OPTIMIZATION OF MEAT YIELD AND MORTALITY DURING SNOW CRAB (*Chionoecetes opilio* O. Fabricius) FISHING OPERATIONS IN EASTERN CANADA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

RÉSUMÉ

Dufour, R., D. Bernier et J.-C. 1997. Optimisation de la récolte de chair et mortalité durant les opérations de pêche au crabe des neiges (*Chionoecetes opilio* O. Fabricius) dans l'est canadien. Rapp. tech. can. sci. halieut. aquat. 2152 : viii + 31 p.

Les changements de dureté de la carapace et de contenu en chair chez le crabe des neiges ont été suivis dans les populations de l'estuaire et du nord du golfe du Saint-Laurent en 1990 et 1991. Parallèlement, une deuxième étude axée sur la mortalité des crabes des neiges soumis à des conditions de pêche similaires à celles rencontrées durant la pêche a été réalisée en 1991.

Les résultats de la première étude montrent qu'une dureté de carapace ≥ 60 unités de duromètre devrait être ciblée par l'industrie si une chair en abondance et de qualité est le principal critère recherché chez les crabes capturés durant les opérations de pêche. De façon générale, la condition et le rendement en chair des crabes entre 60 et 80 unités de duromètre sont constants mais différents de ceux des crabes mous (dureté < 60 unités de duromètre) et des crabes durs (dureté ≥ 80 unités de duromètre). Le contenu en eau des crabes ≥ 60 unités de duromètre est inférieur à celui des crabes de dureté inférieure. Il est suggéré d'éviter de capturer les crabes blancs afin de leur permettre d'augmenter le rendement et la qualité de leur chair et de se reproduire. Il est possible d'estimer précisément le contenu en chair d'un crabe en connaissant son poids vif et sa dureté mesurée à l'aide d'un duromètre, et en incorporant ces valeurs dans les équations proposées dans ce document.

Les crabes des neiges rejetés à la mer durant les opérations de pêche survivent relativement bien aux traitements qu'on leur fait subir. Seulement 14,3 % des crabes blancs et 2,2 % des crabes durs soumis aux traitements sont morts durant notre étude après une réimmersion en eau de mer d'une durée maximale de 72 heures. Ces valeurs sont similaires à celles obtenues pour des espèces apparentées dans d'autres études du même genre. Toutefois, les crabes blancs sont nettement plus sensibles aux opérations de pêche que les crabes durs surtout durant la période estivale ou leur mortalité peut atteindre un niveau huit fois plus élevé qu'au printemps. Trois types de facteurs interviennent simultanément et affectent leur survie. Ce sont dans l'ordre : 1) les facteurs reliés directement aux opérations de pêche, la vitalité des crabes à leur arrivée sur le pont et leur nombre de pattes manquantes, 2) un facteur propre à l'individu, la taille des crabes, et 3) un facteur relié à l'environnement, le niveau de dessèchement des crabes avant leur remise à l'eau. Ces facteurs agissent directement ou indirectement sur les crabes et diminuent leur chance de survivre aux opérations de capture lorsqu'ils sont rejetés à la mer.

ABSTRACT

Dufour, R., D. Bernier and J.-C. Brêthes. 1997. Optimization of meat yield and mortality during snow crab (*Chionoecetes opilio* O. Fabricius) fishing operations in Eastern Canada. Can. tech. rep. fish. aquat. sci. 2152 : viii + 30 p.

Changes in shell hardness and meat content were studied in the snow crab populations of the estuary and northern Gulf of St Lawrence in 1990 and 1991. In parallel with this, an investigation on mortality of snow crab under fishing conditions approximating those of commercial fishing operations was conducted in 1991.

The results of the first study showed that a shell hardness ≥ 60 durometer units should be targeted by the industry if abundant and quality meat is the main criterion for snow crab catches during fishing activities. In general, the condition and meat yield of crab measuring between 60 and 80 durometer units are constant but differ from those of soft crabs (hardness < 60 durometer units) and hard crabs (hardness ≥ 80 durometer units). The water content of crabs ≥ 60 durometer units is lower than that for crabs with a lower hardness value. It is recommended that fishermen should avoid capturing white crabs so that they have the opportunity to reproduce and to increase their meat yield. A precise estimate can be made of a given crab's meat content by taking its live weight and durometer reading (hardness) and entering these values into the equations put forward in this document.

Snow crabs that are thrown back during fishing activities survive relatively well despite the treatment to which they have been subjected. Only 14.3 % of white crabs and 2.2 % of hard crabs subjected to this handling died during the study after being reimmersed in sea water for up to 72 hours. These values are comparable to those obtained for related species in other, similar investigations. However, white crabs are markedly more sensitive to fishing operations than hard crabs, especially in summer when their mortality rates can be eight times higher than in spring. Three types of factors which operate simultaneously affect their survival. They are, in order of importance: 1) factors related directly to fishing activities, the vitality of the crabs when landed on deck and the number of missing legs, 2) a factor related to the individual, the size of the crabs, and 3) an environmental factor, the extent of dessication of the crabs before they are returned to the water. These factors have a direct or indirect impact on the crabs and reduce their chances of survival between the time they are caught and then released at sea.

INTRODUCTION

Moulting is a cyclical phenomenon whereby the snow crab, in order to grow in size, sheds its old shell and replaces it with a new, larger shell. Snow crabs in Eastern Canada with a carapace width > 30 mm generally moult every year between April and June until they reach their terminal moult, which marks the attainment of maturity in both males and females (Conan and Comeau 1986, Sainte-Marie and Hazel 1992). The terminal moult occurs at a variable size in both sexes. The final carapace width for snow crabs is between 40 and 165 mm for males and 37 and 95 mm for females (Alunno-Bruscia 1993, Sainte-Marie *et al.* 1995).

In the period between moults, known as the intermoult, the snow crab's shell gradually hardens and its meat content increases. These two processes occur continuously in fully grown adult crabs until they are old. After moulting, the snow crab takes up water and swells to fill the new space available in its soft shell. At that point, the crabs are called "white crabs" because of their spotless white abdominal surface (Dufour and Sainte-Marie 1996). Crabs are relatively inactive during this period and do not begin their normal feeding and other activities for a few weeks (O'Halloran and O'Dor 1988). As their shells harden, the crabs gradually build more tissue which replaces the water absorbed at moulting. It may take two to four months for the shell to harden, a time period which appears to be independent of size for commercial-sized crabs (Watson 1971, Taylor *et al.* 1989). The growth of flesh to replace the water absorbed takes longer, generally a minimum of six months according to information compiled from fishing activities.

In the late 1980s, a massive influx of white crabs to the fishery caused many problems in the snow crab industry of Eastern Canada (Dufour and Coutu 1989, Hare and Dunn 1993, Dufour 1995). The fishery in the estuary and northern Gulf of St Lawrence was particularly hard hit as of 1985, and white crabs remained abundant in catches until 1989. Landings slid during this period, from 5 818 t in 1985 to 2 622 t in 1989, almost resulting in the complete closure of the fishery on the Lower North Shore of Quebec (management areas 13 and 14) in 1989 (Dufour 1995).

The results of recent studies on the biology and dynamics of snow crab populations show that the reduced catches during that period were largely attributable to three less abundant year-classes (1977-79) which took nine to ten years to become available to the fishery (Sainte-Marie and Dufour 1995). This sharp decline in recruitment coupled with intensive harvesting of commercial-sized crabs which previously had been left on the fishing grounds, meant that only the recruits of the year, that is, white crabs, were available to the fishery. That is why their contribution to catches increased so drastically during this period. Owing to their high water content, these crabs are of poor quality and are often thrown back by fishermen.

In the late 1980s, Foyle *et al.* (1989) recommended that a durometer be used to distinguish white crabs from those with a harder shell. This gauge, which is used to measure shell hardness in snow crabs, was originally developed on the Pacific coast by Hicks and Johnson (1991) for use with dungeness crabs (*Cancer magister*). The durometer employed to measure this parameter in snow crabs is a gauge that can exert 4.9 grams of pressure per square millimetre. It gives a reading proportional to shell rigidity when the pointer is pressed firmly against the claw. The cut-off reading used to separate white crabs from those with a harder shell was initially set at 72 units and subsequently lowered to 68 units following field tests in the Newfoundland region (J. R. Botta, Inspection Service, Department of Fisheries and Oceans, Newfoundland, personal communication). That cut-off value for separating white crabs and harder-shelled crabs is now used to manage all the snow crab fisheries in Eastern Canada.

The survival rate of snow crabs that are thrown back during fishing activities has not been studied extensively. Miller (1977) showed that “white” snow crabs discarded at sea sustained 20 % mortality when exposed to air and sunlight on the vessel deck for three minutes in the summer. However, the mortality of white crabs rose to 64 %, compared to 30 % for hard-shelled crabs, when exposure to the elements increased to 35 minutes. Kruse *et al.* (1994) obtained a mortality rate for legal-size dungeness crabs (carapace width > 165 mm) which was 45 % higher in white crabs than hard-shelled ones. The crabs in this study were caught with traps, handled carefully and exposed to air for periods not exceeding 60 minutes. In a laboratory investigation, Carls and O’Clair (1995) monitored the effects of prolonged exposure to very cold air temperatures (-20°C to +5°C) on the crab species *Chionoecetes bairdi*. The results indicated that the crabs subjected to the coldest temperatures died quickly, after one or two days. In addition, exposure to intense cold diminished the crabs’ vitality, caused autotomy of their claws and reduced the feeding rate of adults and the growth of juveniles.

Injuries that occur when crabs are being removed from fishing gear can also be fatal. Stevens (1990) observed a mortality rate of 78 % for *Chionoecetes bairdi* caught during trawl fishing operations. *Ranina ranina* that lost a few claws while being disentangled from gillnets exhibited a mortality of 60 to 70 % (Kennelly *et al.* 1990).

Post-moult shell hardening and increased meat yield were monitored in the snow crab populations of the estuary and northern Gulf of St Lawrence in 1990 and 1991. The main objective of this investigation was to determine the relationship between shell hardness and meat content in snow crabs derived from the fishery. In addition, a study on mortality among snow crabs, particularly white crabs, under experimental fishing conditions similar to those characterizing commercial fishing was conducted in 1991. The aim was to assess the impact of fishing activities on the survival of snow crabs discarded at sea and identify the main factors affecting their survival. As well, the specific effect of air temperature on the survival of snow crabs was studied. The ultimate objective of the two investigations was to help the snow crab fishing industry to develop catch management strategies which would be better adapted to the changing conditions of the fishery.

MATERIALS AND METHODS

GENERAL

The terminology used to describe the maturity of male snow crabs is as defined in Sainte-Marie *et al.* (1995). Males are classified as follows: *immature* crabs are small and still growing, their gonads are developing and they have small undifferentiated claws; *adolescents*, although still growing, have functional gonads and a reproductive system but their claws are not yet differentiated; *adults* have finished growing (terminal moult completed) and have functional gonads and a reproductive system. Their claws are well developed and differentiated.

SHELL HARDNESS AND MEAT CONTENT

The snow crabs used in the study on shell hardness and meat content came from the harvested populations of the estuary and northern Gulf of St Lawrence (Figure 1). Fishing was carried out from April 17 to October 18, 1990 and again from August 4 to September 2, 1991. The crabs were individually frozen at 20°C shortly after being caught and were then sent to the MLI for analysis. We focused our efforts on collecting samples which would be representative of commercial catches throughout the area.

Adult and adolescent male crabs were separated on the basis of the allometry of their claws, using the sorting equation developed by Sainte-Marie and Hazel (1992). Shell condition was evaluated by the methods used in Lamoureux and Lafleur (1982) and Foyle *et al.* (1989); see also Appendices 1 and 2. Durometer readings were taken at three different positions at the base of the right claw (Figure 2), to verify the measurement bias attributable to the position of the reading itself. The crabs were thawed slowly at ambient temperature and then subjected to a series of measurements and manipulations (Figure 2): carapace width (CW, ±0.1 mm); shell hardness using a durometer; the width (cw), length (cl) and height (ch) of the right claw and left claw (±0.1 mm); the volume of the right and left claws (±0.5 ml) as determined based on displacement of water in a graduated container; the total wet weight of the crab before cooking (± 0.1 g); the wet weight prior to cooking of the meat from the right claw severed at the junction of the protopodite and carpopodite (± 0.1 g); the dry weight of the meat from the right claw after it was dried in an oven at 60°C to a constant weight (± 0.1 g); the wet weight after cooking of the meat from the left claw (± 0.1 g); and the wet weight of the crab meat, minus the two claws, after about 12 minutes of cooking (± 0.1 g). The number of missing legs was also noted.

The total meat yield and water content values for a given crab (weight and %) were calculated using the following equations:

(1) Total weight of the meat extracted (g) = Wet weight of the meat after cooking the crab, minus the two claws + 2 × Wet weight of the meat from the left claw after cooking;

(2) Meat yield (%) = 100 × Total weight of the meat extracted / Wet weight of the crab before cooking;

(3) Water content (%) = 100 × (Wet weight of the meat from the right claw before cooking - Dry weight of the meat from the right claw) / Wet weight of the meat from the right claw before cooking.

The base statistics for the main variables, the analyses and statistical tests conducted for this investigation (multiple regression analysis, logistical analysis, Chi-square test, Fisher's exact test, Kruskal-Wallis test and Dunn's test and the Wilcoxon signed rank test) were all performed using the SAS (Statistical Analysis System, Cary, USA) and SigmaStat (Jandel Scientific Software, San Rafael, USA) software.

To assess temporal changes in the general condition of individuals from the same species, condition factors are often used. The Fulton index, the most widely used index of condition (Ricker 1975), corresponds to the ratio of the animal's weight to its cubic size. The greater an animal's weight is at a given size, the better its condition. The index can also reveal certain changes in condition related to different fishing seasons and sites. The Fulton index was calculated for all crabs harvested during the 1990 and 1991 fishing seasons, as follows:

Fulton Index= Total weight of the meat extracted (mg) / Carapace width (mm) ^{3}

MORTALITY DURING FISHING OPERATIONS

The study on mortality of crabs during fishing activities took place from April 15 to July 27, 1991 in the lower estuary of the St Lawrence (Figure 1). Male crabs were caught using traps with commercial-sized mesh or beam trawls with an opening 3 or 10 metres wide and a cod-end with 25 mm mesh (stretched mesh). The following measurements were made on all crabs once they were landed on the deck: carapace width (CW, in mm); height of the right claw, or the left claw if the right claw was missing (ch, in mm). Lastly, any lesions on the shell and missing legs were recorded. Subsequently, all the crabs were tagged with a spaghetti tag and kept in a tank supplied with fresh seawater until the start of the experiment, which generally occurred less than 30 minutes later.

The air temperature on the vessel deck and average wind speed according to the Beaufort scale were recorded during each treatment. The vitality of the crabs before and after treatment was established using the scale developed by Stevens (1990). The crabs were classified as follows: 1) *live*: the crab was moving on its own and trying to escape; 2) *weak/dying*: the crab showed a response only when its claws or mouthparts were stimulated; and 3) *dead*: no movement was observed, not even after repeated stimulation of the claws and mouthparts. Death was confirmed by checking for a heart beat by delicately raising the dorsal part of the carapace. Two air exposure periods were decided on prior to the experiment, that is, 15 and 30 minutes. The 30-minute period represented the maximum time that a crab would normaly spend on the vessel deck during commercial fishing activities. Following exposure, the crabs were placed in Japanese-style traps in which the opening had been obstructed; the traps were submerged near the sites of capture for time periods of 24, 48 or 72 hours. The number of crabs in each trap could vary but was generally kept low, at about 10. The vitality of the crabs was recorded again when the traps were hauled back on deck at the end of the treatment.

The laboratory experiment consisted in evaluating the mortality rate of a few white crabs subjected to high temperatures, comparable to those encountered in the study area in the summer. About ten crabs in all, each bearing a spaghetti tag, were exposed to air in a controlled temperature room (between 5 and 30°C) for periods ranging from 15 to 45 minutes. The crabs were held in boxes containing roughly 0.26 m^3 of sea water at 4°C before and after the treatment; their vitality was checked 48 hours after they were returned to the boxes after treatment.

RESULTS

SHELL HARDNESS AND MEAT CONTENT

Table 1 presents the base statistics collected on the crabs sampled in the field. A total of 464 male snow crabs with a carapace width (CW) between 70.0 and 134.0 mm were caught for the study. Adult males dominated the sample and adolescents made up only 7 % (Figure 3). The total weight of the meat content of the sampled crabs varied between 40.3 and 443.7 g, for a mean of 181.1 g per crab. These values represented an average meat yield of 41.0 ± 6.0 % of the total weight of the crabs. The water content of the crabs, as determined from the right claw, ranged from 50.0 to 96.6 %, for a mean value of 82.4 %.

The width, length and height measurements did not not differ significantly between the right claw and the left claw (Wilcoxon signed rank test, length p=0.11, height p=0.47, width p=0.40). The durometer readings taken on the front area of the right claw (Figure 2) differed significantly from those taken on the middle and back of the claw (Wilcoxon signed rank test, $p < 0.0001$). The values for the middle of the claw, which is where this measurement is usually taken on snow crabs, were lower on average than those for the other two positions (Table 1).

The condition of the crabs caught during fishing improved steadily with increasing shell hardness (Figure 4A). After a relatively stable period, their condition increased from 0.076 mg of meat/mm^3 of carapace width (CW) on average to an upper limit of approximately 0.166 mg/mm^3 on average at a hardness of about 90 durometer units.

Between 60 and 80 durometer units, the condition of the crabs was fairly constant (0.147 ± 0.025 mg/mm^3) but differed significantly (Dunn's test, $P<0.05$) from that of crabs with a hardness value below 60 durometer units (0.086 ± 0.018 mg/mm^3) and over 80 durometer units (0.164 ± 0.017 mg/mm^3). The mean condition of crabs with shell hardness ≥ 60 durometer units exceeded (Mann Whitney rank sum test, $P<0.0001$) and was nearly two times greater than that of crabs with a shell hardness lower than 60 durometer units, that is, 0.160 ± 0.020 mg/mm^3 and 0.086 mg/mm^3 respectively.

The meat yield also rose with increasing shell hardness (Figure 4B). The regression curve fitted to the data shows an increase beginning at about 27 durometer units, which corresponds to crabs containing approximately 26 % meat on average, to some 90 durometer units for crabs with a meat content slightly greater than 43 % on average. The crabs can thus be grouped in 3 shell hardness classes with fairly constant but differing meat yields (Dunn's test, $P<0.05$): 1) crabs with a shell hardness < 60 durometer units (28.3 ± 4.5 % meat), 2) crabs with an intermediate shell hardness of 60 to 80 durometer units (39.9 ± 5.4 % meat), and 3) crabs with a shell hardness ≥ 80 durometer units (43.1 ± 3.5 % meat). The average meat yield of crabs with a hardness value ≥ 60 durometer units (42.4 ± 4.2 % meat) differed (Mann Whitney rank sum test, $P<0.0001$) and was 50 % greater than that of crabs with a shell hardness < 60 durometer units (28.3 ± 4.5 % meat).

Conversely, the water content of the meat from the right claw declined steadily with increasing shell hardness (Figure 4C). It dropped from about 93 % at 26 durometer units to approximately 80 % on average at about 85 durometer units. Two groups of crabs can be differentiated on the basis of the homogeneity of their water content (Mann Whitney rank sum test, $P<0.0001$): 1) crabs with a shell hardness < 60 durometer units that contain 91.4 ± 3.3 % water, and 2) those with a hardness value ≥ 60 durometer units that contain 81.4 ± 3.6 % water.

When the shell type of each crab was identified by the methods reported in Lamoureux and Lafleur (1982) and Foyle *et al.* (1989), which are presented in Appendices 1 and 2, it was observed that, at the cut-off value of 60 durometer units, the two methods were in agreement and allowed soft crabs (shell type 1: mean hardness of 36.7 ± 11.0 durometer units for Lamoureux and Lafleur, and 36.0 ± 10.3 durometer units for Foyle *et al.*) to be separated from the other categories of crabs sampled (Figure 5A and 5B). Likewise, this cut-off value appeared to be effective for distinguishing old soft-shelled crabs, that is, shell type 4 according to Foyle *et al.* (1989), from the other crab groups. The two methods also agreed quite well when a cut-off value of 80 durometer units was employed to distinguish hard-shelled crabs (shell type 3: mean hardness of 88.1 ± 7.6 durometer units for Lamoureux and Lafleur and 88.1 ± 8.0 durometer units for Foyle *et al.*) from the other categories of crabs (≥ 87.5 % and ≥ 87.0 % based on shell type 3 crabs for Lamoureux and Lafleur and Foyle *et al.* respectively). At values above the cut-off of 68 units, the two methods permitted the retention of 41.7 % and 69.7 % of crabs with intermediate shell hardness (shell type 2 for both methods) respectively, compared to 83.3 % and 89.9 % of intermediate-shell crabs at values greater than 60 durometer units.

The condition of snow crabs caught in the fishery varies over time and with the different sites fished from year to year (Figure 6). The condition of adolescents and young adults with shell type 1 or 2 hovered around 0.139 mg/mm^3 until late June 1990 and then fell sharply to 0.086 mg/mm^3 in early July 1990. Although the condition of adolescents and young adults improved steadily thereafter, it took a few months for them to reach a level comparable to that of crabs sampled during the first few months of fishing. In fact, the condition of crabs sampled at the latest point in the fall of 1990 (October 18) stood at 0.118 mg/mm^3, which is lower than the value obtained for crabs sampled before July of that year. In contrast, the condition of adolescents and young adults sampled in the fall of 1991 (September 2: 0.149 mg/mm^3) was slightly greater than that of crabs in the same category sampled before July 1990. The relative condition of the oldest adult males (shell type 3 and 4) varied five times less over the same period (coefficient of variation=3.9 % versus 18.2 % for adolescents and young adults). It fluctuated around 0.165 mg/mm^3 on average over the two years, which is slightly above the average condition obtained for adolescents and young adults sampled before July 1990.

A number of parameters were selected to develop a model to determine the quantity of meat that can be extracted from a crab on the basis of its condition. The wet weight of the crab, its carapace width, the dry weight of the meat, the volume and height of the right claw, the number of missing legs and the corresponding durometer values were employed in the regression analysis. The results showed firstly that 86 % of the variation in total meat content values for crabs could be explained by the natural logarithm of their wet weight. Secondly, the explained variance reached 90 % when the natural logarithm of durometer values was included in the model. The two models satisfy the two primary conditions of regression analysis, that is, a normal distribution of data around the regression line and homogeneity of variance for total meat content relative to the corresponding wet weight and durometer values. The equations for the resulting models are as follows:

$$TOT\_MEAT = -918{,}221 + (183{,}642 \times \ln WW\_CRAB)$$
$$n = 458$$

and

$$TOT\_MEAT = -1117{,}65 + (171{,}737 \times \ln WW\_CRAB) + (62{,}019 \times \ln DUROM)$$
$$n = 446$$

where TOT_MEAT = Total meat content of a crab (g)
WW_CRAB = Wet weight of the whole crab measured to the nearest 0.1 g
DUROM = Durometer value (units)
and n = Number of data used in the model

A confidence interval for the mean of the total meat content variable can be calculated in accordance with Dagnelie (1975).

MORTALITY DURING FISHING OPERATIONS

A summary of the measurements made and the main results of the study on snow crab mortality during fishing activities is provided in Table 2. Seventy-five per cent of the 729 male snow crabs whose maturity could be determined were white (hardness < 68 durometer units), and 74 % of these were adolescents (Figure 3B). Their size ranged from 57.0 to 138.0 mm carapace width (CW), and 35 % of the 737 males that could be measured were larger than or at the legal size of 95 mm (Table 2).

The total mortality of all male crabs (white and hard-shelled) recorded within a maximum of 72 hours after the treatments was low (11.2 %). Ninety-five per cent (78/82) of the crabs that died were white crabs. The mortality of white crabs rose to 14.3 % (78/547) and differed significantly (χ^2, $p<0.001$) from that for hard-shelled crabs, namely 2.2 % (4/182).

Interestingly, nearly a third (32.1 %) of the white crabs that died were missing part or all of their flesh, as they had been devoured by necrophagous organisms present on the fishing grounds. Most of these crabs (84 %; 21/25) had at least one missing leg or a recent and visible injury on their shells (broken claw, lesions on carapace). Only one hard-shelled crab of commercial size that was missing a leg suffered the same fate as the white crabs. Sixty-eight per cent (17/25) of the white crabs that had been devoured by necrophages were of legal size, and at least half (13/25) of all white crabs whose flesh had been eaten were devoured within 24 hours.

Rates of mortality among white crabs shoot up during the summer. Eight times more white crabs died in June and July (Fisher's exact test, $p<0.01$), that is 88.5 % of all dead white crabs (69/78), compared to 11.5 % (9/78) in April and May. The difference in mortality rates between white crabs and hard-shelled crabs was significant only in June (23.0 % for white crabs and 0.0 % for hard-shelled crabs, χ^2: $p<0.001$) and July (15.7 % for white crabs versus 2.9 % for hard-shelled crabs, χ^2: $p<0.05$). Mortality among white crabs did not differ significantly between June and July (Fisher's exact test, $p=0.37$).

Among the different variables subjected to logistic regression analysis to determine which ones had a significant impact ($p<0.05$) on the mortality of white crabs, four were selected on account of their key contribution to the model. They are as follows, in order of importance:

1) The vitality of the crab when brought onto the vessel deck;
2) The number of missing legs;
3) The size of the crab; and

4) The degree of dessication of the crab; as represented by a composite variable comprising three factors measured on the boat deck: air exposure time (hours), air temperature (°C), and average wind speed (metres/second).

The equations of the logistical linear model used to calculate the probability of mortality on the basis of the four variables are as follows:

$$Logit(p) = -7{,}3713 + (0{,}8839 \times VITALITY) + (0{,}4667 \times MISSING\,LEGS) + (0{,}0377 \times SIZE)$$
$$+ (0{,}0126 \times DESSICATION)$$

and,

$$p = e^{\mathrm{logit}(p)} \Big/ \left(1 + e^{\mathrm{logit}(p)}\right)$$

where, p = Probability that a white crab will die, in view of the following factors:

VITALITY = Vitality of the crabs when they are landed on the deck: 1=active or 2=weak or dying;
MISSING LEGS = Number of missing legs: 0=none to n=10 (maximum value);
SIZE = Carapace width in mm;
DESSICATION = Composite factor including air temperature on deck, exposure time and wind speed (°C-hour-metre-second).

The model prediction (live or dead white crabs) agreed with reality 75.6 % of the time.

In keeping with the logistical model, the data collected on live white crabs showed that mortality rose rapidly as the number of missing legs increased. In white crabs that were initially active, the mortality rates rose from 7.1 % (13/183) for crabs with all their claws to 20.0 % (2/10) for those missing more than two legs. However, these mortality values were not significantly different from those for crabs that survived (χ^2, p=0.222). However, the mortality rates were significant (χ^2, p<0.01) and even higher when the white crabs were weak to begin with. They increased rapidly from 10.5 % (11/105) in crabs that had all their claws to 47.6 % (10/21) in those that had lost more than two claws, with a maximum value that was 2.5 times higher than for crabs that were initially active.

Size also has an influence on the mortality of white crabs, particularly when they were weak at the time they are brought on deck. For white crabs that were initially active, the mortality rates differed significantly (χ^2, p<0.05); they increased from 6.6 % (14/211) in those under the legal size (CW<95 mm) to 14.2 % (16/113) in those of legal size (CW ≥95 mm). The mortality rates were also significantly different (χ^2, p<0.01) and twice as high when the white crabs were weak at the outset, rising from 14.7 % (20/136) for undersize white crabs to 35.1 % (27/77) for legal-sized white crabs.

Wind speed and air temperature, coupled with exposure time on deck, which together comprised the composite variable of dessication, also played a key role in the mortality of white crabs. In general, mortality rose as dessication increased (Figure 7). Whereas the mortality ratio was about 0.12 white crabs per dessication unit when only dead crabs whose flesh had not been devoured were considered, it reached 0.20 white crabs per dessication unit when all dead white crabs were considered. The mortality rate fluctuated between 1.9 % (1/53) and 15.1 % (8/53) until a value of 13.1 dessication units was reached, at which point it moved up steadily and finally peaked at 18.9 % (10/53) and 68.8 dessication units. The nearly constant increase in mortality observed as of 13.1 dessication units corresponded to a steady increase in wind speed from 1.5 metres/second to 10.2 metres/second at 68.8 dessication units, the highest wind speed recorded during the project (Table 3 and Figure 7). However, the data show that substantial mortalities of up to 15 % (8/53) can also occur when wind speed is low (about 2.4 metres/second on average during the study). Air temperature (14.8°C on average during the study) therefore seems to be one of the determining factors that need to be considered to explain the elevated mortality rates.

DISCUSSION

SHELL HARDNESS AND MEAT CONTENT

The durometer is a both useful and necessary tool for measuring shell hardness in snow crabs and ensuring the release of white crabs during harvesting activities. However, on its own, it is not always effective for measuring the shell hardness of all crabs that can be caught during fishing. The currently used gauge provides readings of variable validity when used on crabs with a very soft shell, ie, those that generally had values < 60 units in the present study. The barely calcified shell of these crabs, some of which may be very old, are fragile and bend or are easily perforated by the durometer pointer. This tool cannot be used on its own to distinguish newly moulted soft-shelled adult crabs from old crabs whose shell is soft shell due to degenerative processes and which might be considered suitable for harvesting in certain contexts (Sainte-Marie and Dufour 1995). It is therefore recommended that one of the empirical methods of identifying shell type, such as the one developed by Sainte-Marie *et al*. (1995) which assigns a relative age to adult crabs based on their shell type, be employed in conjunction with a durometer to permit more rational identification and management of the different categories of crab caught in the fishery.

If abundant and quality meat is an important criterion in the industry, the fishery should above all target crabs with a durometer reading ≥ 60 units. Our study indicates that those crabs have a condition and meat yield that is superior to that of crabs with a lower hardness value and that their water content is also not as high. The cut-off values for crabs with a shell hardness greater than or less than 60 durometer units would be, on average, 0.123 mg of meat / mm^3 of shell for condition, 35.6 % for meat yield and 85.2 % for water content. Crabs with a shell hardness ≥ 60 durometer units can also be grouped in two categories based on condition and meat yield, that is, crabs with a shell hardness between 60 and 80 durometer units and those with a value ≥ 80 durometer units. Crabs with shell hardness ≥ 80 durometer units are superior in terms of condition and meat yield to those with a shell hardness between 60 and 80 durometer units. The cut-off value of 60 durometer units can therefore be used to distinguish soft-shelled crabs (type 1 according to Lamoureux and Lafleur (1982) and Foyle *et al.* (1989)) from the other categories of crab. At the same time however, a larger proportion of crabs with intermediate shells (condition 2 based on both methods) would be conserved with this cut-off value versus the present value of 68 durometer units used to separate white crabs from other categories of crab. Crabs with shells of intermediate hardness, in particular those with shell type 2 as defined by Foyle *et al.* (1989), have likely undergone their most recent moult in the past 5 months to 1 year approximately, according to Sainte-Marie and Dufour (1995). Consequently, together with soft-shelled crabs they represent the recruits of the year. Yet, it is known that the protective measure of immediately releasing recruits of the year, particularly adolescents which may still be growing, can substantially boost the yield per recruit because those crabs may become available to the fishery the following year, when their meat yield will be greater and size also in the case of adolescents (Sainte-Marie and Dufour 1995). Furthermore, by conserving a larger number of these crabs, we can increase the number of males that are available to participate in mating the following spring. Therefore, for the above reasons, we encourage the present practice of releasing white crabs at sea (shell hardness <68 durometer units), although some of them, ie, about 20 % of crabs with an intermediate shell, have characteristics (appearance, meat yield and quality) that are very much in demand at present.

In our study, the average meat yield, although very high, is comparable to that found by Sims *et al.* (1980) for the same species. In our investigation, the average yield was lower for white crabs (33.5 ± 7.7 %) than for crabs with a harder shell (durometer values ≥ 68 units), ie, 42.7 ± 3.9 %. Sims *et al.* (1980) reported similar values, 34.6 % and 41.8 % respectively, in connection with the use of both manual and automatic methods to extract meat at a processing-plant. In a laboratory experiment involving careful extraction procedures, Foyle *et al.* (1989) reported an average meat yield of 41.2 % for hard-shelled crabs (type 3-5), which is very close to the value we obtained for hard-shelled crabs. In our study, the crab meat was manually extracted in a very meticulous fashion, which probably explains the very high meat yields we obtained compared to those generally observed in processing plants in Eastern Canada, ie, between 20 and 30 % on average (Foyle *et al.* (1989) and Francis Coulombe, personal communication). Hence, major meat losses of at least 10 % occur during in-plant deshelling of crabs, which could probably be reduced through more careful operations.

Our investigation indicated that the live weight (wet weight) of crabs can be a good indicator of their meat content (86 % of variance explained in the first model predicting meat content). Our results contrast with those of Taylor and Warren (1991), who indicated that the meat content of crabs did not differ to a great extent for different shell types. The condition of crabs caught in the fishery can vary from year to year (Figure 6), especially for adolescents and young adults (shell conditions 1 and 2). By contrast, the condition of older adults (shell type 3 and 4) does not appear to fluctuate much over time from one region to another, and it is conceivable that the considerable abundance of older crabs on fishing grounds during certain years can offset the variations in shell type that normally occur in exploited populations. That is why we felt it was advisable to add a second explanatory variable, the durometer values, to the base model to account for variations in condition generally associated with the entry of new recruits to the fishery, which can be estimated by measuring shell hardess. However, the use of the second predictive model of meat content is recommended only for a shell hardness ≥ 60 durometer units, to avoid reading errors caused by overly soft carapaces. The equipment required to take the measurements used in the models is easy to find and consists in an analytical balance (giving weight to the nearest 0.1 g) and a durometer like the kind employed by DFO sampling staff and observers during fishing activities. Since in our study extraction was done manually and with the utmost care, the values obtained constitute maximums. Calibration can be carried out on request to assess a given processing plant's efficiency.

The relationship between the condition and shell hardness of a crab after moulting appears to indicate that the process of shell hardening (calcification) has to be quite advanced before the crab will start feeding again and increase its meat content significantly. Moulting involves highly complex physiological processes. In studies on moulting of decapod crustaceans, Drach (1939) reported that tissue growth, especially muscle tissue, in two crab species, the spinous spider crab (*Maia squinado*), which belongs to the Majidae family like the snow crab, and the rock crab (*Cancer pagurus*), occurs mainly between stages C_2 and C_4 of the intermoult cycle, more specifically in stage C_3. Yet, hardening of most parts of the exoskeleton, including the claws, is completed during this period. During the first three or four weeks after moulting, fasting has been observed in snow crabs held in tanks (O'Halloran and O'Dor 1988). Drach (1939) stated further that it is only after one or two weeks of active feeding that tissues will show a considerable weight gain reflecting renewed growth. Since it can take two to four months for the shells to harden completely (Watson 1971, Taylor *et al.* 1989), it is unlikely that individuals that moult in the spring can increase their meat content significantly by the fall of the same year, and this is evidenced by the Fulton index trends for adolescents and adults with shell type 1 and 2 in the present study. Hence, to enable new recruits to increase their meat yield appreciably, crabs that have moulted during the current year should not be harvested until September. This fishing practice would also boost meat quality in the recruits. However, a fall snow crab fishery is not desirable because it would lead to increased harvesting of adolescents that are still growing and it could also have a longer term impact on the reproductive potential of the targeted populations due to indiscriminate catches of the large-sized adults that are the best reproducers. It would be better to encourage harvesting of crabs the year after they become available to the fishery to allow them to reproduce or to moult again so they reach a larger size.

MORTALITY DURING FISHING OPERATIONS

The simulations performed in the study on mortality among snow crabs during fishing activities approximate the real situation during the fishing season. The size range covered, 57 to 138 mm, is practically the same as in the fishery, that is, 60 to 140 mm (Dufour 1995). White crabs and undersize crabs are well represented, making up 75 % and 65 % of the crabs sampled in the present study. In addition, 74 % of the sample consisted of adolescent males of variable size; it is recommended that they be carefully returned to the water so they can continue their growth and also boost the biomass of commercial-sized crabs (Sainte-Marie and Dufour 1995). This experiment was carried out from April to July to cover a period equivalent to a complete spring fishery, in which the incidence of white crabs can be very high. The same gear types were used as in the fishery, that is, Japanese-style traps, along with a similar fishing method, including comparable bait types and soak times.

The manipulation of the crabs during on-deck activities and the different treatments were not applied with the utmost care. The only manipulation differing from the handling that occurs in the fishery is that the crabs were returned to the water in traps following their period of exposure on deck and the traps were subsequently hauled up to check the crabs' condition. However, since the verification of mortality was made after the traps had been in the water for 72 hours at most, the long-term survival rate in our investigation might be underestimated since additional mortalities resulting from the treatments could occur later (Kenelly *et al.* 1990).

The snow crabs thus returned to the water showed a fairly high survival rate subsequent to the treatments they underwent during catch operations. The mortality rates for white crabs (14.3 %) and for hard-shelled crabs (2.2 %) remained relatively low during the study, and in all, only 11.2 % of the 729 snow crabs subjected to the different treatments died after being reimmersed in sea water for up to 72 hours. Other studies have reported comparable mortality rates. Barry (1984), as reported in Murphy and Kruse (1995), obtained a mortality rate of 11.3 % for white dungeness crabs (*Cancer magister*) during fishing operations. In an investigation of the same species, Tegelberg (1970), as reported in Murphy and Kruse (1995), calculated mortality rates of 15-16 % and 4 % respectively for white crabs and hard-shelled crabs subjected to normal fishing operations and then submerged in traps for two days. Variations in the density of white crabs per trap did not affect the mortality rates obtained in that study.

Our investigation demonstrated that white crabs are definitely more sensitive to fishing operations than hard-shelled crabs are and that their survival rate is lower when they are caught and released at sea during the summer. The vast majority of crabs that died during the present study were white ones (78/82). Even more interesting, the white crabs and the hard-shelled crabs had the same survival and mortality rates in the spring, whereas the situation changed in the summer, with a marked increase in mortality of white crabs versus hard-shelled crabs.

Three interrelated types of factors in fishing operations represent the main sources of mortality among white crabs released at sea. The factors related to fishing, that is, the vitality of the crabs when landed on deck and the number of missing legs, were identified as the two main causes of mortality among white crabs, in that order. The type of gear used appears to have a major impact in terms of the crabs' vitality. Mortality resulting from the use of trawls, for example, may be higher than that associated with traps (Chapman 1981, Hayes 1973 and Reilly 1983, as reported in Murphy and Kruse (1995)). We are referring here to large-sized trawls (*Nephrops* and groundfish trawls) dragged over the bottom for longer time periods than in this study. Crabs caught in the cod-end during trawl tows may be injured or considerably weakened by the time they are brought aboard the vessel.

Furthermore, the use of nets increases the probability of leg losses during disentanglement and such losses can be fatal for crabs (Kennelly *et al.* 1990). In our study, the mortality rate increased to 47.6 % and was nearly five times higher for white crabs that were weak at the outset and had more than two missing legs, when compared to similar white crabs with no missing legs (10.5 %).

External injuries (lesions and broken or missing legs) that arise during fishing allow deep-dwelling necrophagous organisms which are fond of snow crabs, especially sea fleas (amphipods) and hagfish, to penetrate the crabs' shells and eat their flesh. Three voracious lysianassid amphipods (*Anonyx lilljeborgi, A. sarsi* and *Orchomenella pinguis*) living at depths typifying the habitat of snow crabs in the northern Gulf can enter a carapace through tiny openings (Sainte-Marie *et al.* 1989, Cyr and Sainte-Marie 1995). White crabs, which are generally weaker than those with a harder shell, are very vulnerable to this type of predation, and variable numbers of amphipods were found inside nearly a third of the white crabs that died in our investigation (32.1 % ; 25/78).

Body size (factor intrinsic to the species) and degree of dessication (factor related to the natural environment) of the crabs were the next two most influential factors in terms of the survival of white crabs. Regardless of whether they were weak or active when landed on deck, white crabs exhibited higher mortality rates when commercial-sized (CW ≥ 95 mm). The mortality rate for white crabs basically doubled between undersize (CW < 95mm) and legal-sized (CW ≥ 95 mm) individuals. However, the rate was higher in crabs that were already weak, reaching as much as 35.1 % for commercial-sized specimens.

Wind and high air temperatures on deck during fishing acted with exposure time to affect the survival of white crabs. The mechanism of action is complex: all three factors can operate together, as well as in conjunction with other factors, such as sunlight and the humidity rate, or individually, primarily affecting the physiology and behaviour of crabs without necessarily directly causing their death. White crabs can last a long time when exposed to air, even at a high temperature. Of the 10 white crabs exposed for 15 to 45 minutes to temperatures between 5 and 30°C in a controlled atmosphere room, only two died after being subjected to the longest and most exacting treatment, ie, 45 minutes of air exposure at 30°C. Exposure to air over long periods dries the animal and appears to cause major osmotic changes in its haemolymph. Faster haemolymph changes were observed during the first 30 minutes in spiny lobsters *Panulirus argus* exposed to air for two hours, inducing secondary physiological damage as manifested by abnormal defense and escape behaviours (Vermeer 1987). After the treatment, the spiny lobsters survived and their haemolymph returned to its normal state after they had been reimmersed in water for 24 hours. Hence, white crabs that are exposed to air on deck during fishing may be weakened further, possibly causing abnormal defense and escape behaviours which would make them even more vulnerable to predation and disease.

CONCLUSION

If abundant and quality meat is the main criterion of snow crab fishing activities, the industry should target crabs with a shell hardness ≥ 60 durometer units. In general, the condition and meat yield of crabs with shell hardness between 60 and 80 durometer units is constant but differs from the corresponding characteristics of both soft-shelled (shell hardness < 60 durometer units) and hard-shelled (shell hardness ≥ 80 durometer units) crabs. The water content of crabs with a shell hardness ≥ 60 durometer units was lower than that for crabs with softer shells. It is recommended that fishermen avoid catching white crabs so that they have a chance to reproduce and increase their meat yield and its quality. The meat content of a crab can be accurately determined by entering its live weight and shell hardness (ie, durometer reading) values into the equations put forward in this paper.

Snow crabs returned to the sea during fishing activities showed fairly high survival rates. Only 14.3 % of white crabs and 2.2 % of hard-shelled crabs subjected to the treatments died during our study after being reimmersed in sea water for up to 72 hours. These values are comparable to those obtained for related species in similar investigations. However, white crabs are clearly more sensitive to fishing operations than hard-shelled crabs, especially during the summer when their mortality rates can reach a level eight times higher than in the spring. Three types of factors which operate simultaneously affect their survival. They are, in order of importance: 1) factors related directly to fishing activities (vitality of the crabs when they are landed on the deck and their number of missing legs), 2) a factor specific to the individual (size), and 3) a factor related to the environment (degree of dessication of the crabs before they are put back in the water). These factors can have a direct or indirect effect on the crabs and reduce their chances of survival when returned to the water.

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Table 1. Summary of values for the key variables measured during the study on shell hardness and meat content.

PARAMETERS	N	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
WET WEIGHT (g)					
WHOLE CRAB	464	434,8	186,3	113,3	978,8
MEAT-WHOLE CRAB	459	181,1	86,9	40,3	443,7
MEAT-RIGHT CLAW	460	12,6	7,1	1,0	35,5
MEAT-LEFT CLAW	459	11,6	7,0	2,0	36,6
DRY WEIGHT (g)					
MEAT-RIGHT CLAW	461	2,1	1,3	0,3	6,7
MEAT YIELD (%)					
WHOLE CRAB	458	41,0	6,0	21,9	58,0
WATER CONTENT (%)					
RIGHT CLAW	460	82,4	4,7	50,0	96,6
CARAPACE WIDTH (mm)	464	103,5	14,6	70,0	134,0
LEFT CLAW					
LENGTH (mm)	462	47,7	10,1	22,0	72,0
HEIGHT (mm)	461	25,2	5,3	14,0	38,0
WIDTH (mm)	461	22,3	4,9	11,0	49,0
VOLUME (ml)	460	17,8	9,7	3,0	50,0
RIGHT CLAW					
LENGTH (mm)	461	47,7	10,1	23,0	73,0
HEIGHT (mm)	462	25,3	5,3	14,0	38,0
WIDTH (mm)	459	22,3	4,8	12,0	33,0
VOLUME (ml)	457	17,9	9,8	3,0	50,0
MISSING LEGS	464	--	--	0,0	3,0
DUROMETER					
FRONT	227	86,9	16,9	18,0	100,0
CENTER	455	81,0	17,2	12,0	99,0
BACK	224	83,0	16,4	22,0	99,0

Table 2**.** Summary of values for the key variables measured during the study on mortality among snow crabs during fishing operations.

PARAMETERS	N	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
AIR EXPOSURE TIME (min*)*	**738**	**26,7**	**11,2**	**12,0**	**50,0**
IMMERSION TIME (hr)	**738**	**39,4**	**14,0**	**24,0**	**72,0**
AIR TEMPERATURE (°C)	**28**	**11,2**	**4,5**	**0,0**	**18,5**
CAPTURE DEPTH (m)	**43**	**81,9**	**18,8**	**53,0**	**130,0**
CARAPACE WIDTH (mm)	**737**	**90,6**	**15,2**	**57,0**	**138,0**
CRAB SIZE :					
COMMERCIAL (L. c. ≥ 95 mm)	**258**	**107,4**	**10,7**	**95,0**	**138,0**
NON COMMERCIAL (L.c. < 95 mm)	**479**	**81,5**	**7,5**	**57,0**	**94,3**
CLAW HEIGHT (mm)	**728**	**18,1**	**5,9**	**10,0**	**40,0**
DUROMETER READINGS (unit)	**588**	**62,7**	**11,6**	**27,0**	**97,0**

Table 3. Mortality rates for snow crabs as a function of dessication, wind speed, air temperature and exposure time on the vessel deck.

Mortality		**Dessication (°C-hr-m/s)**	**Wind speed (m/s)**	**Air temperature (°C)**	**Exposition (minute)**
Number	%				
1	**1,9**	**0,2**	**7,8**	**0,1**	**15**
1	**1,9**	**6,7**	**3,4**	**7,9**	**15**
1	**1,9**	**9,9**	**3,4**	**5,8**	**30**
1	**1,9**	**13,1**	**1,5**	**10,5**	**50**
2	**3,8**	**0,4**	**7,8**	**0,1**	**30**
3	**5,7**	**19,0**	**3,4**	**13,4**	**25**
3	**5,7**	**19,5**	**7,8**	**5,0**	**30**
3	**5,7**	**21,0**	**5,6**	**15,0**	**15**
4	**7,5**	**6,1**	**1,5**	**16,3**	**15**
7	**13,2**	**12,2**	**1,5**	**16,3**	**30**
8	**15,1**	**9,1**	**3,4**	**13,4**	**12**
9	**17,0**	**34,4**	**10,2**	**13,5**	**15**
10	**18,9**	**68,8**	**10,2**	**13,5**	**30**

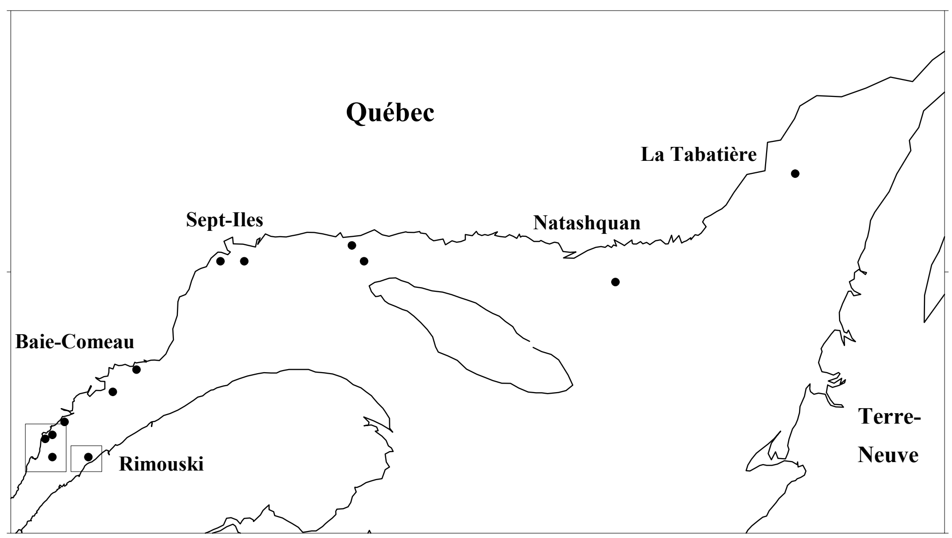

Figure 1. Sampling sites for snow crabs in the investigations of shell hardness and meat content (•), and mortality among crabs during fishing operations (□).

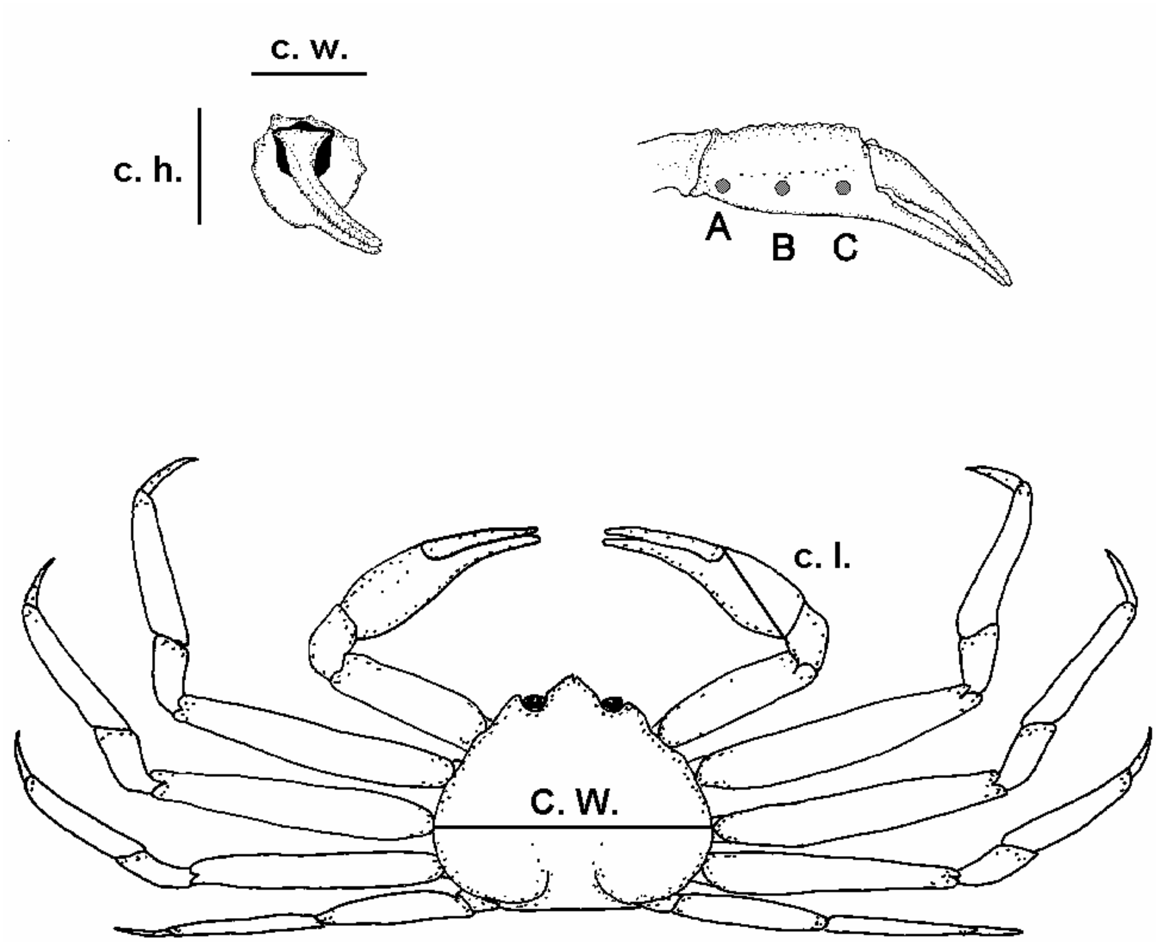

Figure 2. Schematic diagram of the measurements conducted in the investigations on shell hardness and meat content: C.W.= carapace width; c.w., c.h. and c.l., respectively claw width, height and length; A, B and C=areas where the durometer readings were taken.

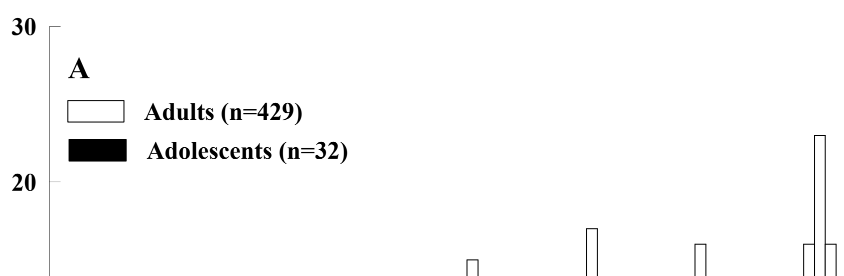
30
A
Adults (n=429)
Adolescents (n=32)
20

Figure 3. Size frequency distribution of snow crabs in the study on: (A) shell hardness and meat content, and (B) mortality during fishing activities.

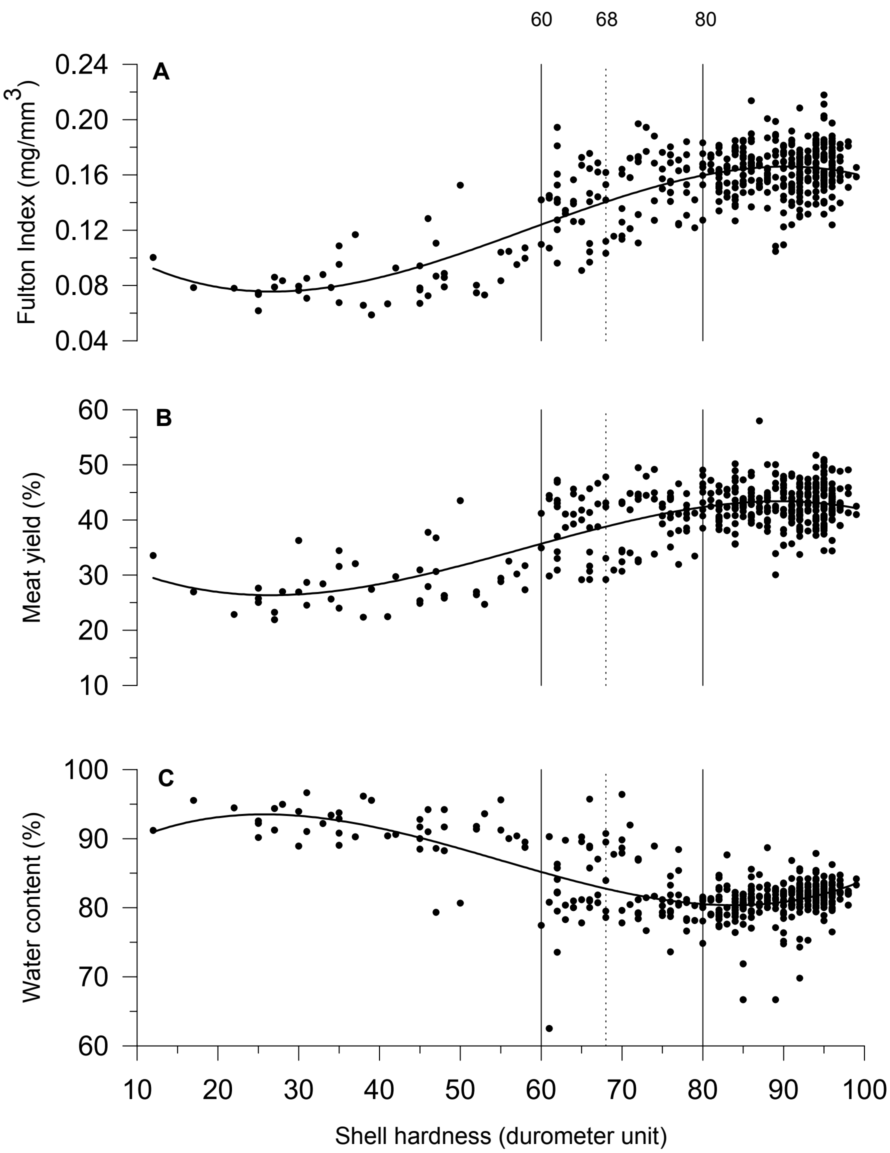

Figure 4. Relationship between the condition (A), meat yield (B) and water content (C) of crabs and their shell hardness.The equation for the regression curve for each of the graphs is as follows: (A) $y = 0.137 - 5.087\times10^{-3}\ x + 1.234\times10^{-4}\ x^2 - 7.027\times10^{-7}\ x^3$; (B) $y = 37.897 - 0.966\ x + 0.024\ x^2 - 1.358\times10^{-4}\ x^3$; (C) $y = 83.510 + 0.866\ x + 0.022\ x^2 + 1.340\times10^{-4}\ x^3$.

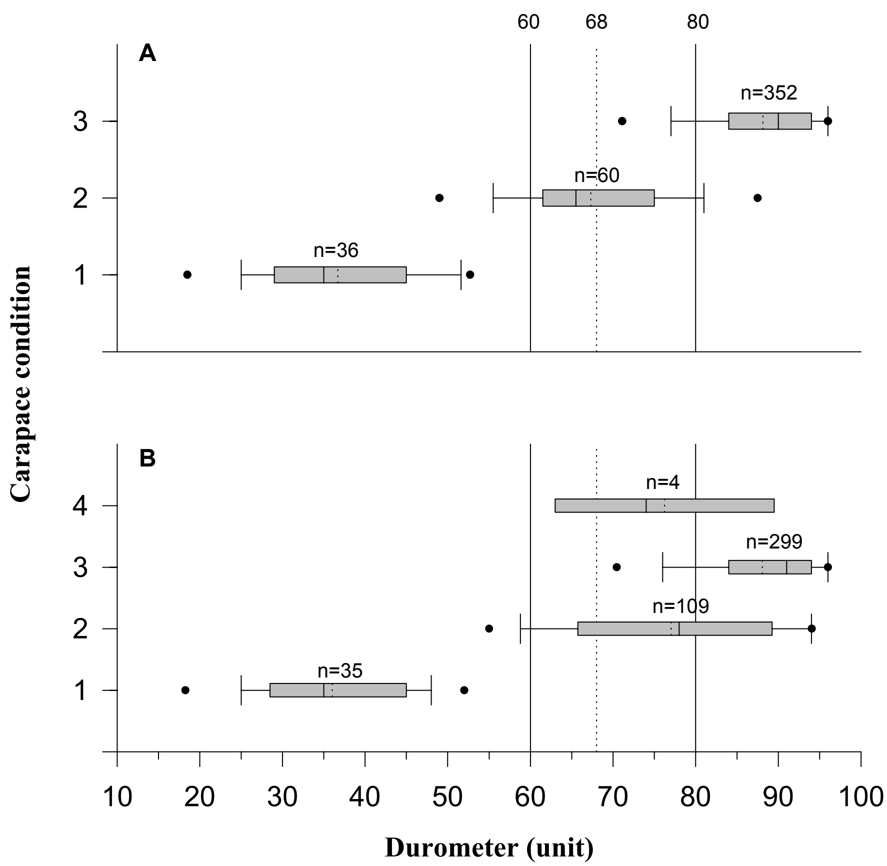

Figure 5. Relationship between shell condition, as defined by (A) Lamoureux and Lafleur (1982) and (B) Foyle *et al.*. (1989), and shell hardness. The small "n" denotes the number of crabs in each category. The points at either end correspond to the 5th and 95th percentiles; the mean is shown by the dashed line and the median by the solid line.

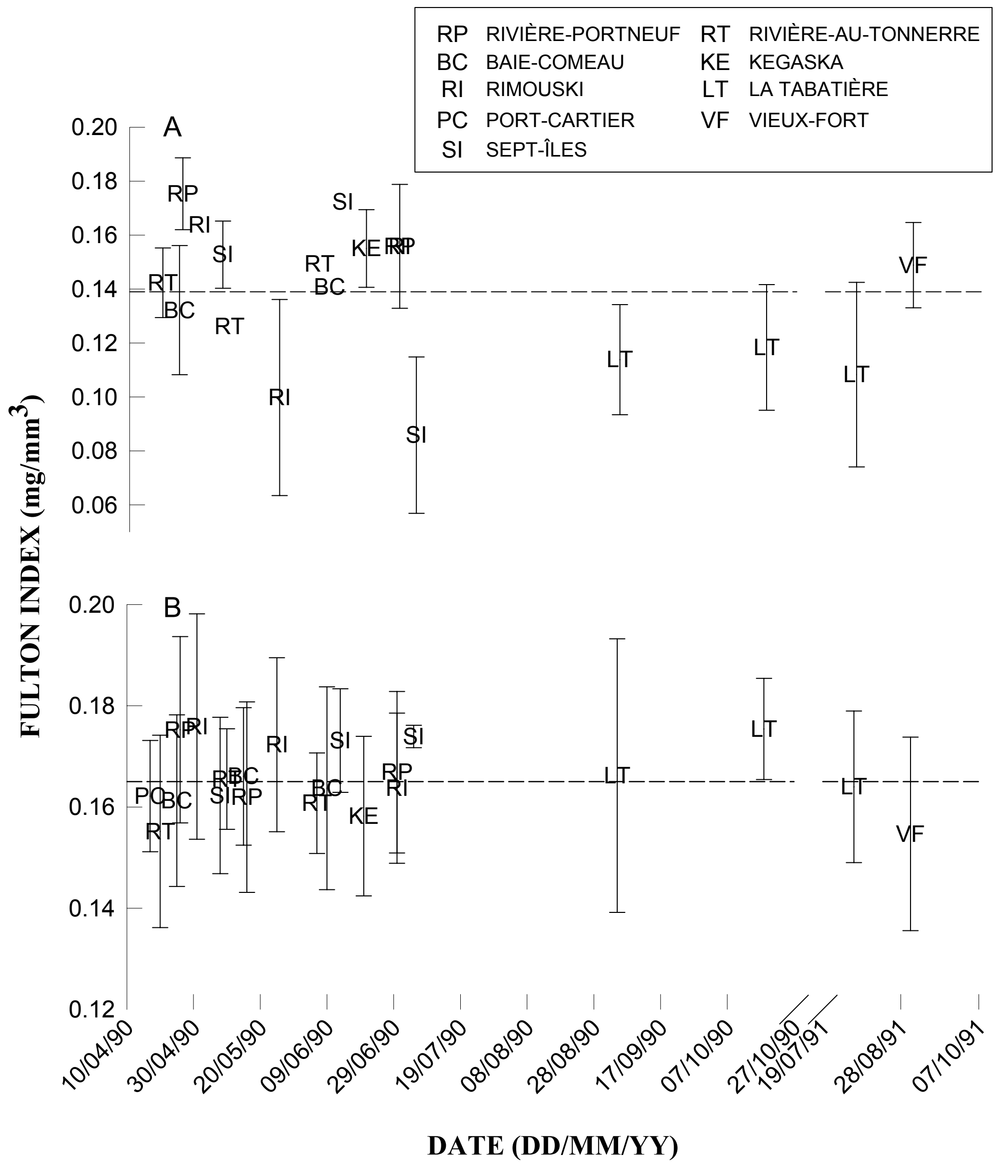

Figure 6. Mean Fulton index calculated for crabs caught in 1990 and 1991. (A) adolescent and adult males with shell type 1 and 2, as defined by Lamoureux and Lafleur (1982) and Foyle *et al.* (1989); (B) male adults with shell type 3 and 4, according to Lamoureux and Lafleur (1982) and Foyle *et al.* (1989). The mean indices are accurate to ± 1 standard deviation. The dashed line represents: (A) the mean Fulton index for all crabs caught before the end of June 1990 and (B) the mean Fulton index for all crabs with these shell types during the entire year.

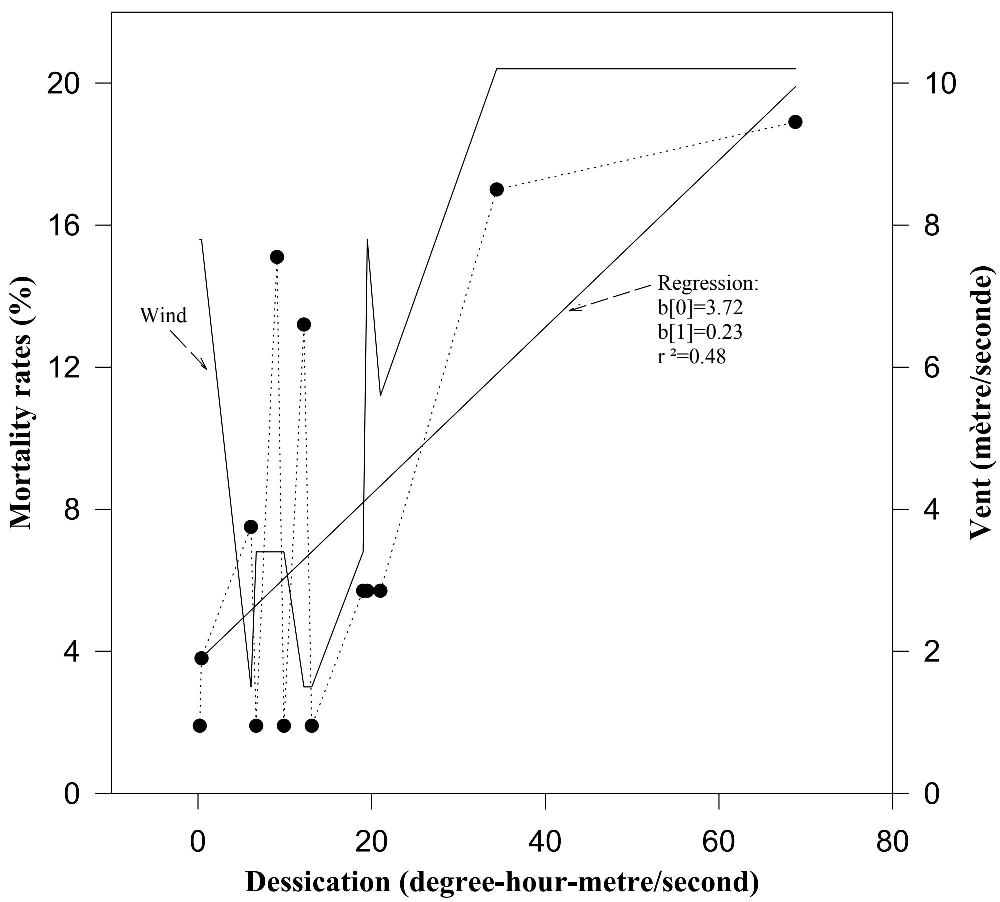

Figure 7. Mortality rates for white crabs as a function of the composite variable (••••) which represents the degree of dessication in crabs that have been exposed to air on the boat deck. The regression line was calculated on the raw mortality data. The effect of the wind (—) on the relationship is shown also.

Appendix 1.

Shell condition and criteria used to determine the condition of snow crab according to the method of Lamoureux et Lafleur (1982). The numbers denote the shell condition.

«1» Shell light-coloured and looks soft. Claw very iridescent and easily broken (soft).

«2» Shell light-coloured, sometimes contains epibionts. Claw not very iridescent and easily broken (intermediate).

«3» Shell light brown on dorsal side, yellowish brown on ventral side; contains marks and epibionts on the dorsal side. Claw not iridescent and not easily broken (hard).

«4» Shell old, dirty and soft; shows signs of decalcification especially around claw joints (old).

Appendix 2

Shell condition and criteria used to determine the condition of snow crabs according to the method of Foyle *et al*. (1989). The numbers denote the shell condition.

«1» Claw deforms under thumb pressure. Shell appears new, brightly coloured and lacks fouling organisms (epibionts). Claws are iridescent on outer edge. Shell is white or bright pink underneath (soft).

«2» Slight or no deformation in claw under moderate thumb pressure but shell appears new, brightly coloured and lacks fouling organisms (epibionts); claws are iridescent on outer edge; shell white or bright pink underneath (new hards).

«3» Shell older than type 2; orange-brown with some epibionts; claws are iridescent on outer edge; shell white or pink underneath (old hards I).

«4» Shell dull, with numerous epibionts, and commonly yellow underneath (old hards II).

«5» Shell dark, soft and usually covered with epibionts; black spots common with decay at some joints which are also rigid (old hards III).