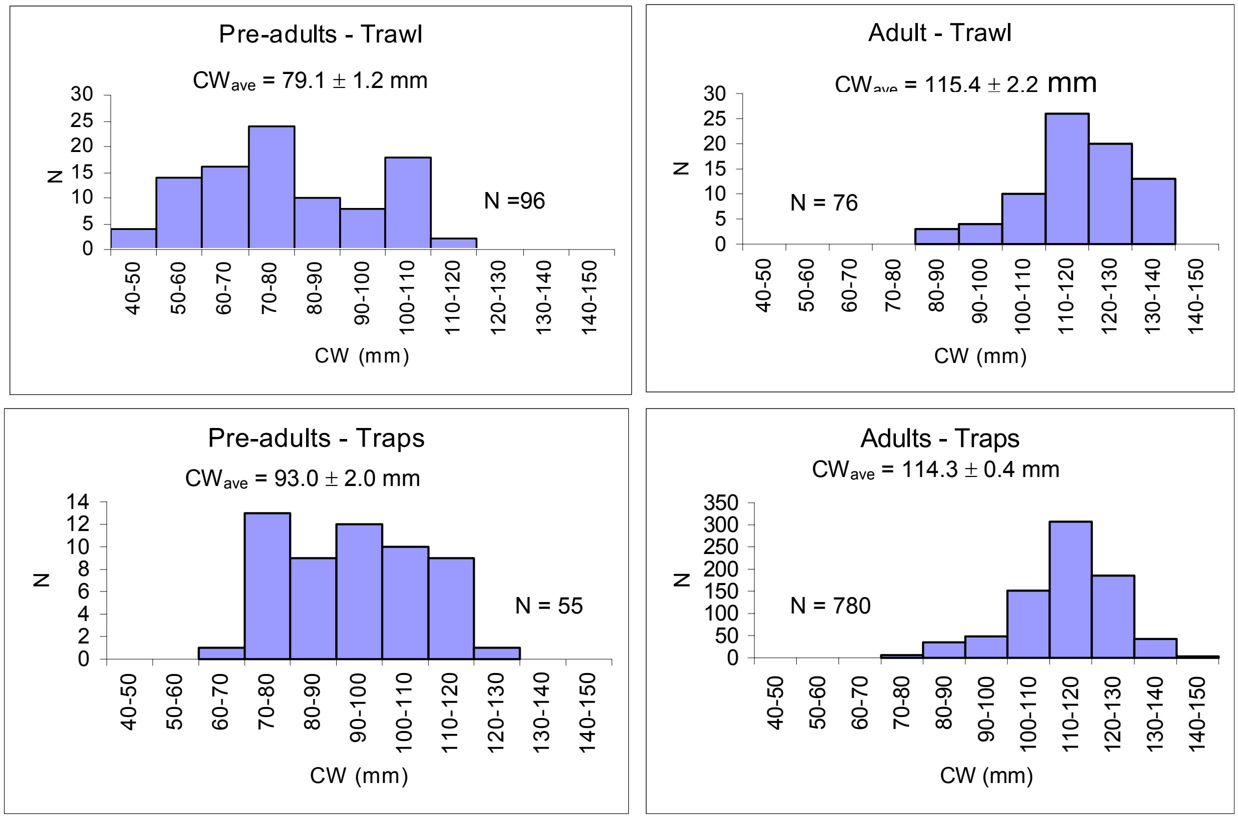

Figure 2. Distribution of frequencies of carapace width (CW) of snow crab (*Chionoecetes opilio*) pre-adult and adult males captured by the beam trawl and Japanese traps during the experiment on catchability.

Table 4. Average (± standard error) of Japanese trap yield and bottom density of snow crab (*Chionoecetes opilio*) pre-adult and adult males during the experiment on catchability by localization of trap lines and trawl tows. N, number of valid samples.

Localization of trap lines and of trawl tows	Yield males · trap $^{-1}$			Bottom density males · 1000 m^{-2}		
	Pre-adults	Adults	N	Pre-adults	Adults	N
East	1.8 ± 0.6	20.1 ± 3.0	9	0.4 ± 0.4	0.6 ± 0.1	3
Centre-East	1.3 ± 1.0	27.6 ± 1.0	7	–	–	–
Centre	–	–	–	3.5 ± 0.6	2.0 ± 0.6	4
Centre-West	1.3 ± 0.4	31.8 ± 3.3	8	–	–	–
West	2.1 ± 1.3	17.0 ± 3.7	9	0.1 ± 0.1	1.0 ± 0.3	3

The catchability of male snow crabs by Japanese traps was calculated according to various criteria of maturity and size (Table 5). Four catchability estimates were calculated for each category of males, based on the average yield by line of traps and the average density of crabs in directly adjacent trawl tows: (i) the east line relative to the density in the east; (ii) the centre-east line relative to the density in the centre; (iii) the centre-west line relative to the density in the centre; and (iv) the west line relative to the density in the west (see Table 4). The average catchability of males of more than 90 mm CW, irrespective of their maturity and shell condition, was 17,786 m^2. Considering only adult males ≥ 95 mm CW, i.e., the exploitable portion of the population, the average catchability was even greater (28,278 m^2). However, this value hides very large variations of catchability of adult males according to their relative age (SC). Recently moulted adult males (with a new shell) were on average 975 times less catchable than males having moulted within approximately the last 2 to 4 years (intermediate shell), and they in turn were approximately 11 times more catchable than males having moulted within approximately the last 4 to 6 years (old shell). Finally, the adolescent males, whether pre-recruits (78 ≤ CW < 95 mm) or legal size (CW ≥ 95 mm), had a catchability approximately 30 times lower than that of adult males of legal size with an intermediate shell.

Table 5. Estimates of average catchability (± standard error) for snow crab (*Chionoecetes opilio*) males by Japanese traps according to various criteria of maturity and size. CW, carapace width in mm; SC, shell condition: N, new shell; I, intermediate shell; O, old shell.

Male categories	Catchability in m^2
Adolescents and adults, CW > 85 mm	17,127 ± 2380
Adolescents and adults, CW > 90 mm	17,786 ± 2535
Adolescents, 78 ≤ CW < 95 mm	1864 ± 1087
Adolescents, CW ≥ 95 mm	2157 ± 1089
Adults, CW ≥ 95 mm	28,278 ± 10,572
Adults, CW ≥ 95 mm, SC = N	65 ± 65
Adults, CW ≥ 95 mm, SC = I	63,310 ± 28,938
Adults, CW ≥ 95 mm, SC = O	5,482 ± 3,022

The variability of the catchability of adult males with an intermediate shell was also studied in relation to their size. To do so, catchability was calculated by 10-mm size classes ranging from 57.5 mm to 147.5 mm of CW, based on average trap yield and bottom density per size class calculated for all traps and trawl tows. The result of this analysis is shown in Fig. 3. It should be noted that the relation between catchability and CW is similar to a bell-shaped function, with very low values at the extremities of the size range of adult males and a maximum value at about 107 mm of CW. A polynomial regression adjusted to data (Fig. 3) shows that the CW explains 88.5% of the variability of the average catchability of adult males with an intermediate shell.

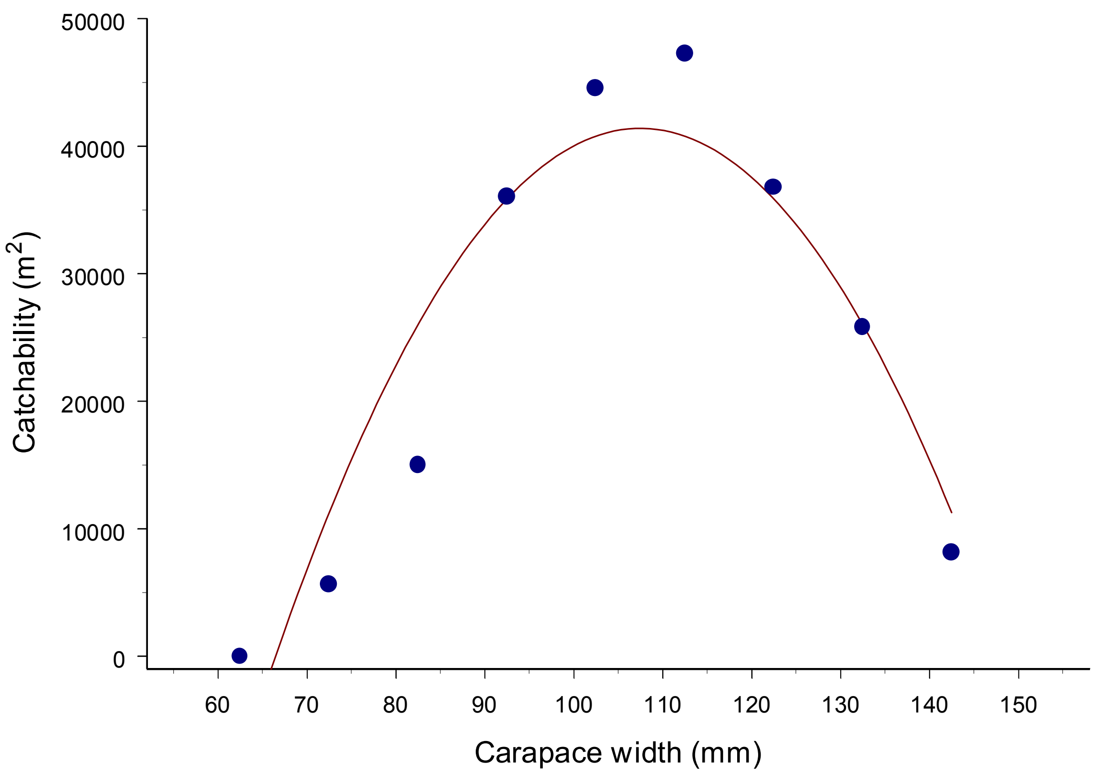

Figure 3. Variation of the average catchability (*q*) by the Japanese trap of snow crab (*Chionoecetes opilio*) adult males with an intermediate shell in relation to carapace width. The curved line adjusted to data is a polynomial regression: $q = -243{,}014.0 + 5{,}291.3 \cdot CW - 24.6 \cdot CW^2$ ($r^2 = 0.885$, $F = 23.10$, $N = 8$, $p = 0.001$).

3.3 INFLUENCE OF PRIOR OCCUPANCY

Figure 4 shows the size frequency distribution of snow crabs during the experiment examining the effect of prior occupancy on yields of Japanese traps (baited traps and control traps together). Two modes are present, representing moult instars XII and XIII (see Sainte-Marie et al., 1995).

Table 6 summarizes the results of the two experiments carried out to verify the impact of prior occupancy on the yield of Japanese traps. Occupying crabs suffered a certain amount of mortality even though they were carefully manipulated. In particular, soft crabs had an average mortality much higher (53.5%) than hard crabs (7.7%), and the difference in mortality between the two types of occupants was highly significant (arcsine transformation, ANOVA: $F_{1,24} = 28.99$, $p < 0.001$). Although the mortality of occupying crabs was higher for hard adolescents (12.2%) than for hard adults (2.5%), the difference was not significant (arcsine transformation, ANOVA: $F_{1,29} = 2.82$, $p = 0.104$). Given the possible aversion of crabs for dead conspecifics, causing a reduction in trap yield, we used linear regression to verify if there was a relation between trap yield with occupying crabs and the number of dead occupying crabs. The relation between the two variables was negative and significant ($F = 19.51$, $N = 57$, $p < 0.001$).

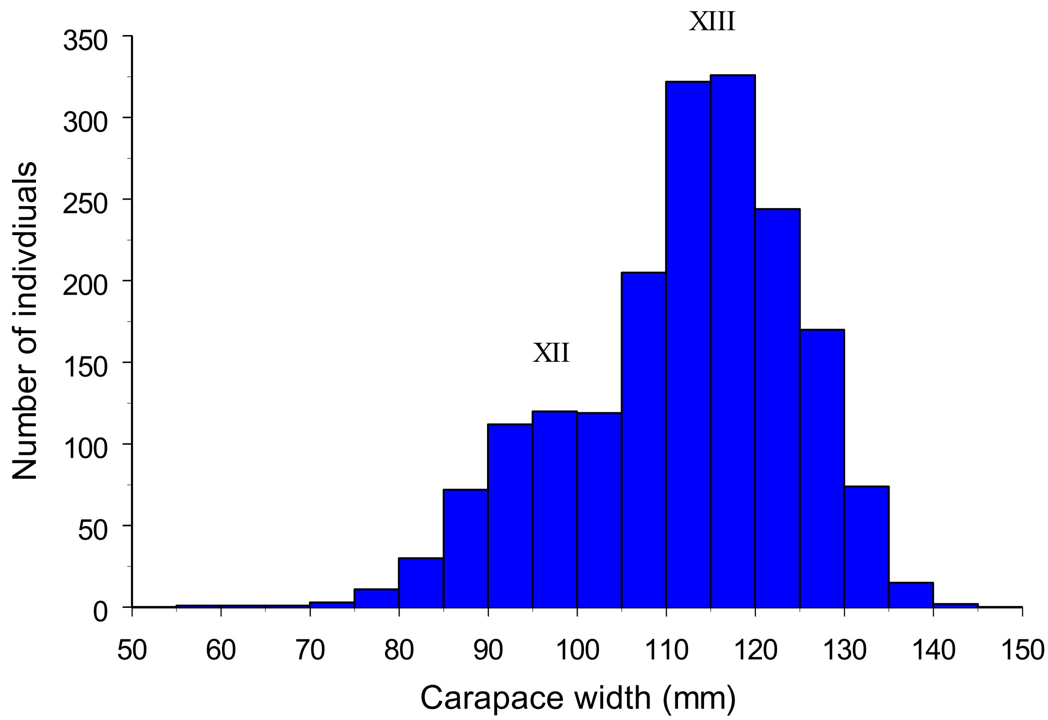

Figure 4. Frequency distribution of carapace width for all snow crab (*Chionoecetes opilio*) males captured (1,828 individuals) during the two experiments on the impact of prior occupancy on Japanese trap yield. The Roman numerals correspond to modes representing the inter-moult stages.

Generally, the average yield of control traps (bait only) was better than that of traps with prior occupancy (Table 6). During the first experiment, a significant difference in yield was noted among traps occupied by hard crabs, those occupied by soft crabs, and the controls traps (ANOVA: $F_{2,38} = 12.85$, $p = 0.001$). The traps occupied by soft crabs had a smaller yield than those of the traps occupied by hard crabs or the control traps, and the differences were significant (Bonferonni test at the 5% threshold).

In the second experiment (Table 6), the average yield of traps with prior occupancy was significantly lower than those of control traps (ANOVA: $F_{2,42} = 4.70$, $p = 0.014$). The Bonferroni test at the 5% threshold shows that average yield differed significantly between the traps occupied by adult males and the control traps, but not between the traps occupied by adult males and those occupied by adolescent males, nor between the traps occupied by adolescent males and the control traps.

Table 6. Summary of average yield and average characteristics (± standard error) of snow crab (*Chionoecetes opilio*) males captured by Japanese traps during the experiments on the impact of prior occupancy as well as percentage of mortality of the prior occupants. N, number of valid traps; SC, shell condition; CW; carapace width in mm.

Experiment Occupant	N	Yield males · trap^{-1}	% of adults	SC	CW	% dead occupants
Experiment 1						
Soft adult	13	10.9 ± 2.5	96.3 ± 0.0	3.1 ± 0.0	111.1 ± 1.3	53.5 ± 0.1
Hard adult	13	21.6 ± 1.8	97.0 ± 0.0	3.1 ± 0.0	114.0 ± 0.7	7.7 ± 0.1
Control	15	26.9 ± 3.1	95.4 ± 0.0	3.1 ± 0.0	113.0 ± 0.6	–
Experiment 2						
Hard adolescent	15	19.2 ± 1.9	95.5 ± 0.0	3.0 ± 0.0	112.6 ± 0.7	12.2 ± 0.1
Hard adult	16	17.9 ± 1.9	93.9 ± 0.0	3.0 ± 0.0	110.4 ± 0.8	2.5 ± 0.0
Control	14	26.0 ± 2.0	94.9 ± 0.0	3.0 ± 0.0	110.3 ± 0.6	–

Although prior occupancy and mortality had a perceptible impact on trap yield, they did not modify catch composition (Table 6). The average proportion of adults in the catches remained the same (arcsine transformation, ANOVA: first experiment, $F_{2,38} = 0.40$, $p = 0.672$; second experiment, $F_{2,42} = 0.77$, $p = 0.471$). Moreover, there was no difference in average CW between treatments and controls (Kruskal-Wallis: first experiment, H = 4.02, df = 2, p = 0.134; second experiment, H = 2.62, df = 2, p = 0.270).

4.0 DISCUSSION

4.1 VARIABILITY OF CATCHABILITY

Catchability is a measurement of the vulnerability of a species, or one of its demographic components, to a fishing gear—the Japanese trap in this study. The catchability of a species by a given type of trap is not an immutable measurement because it depends on (i) the quantity and the quality of bait and of alternative food sources, (ii) the physicochemical conditions of the environment, (iii) the presence of competing or predatory species in the vicinity of the trap or already captive inside the trap, and (iv) the characteristics of individuals in the target population. Bait freshness was maintained throughout the experiments, which proceeded over a short period of time characterized by uniform weather conditions. So, we will not address the bait or abiotic environmental issues, which were apparently quite constant. We will rather discuss the variability of catchability according to the characteristics of the various demographic components of the snow crab male population. We will try to develop from our results conclusions that are relevant to the interpretation of CPUE time series of commercial fishery and research surveys made using baited traps.

The level of catchability of a species by a baited trap results also from the species' aptitudes and a sequence of optional behaviours. The olfactory sensitivity, the strategy adopted to search food, the behavioural attitude and mobility necessary to track an odour plume to its source, the physical capability to enter the baited trap and the facility to escape from it once satiated are all factors affecting catchability (e.g., Brêthes et al., 1985; Miller, 1990; Addison and Bannister, 1998). These aptitudes and behaviours can vary according to ontogeny, the level of appetite and the stages of moult and reproduction. For example, in lysianassoid amphipods (the most efficient of necrophagous organisms), it is well known that juveniles are less catchable than adults, that satiated individuals are not attracted to bait, and that mature females are not attracted to bait when they bear eggs, but are in other circumstances (Sainte-Marie, 1986a, 1986b).

Our results indicate that the level of maturity and relative age (time elapsed since the last moult) have a great influence on male catchability. Adolescent males proved to be much less catchable that adult males, and among the latter, individuals with an intermediate shell were much more catchable than recently moulted individuals or individuals with an old shell. We combined shell conditions 1 and 2 to determine the catchability of recently moulted individuals, because both of these categories were too poorly represented in the traps for separate analysis. However, it is likely that SC1 males are less catchable that SC2 males since the first group was relatively less abundant in traps than in the trawl and the contrary was true for the second group. As well, we did not capture any SC5 males, but given their more advanced level of senescence, one can suppose that they are less catchable than SC4 males. These observed or supposed differences in catchability could reflect a lesser degree of aggressiveness of adolescents compared to adults, the lack of appetite or worse physiological condition of recently moulted adults, and a reduced vitality of senescent adults. It is known that snow crab adult males have a natural diet different from that of adolescent males, as shown in particular by the greater propensity of adults for cannibalism and predation on other crab species (Lovrich and Sainte-Marie, 1997). There is also a close convergence between the magnitude of the catchability of the various categories of males and the magnitude of their participation in the reproductive process (see Sainte-Marie et al., 1999), an activity which also requires a great level of mobility and aggressiveness. The very low catchability of recently moulted individuals is a fact recognized for many other crustacean decapod species (see the review by Miller, 1990), although it has been rarely quantified. On the other hand, the negative impact of senescence on adult male catchability is demonstrated here for the first time.

From this perspective, it is interesting to note that prior occupancy modified the yield of Japanese traps. In general, trap yield was lower with adult males as prior occupants than with no prior occupant (control), and the reduction was significant in the second experiment. Other authors also observed a decrease in the yield of traps with occupying crabs compared to traps without occupying crabs. Miller (1978a) explains this effect by the intimidation of crabs approaching the trap by those captive inside the trap. We also noted a reduction in the yield of the Japanese trap when it was occupied by one or more recently moulted males. In this case, however, the yield reduction was directly proportional to the number of occupying crabs that died during the experiment. The yield reduction can thus be attributed to the aversion of snow crabs for dead conspecifics, as is the case with other species (Hancock, 1974; Miller, 1990). This aversion may have an adaptive value if it allows individuals to avoid conditions likely to result in wounds or death. Our study confirms the great vulnerability of recently moulted crabs and highlights the fact that they must be handled delicately and returned to the water as soon as possible (see Miller, 1977; Dufour et al., 1997). It also suggests that cannibalism documented in wild snow crabs (Lovrich and Sainte-Marie, 1997) results mostly or exclusively from predation, and not from necrophagia.

Our study also reveals a very important variation of adult male catchability by size. The decreasing catchability of adult males as size decreased, starting from a maximum catchability at 107 mm of CW, probably reflects the combined impact of a decreasing odour detection threshold and mobility, an increasing difficulty to climb the walls of the trap to enter it, and an increasing facility to escape through the meshes of the trap. Several studies showed that Japanese traps (approximately 1.2 m at the base and 0.6 m in height) and conical or pyramidal traps (approximately 1.7–1.8 m at the base and 0.5–0.7 m in height) selected larger crabs than rectangular traps, which have a less tilted access slope (Lafleur et al., 1983; Dufour, 1984; Moriyasu et al., 1990). Moreover, the minimum and average sizes of crabs retained in Japanese traps are directly proportional to the mesh size used (e.g., Tanino and Kato, 1971; Jeong et al., 2000). In our experiment, however, the progressive reduction of the catchability of adult males with a CW greater than 107 mm probably demonstrates their increasing capability to escape from the trap by the apical entry once satiated. Miller (1990) summarizes the relationships between the catchability and the size of the individuals by stating that they are similar to an asymptotic relationship for certain species or a bell-shaped function for others.

There are only two other studies that tried to evaluate the catchability of snow crabs by baited traps. In the study of Miller (1975), the catchability of males larger than 90 mm CW was evaluated by comparing the yield of Japanese traps with the bottom density of crabs measured through photographic surveys; it varied on average between 2472 and 5293 m^2, depending on the location (general average: 4194 m^2). In the study of Brêthes et al. (1985), the catchability of males with a CW greater than 85 mm was indirectly estimated from a capture–recapture experiment and varied from 8800 to 15200 m^2 for a pyramidal type trap (see the criticism of Miller, 1985, followed by the response of Brêthes, 1985). However, neither of these two studies took into account the maturity or relative age of males during the assessment of catchability, and it may also be possible that the average and maximum sizes of the males in the target population varied considerably between the two studies. So, any comparison between these studies is difficult. Our estimates for all males having a CW > 90 or > 85 mm (Table 5) are respectively

4.2 times greater than the general average of Miller (1975) and 1.4 times greater than the middle value (i.e., 12,150 m^2) established by Brêthes et al. (1985).

4.2 STUDY LIMIT

A possible bias of our study, involving an under-evaluation of density and thus an over-evaluation of catchability, is associated with the coefficient of catchability of snow crab by the beam trawl, which is unknown. Miller (1975) also used a beam trawl to evaluate the density of snow crabs and concluded that this trawl under-estimated the density by a factor of 3.6 to 5.6 times compared to photographic estimates, which were considered to be representative. He also noted, like Powles (1968) did before, that large crabs seemed to avoid the trawl. However, our trawling technique was different from that of Miller (1975) as our trawl had chains to dislodge buried crabs and was towed at almost twice the speed and without stopping after the initial uncoiling of the cable. We did not note any difference in average size of adult males with an intermediate shell caught with the trawl and the traps, which can suggest that our trawl and our mode of fishing were more effective than those of Miller.

4.3 PRACTICAL APPLICATIONS

The practical aspect of our study for snow crab stock assessments based on CPUE of commercial or research traps is rather obvious. On one hand, whatever the type of trap used, it is certain that the catchability of adolescent males, recently moulted adult males and senescent adult males will be quite lower than that of adult males with an intermediate shell. Consequently, the traps will present a biased image of the population's demographic structure. Since snow crab populations of the Gulf of St. Lawrence are apparently prone to alternating episodes of intense recruitment and very low recruitment (e.g., Hare and Dunn, 1993; Conan et al., 1996; Sainte-Marie et al., 1996), it is clear that the temporal perception of the maximum abundance and the subsequent decline of the commercial fraction of the population will be noted with a delay of approximately one or two years in the trap surveys and the commercial fishery compared to reality and to the perception from trawl survey results. Indeed, the very marked increase in the catchability of adult males between the moult and the time the intermediate shell condition is reached—that is to say approximately two years—will largely compensate for their numerical decline in the initial phase of population decrease. On the contrary, the perception of commercial biomass increase from trap surveys should occur with a certain delay compared to the reality and to the trawl survey results. It is also obvious that trap surveys will under-estimate the importance of future recruitment, adolescents being much less catchable than adults. Finally, in the event of a great abundance of snow crabs, it is possible that traps become saturated (Miller, 1978b, 1990) and thus that the catch per unit of effort will not adequately reflect the availability of crabs.

Baited traps will also introduce a biased perception of the adult male population size structure, but in this case, the impact will probably be closely related to the type of trap used. Small adult males will always be under-represented compared to larger adult males. However, it is likely that the conical traps—whose popularity has greatly increased since the time our study was made—retain a more significant fraction (if not the totality) of the very large males than Japanese traps do because of their greater volume and height, which reduce the possibility of escapement. It would thus be important to repeat the experiments on catchability with the conical traps usually employed in the post-season surveys in order to adequately quantify their selectivity.

The gap between the real demographic structure of a snow crab population and the perception we have of it based on a trap survey could be filled by applying correction factors to the trap yields for the various categories of males. Although the results of this study make it possible to calculate such correction factors, one should ensure that these factors are suitable (robust) in a wide range of demographic contexts since the interactions between various categories of males could influence their catchability. For example, when adolescent males outnumber adult males with intermediate shells, does the catchability of both categories remain the same as it would be in the opposite situation? A possible option to verify this assumption would be to carry out an experiment to evaluate the catchability of males at several sites with homogeneous abiotic characteristics, but with different demographic structures.

5.0 CONCLUSION

The relationships between the catchability of snow crab by the Japanese trap and its availability (abundance) on the bottom are complex and depend on maturity, relative age (time elapsed since the moult) and size of individuals. Although the extent of the coefficient of catchability is certainly influenced by the type of trap, some of the answers observed in this study are probably invariable. Adolescent males will always be less catchable that adult males, and recently moulted or senescent males will always be less catchable that males with an intermediate shell. On the other hand, the relation between the catchability and size of adult males with an intermediate shell is probably closely related to the type and mesh size of the traps used.

Our study shows that catchability can be modelled according to the various criteria of maturity and relative age of snow crab. Such an approach would make it possible to correct the abundance indices derived from commercial fishery and research trap surveys in order to better quantify the abundance and the demographic situation of the snow crab stocks from year to year. This represents an essential step for the modelling and the formal analysis of populations based on trap fishing data (see Zheng et al., 1996). It would thus be important to repeat our study with the type(s) of traps used for post-season surveys. Finally, our study as well as previous studies on the selectivity of various types of traps indirectly revealed that it would be important to encourage the adoption of a single type of trap and mesh size for the post-season research surveys. One can also ask if the quality of the assessment of snow crab population status based on commercial fishery data would not be greatly improved by the imposition of limits on the type of trap and mesh size authorized for commercial fishing.

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