Mortality of Snow Crab Discarded in Newfoundland and Labrador's Trap Fishery: At-Sea Experiments on the Effect of Drop Height and Air Exposure Duration

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ABSTRACT

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The survivability of undersized immediate pre-recruits (70-94 mm carapace width, CW) and high graded (95-101 mm CW) snow crab (*Chionoecetes opilio*) discarded in Newfoundland and Labrador's recruitment dependent fishery has been a growing concern among harvesters and fisheries managers in recent years. Many fear the long-term conservation of the stock may be threatened because tonnes of discarded crab are mishandled every year when they are dropped onto hard surfaces and held out of the water for prolonged periods of time before being returned to the ocean. This study investigated whether drop heights of two, four, and six feet (0.3, 1.2, and 1.8 m) and air exposure durations of five, 30, 60, and 120 (±3) min negatively influence the survivorship of male hard-shelled snow crab within a 74 to 101 mm CW size range. At-sea experiments were conducted from 19 June to 19 July 2002. Drop and air exposure related instant and delayed mortality were assessed and combined to provide estimates of total mortality. Instant mortality was assessed within three hrs of subjecting crab to a treatment and delayed mortality was assessed by holding crab on the ocean floor at depths ranging from 174-201 m for 24-25 days. There were no mortalities, either instant or delayed, in the control treatments (i.e., no drop and 5 ± 3 min air exposure). These results indicate that survival can be maximized (100%) when discarded crab are handled gently and quickly returned to the ocean. Both instant and delayed mortality increased substantially with an increase in drop height and air exposure duration, and analysis of delayed mortality indicated that both factors had a significant negative effect on survival. Based on the levels of mortality demonstrated in this study and reports of high vulnerability and catchability of immediate pre-recruits during the two to three year period before they recruit to the fishery, it is concluded that mishandling of discarded snow crab by dropping and holding them out of the water for more than 5 ± 3 min can have a substantial negative effect on the quantity of legal-sized crab available to the fishery.

RÉSUMÉ

Grant, S. M. 2003. Mortality of snow crab discarded in Newfoundland and Labrador's trap fishery: At-sea experiments on the effect of drop height and air exposure duration. Can. Tech. Rep. Fish. Aquat. Sci. ###: vi + 28 p.

Dans la pêche du crabe des neiges (*Chionoecetes opilio*) à Terre-Neuve et au Labrador, pêche qui repose sur le recrutement, la capacité de survie des prérecrues immédiates de taille inférieure à la taille réglementaire (celles ayant une largeur de carapace [LC] de 70-94 mm) et des crabes faisant l'objet de rejets sélectifs (LC de 95-101 mm) qui sont remis à l'eau a suscité des inquiétudes croissantes parmi les pêcheurs et les gestionnaires des pêches ces dernières années. Nombreux sont ceux qui craignent que la conservation du stock à long terme soit menacée parce que des tonnes de crabes rejetés sont manipulées sans précaution chaque année : on laisse tomber ces crabes sur des surfaces dures et on les garde hors de l'eau pendant de longues périodes avant de les rejeter. L'étude dont il est question ici visait à déterminer si des hauteurs de chute de deux, quatre et six pieds (0,3, 1,2, et 1,8 m) et une exposition à l'air pendant des périodes de cinq, 30, 60, et 120 (±3) minutes ont une influence négative sur la capacité de survie des crabes des neiges mâles dont la largeur de carapace se situe entre 74 et 101 mm. Des expériences en mer ont été réalisées du 19 juin au 19 juillet 2002 pour évaluer la mortalité instantanée et la mortalité différée dues aux chutes et à l'exposition à l'air, et pour obtenir en combinant les résultats des estimations de la mortalité totale. La mortalité instantanée a été évaluée dans les trois heures du traitement infligé au crabe, tandis que la mortalité différée a été évaluée en maintenant les crabes sur le fond marin à des profondeurs allant de 174 à 201 m pendant 24-25 jours. Il n'y a pas eu de mortalité, instantanée ou différée, parmi les crabes-témoins, qui ont été exposés à l'air pendant 5 ± 3 minutes, mais non assujettis à des chutes. Il ressort des résultats obtenus que la survie peut être maximisée (100 %) quand les crabes rejetés sont manipulés avec précaution et rapidement remis à l'eau. Tant la mortalité instantanée que la mortalité différée augmentaient sensiblement lorsque la hauteur de chute et la durée de l'exposition à l'air croissaient, et des analyses de la mortalité différée révélaient que les deux facteurs avaient un effet négatif important sur la survie. D'après les taux de mortalité obtenus dans l'étude et les indications de forte vulnérabilité et capturabilité des prérecrues immédiates dans les deux à trois ans qui précèdent leur recrutement à la pêche, il apparaît que les mauvaises manipulations des crabes des neiges rejetés, c'est-à-dire leur chute et leur maintien hors de l'eau pendant plus de 5 ± 3 minutes, peuvent avoir un effet négatif important sur la quantité de crabes de taille réglementaire disponible pour la pêche.

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1.0 INTRODUCTION

In the Newfoundland and Labrador region, the snow crab (*Chionoecetes opilio*) resource has grown from the status of discarded by-catch in the 1960's to now being the most valuable marine resource, accounting for over 50% of the value of all fish landed. The region's total allowable catch (TAC) for snow crab increased steadily following the 1992 collapse of the groundfish fishery, reaching a peak of 60,650 metric tonnes in 1999 (DFO 2000). However, the 1999 fall survey indicated poor recruitment off Newfoundland's northeast coast, which resulted in a 15.8% reduction in the overall TAC for the region. Reduction in recruitment may reflect natural fluctuations in snow crab stocks, but unaccounted fishing-related mortalities may have also contributed to the declines in abundance. Such mortalities could result from shrimp trawling on crab grounds, by-catch of snow crab in turbot and cod gillnet fisheries, ghostfishing by lost gillnets and snow crab traps, mortality among discarded undersized crab in the trap fishery, and mortality among small legal-sized crab discarded due to high grading. While mortalities caused by shrimp trawls and gillnets are area-specific, discard mortality in the snow crab trap fishery could negatively influence the quantity of undersized and high graded snow crab throughout the geographic distribution of commercial crab harvesting operations.

More than 3,000 vessels participate in Newfoundland and Labrador's snow crab fishery. Fleets are structured by vessel size, which includes the under 35-foot fleet fishing inshore, the 45-foot fleet fishing inshore and mid-shore, and the over 45-foot fleet fishing mid- and offshore. Most of the vessels were not designed exclusively for the crab fishery. Consequently, there is a great deal of variability in vessel design which has led to a wide variety of handling and holding practices, both within and among fleet sectors. For example, once on board, a trap's catch may be dumped directly onto the deck, held over the hold and dumped, or emptied onto a raised table. Drop heights onto hard surfaces typically range from one to six feet (0.3-1.8 m), and in extreme cases crab may drop as much as eight feet (2.4 m). They may also be dropped more than once. Soft-shelled and undersized crab exhibiting a carapace width (CW) less than 95 mm may be immediately sorted and returned to the ocean. However, on some vessels it is more common for crab to be held out of the water for 30 to 60 min, the period of time required to haul one or more trap lines, and in extreme cases they may not be returned to the ocean for two hrs or longer. Holding conditions range from full exposure on an unsheltered work deck, to well sheltered and highly humid conditions in the hold of the vessel. When the crab are discarded, they may be slid down a chute, but in most cases they are either tossed overboard or dropped into the water from tote pans, falling from heights of up to eight feet. More recently, it has been reported that small legal-sized crab measuring 95-101 mm CW have also been discarded due to the individual quota system and higher prices paid for larger crab. This practice is referred to as high grading.

For some time, harvesters and fisheries managers assumed that most of the snow crab returned to the ocean in the Newfoundland and Labrador region would survive the capture, sorting, and discard process. However, preliminary studies conducted at sea (DFO 1995) indicated that mishandling of undersized snow crab by dropping and holding them out of the water for prolonged periods of time may result in high mortality. More recently, controlled laboratory experiments demonstrated that the level of mortality in undersized and high graded snow crab does indeed increase with an increase in drop height onto hard surfaces (Grant et al. 2002). Laboratory estimates of mortality were considered to be conservative because crab were not subjected to the capture, sorting, and discard process that accompanies the drop in the commercial fishery.

The laboratory experiments (Grant et al. 2002) represented Phase II of a snow crab discard survivability project initiated in 2000. Phase I of the project outlined a protocol for conducting experiments at sea (He 2001). However, the protocol proved to be too ambitious for a single suite of survivability experiments, as it proposed taking into account the influence of fishing season, fishing area, vessel size and structure, air temperature, water temperature, water depths where crab are captured, air exposure time, and drop height. For any experiment to be representative and meaningful it is important to limit the number of variables being tested simultaneously. To this end, the at-sea protocol was revised so that the study could focus on the effects of the two factors considered to be most influential with regard to mortality of undersized and high graded crab discarded from commercial vessels: dropping onto hard surfaces and air exposure duration. The revised protocol required investigations into the design of a suitable holding cage to assess mortality at sea, which included laboratory drop experiments (Grant et al. 2002). The current study represents Phase III, the at-sea component of the snow crab discard survivability project.

The purpose of this study was to conduct experiments at sea to determine whether drop heights of two, four, and six feet (0.3, 1.2, and 1.8 m) and air exposure durations of five, 30, 60, and 120 (± 3) min negatively influence the survivorship of undersized and high graded male snow crab in the hard-shelled condition. Both instant and delayed mortality were assessed, and then combined to provide estimates of total mortality. All drop and air exposure experiments were designed to simulate conditions on board harvesting vessels. While handling practices vary widely among harvesters during the physical sorting procedure, and the degree of rough handling at this stage may influence survival of discarded crab, examination of these effects was considered to be beyond the scope of this study. In this study, the physical sorting procedure was standardized, which resulted in crab being handled more carefully than they would be during commercial operations.

2.0 METHODOLOGY

2.1 AT-SEA EXPERIMENTS

This study tested the following null hypothesis: drop heights of two, four, and six feet combined with air exposure durations of five, 30, 60, and 120 (±3) min do not negatively influence the survivorship of male hard-shelled snow crab within the 70-101 mm CW size range. The alternate hypothesis is that drop height and air exposure duration do negatively influence snow crab survivorship. If the alternate hypothesis is true, then as the drop height and air exposure duration increases, mortality will also increase. Control treatments were implemented by eliminating the drop entirely (no drop) and minimizing the air exposure duration (5 ± 3 min). Thus, if the alternate hypothesis is true, there should be significantly fewer mortalities, or none at all, in the control treatments.

The hypotheses were tested by utilizing a two-factor analysis of variance experimental design. To accomplish this, snow crab were subjected to one of four experimental trials in which the air exposure treatment was held constant at five, 30, 60 or 120 (±3) min, while the drop height varied. Each experimental trial was conducted on a separate day over a 0.5 to 2.5 hr period between the hr of 08:00 and 11:00. The trials may be summarized as follows:

Trial 1 — Four treatments: one control treatment, subjected to 5 ± 3 min air exposure and no drop; and three drop treatments of either two, four, or six feet, each of which were subjected to 5 ± 3 min air exposure.

Trial 2 — Four treatments: one control treatment, as outlined in Trial 1; and three drop treatments of either two, four, or six feet, each of which were subjected to 30 ± 3 min air exposure.

Trial 3 — Four treatments: one control treatment, as outlined in Trial 1; and three drop treatments of either two, four, or six feet, each of which were subjected to 60 ± 3 min air exposure.

Trial 4 — Four treatments: one control treatment, as outlined in Trial 1; and three drop treatments of either two, four, or six feet, each of which were subjected to 120 ± 3 min air exposure.

The sampling and experimental platform used for this study was the MV *Mares*, a 13.7 m research and training vessel operated by the Fisheries and Marine Institute of Memorial University of Newfoundland. All crab used in the study were captured in Japanese style conical commercial crab traps (i.e., 1.2 m bottom diameter and 135 mm stretched mesh) fished on the bottom for one to three nights within a depth range of 110-119 m in Conception Bay, Newfoundland (46°33.11' N lat., 53°04.52 W long.). Bottom water temperatures at the sampling site were recorded by attaching a thermograph to one of the traps. Commercial harvesters were fishing in waters adjacent to the study area while the experiments were being conducted.

The drop and air exposure treatments were conducted over a seven-day period, 19-25 June 2002. Snow crab catches were sorted by carapace width and shell condition.

Only male hard-shelled snow crab within a 70-101 mm CW size range were considered for the experiments. A handheld gauge was used to determine size suitability. All soft-shelled crab and larger male crab were returned to the ocean and no females were captured. Females rarely exceed a size of 76 cm CW in the Newfoundland region. Hard-shelled crabs were assessed by firmly grasping the propodus of the claw between the thumb and index finger and applying moderate pressure. If the propodus did not deflect, the crab was considered hard-shelled. It is notable that this criterion reduced the likelihood of using old-shelled terminal molt crab. To avoid additional handling stress to crab used in the experiments, individual measurements of carapace width were reserved until a crab was diagnosed as dead (i.e., instant or delayed mortality), and all surviving crab were individually measured at the end of the experiment. Dead crab determinations followed those developed by Stevens (1990) and summarized in a handbook prepared for the Newfoundland and Labrador snow crab fishing industry (Tavel 2000).

Two-, four-, and six-foot drop platforms were used to simulate drop heights experienced by snow crab on board commercial vessels. Crab were placed on a platform and individually swept to a hatchway where they subsequently fell onto the deck (two-foot drop) or into the hold (four- and six-foot drops). Ten to 30 crab were allowed to accumulate on the deck or floor of the hold before they were removed. During Trial 1, the control and drop treatment crab were quickly placed into a drop specific recovery tank. During Trials 2, 3, and 4, all control treatment crab were quickly placed in a recovery tank, while dropped crab were placed in perforated tote pans and held out of the water in the hold of the vessel for the designated time period before being transferred to a recovery tank. Minimum and maximum air temperature and relative humidity were recorded in the hold during each trial.

Four 420 L insulated fish tubs (inside dimensions: 89 cm long × 48 cm wide × 55 cm deep) were used as recovery tanks during this study. The recovery tanks were held in the hold of the vessel. The tanks were filled with fresh seawater and the temperature was lowered to 6.0 ± 0.5°C by the addition of bagged ice prior to the initiation of an experimental trial. Each recovery tank was outfitted with one large (20 cm) air stone and compressed air cylinders (i.e., SCUBA tanks) were used to continuously aerate the seawater. Minimum and maximum water temperature and percent oxygen saturation were monitored in the recovery tanks during the study.

Throughout the course of the study, individual crab could be expected to remain in a recovery tank for a minimum of 30 min to a maximum of three h, the period of time required to deploy the holding cages for the assessment of delayed mortality. It was arbitrarily decided that to serve as a suitable recovery tank, the oxygen saturation levels should not be allowed to drop below 80%. Therefore, it was necessary to determine the maximum number of crab that could be placed in each recovery tank. This was accomplished by closely monitoring the oxygen saturation levels as crab were added to a control and six-foot drop treatment tank. It was discovered that no more than 60 crab could be added to the control treatment tank without decreasing the oxygen saturation below 80%. By the time 52 crab were placed in the six-foot drop treatment tank, the oxygen saturation had fallen to 78% in one region of the tank. However, saturation was readily restored to 81-82% throughout the tank by manually mixing the water. Based on these observations it was decided to limit the number of crab dropped in each of the two-, four-, and six-foot drop treatments to 52 individuals, while a total of 60 crab were placed in the control treatment tanks. All recovery tanks were manually mixed at approximately 10-minute intervals. Crab that survived the drop and air exposure treatments were transferred from the recovery tanks to holding cages destined for the ocean floor, while those that did not survive were considered as instant mortality.

Five holding cages (i.e., replicates) were used to assess delayed mortality of snow crab in each experimental trial. A total of 20 cages were used during the entire study (four trials × five cages). The holding cages were designed and tested for suitability for snow crab studies during preliminary laboratory drop experiments conducted at the Logy Bay Ocean Sciences Centre (Grant et al. 2002). The holding cages were constructed of 3 mm PVC coated wire with a 38 mm square mesh. Holding cage dimensions were 152 cm L × 99 cm W × 76 cm H. Each cage was divided into four compartments, each measuring 76 cm x 49.5 cm x 76 cm. Each compartment had a total interior surface area (floor + walls + ceiling) of approximately 2.7 m^2. Grant et al. (2002) demonstrated that this compartment size was suitable for holding ten snow crab ranging in size from 79 to 102 mm CW for at least 28 days. During laboratory studies, crabs were observed to utilize the floor, walls, and ceiling of the holding cages.

The holding cages were rigged for use at sea by attaching a 16 mm round-steel frame to the bottom of each cage, and a 20 cm diameter trawl float was suspended from the haul line approximately 1.0 m above the cage. These modifications were made to ensure the cage remained upright while being lowered through the water column. Each cage was deployed separately, and its location visually marked with two large surface buoys. Three crab trap frames were attached at about 35 m intervals to the cage end of the haul line. These frames acted as anchors to prevent the indicator buoys from moving a cage along the ocean floor during high seas.

While on deck, a holding cage was held in a large tub filled with fresh seawater to reduce air exposure and subsequent dehydration of crab while each treatment group was being transferred from the recovery tanks to a cage. Ten live crab were randomly transferred from one of the four drop treatment recovery tanks to one of the cage compartments, for a maximum of 40 crab per cage. Crab liveliness determinations followed those documented in a handbook prepared for the fishing industry (Tavel 2000), and in the current study live crab included lively, weak, and critically weak crab. Instantaneous limb autotomy resulting from the drop treatments (i.e., fresh wounds) and the total number of missing limbs was recorded for each crab by recovery tank and cage compartment. The treatment groups were tracked to the appropriate cage and compartment by affixing a label to each cage.

A supplementary food source was not provided to the caged crab. It was decided not to provide food in the form of herring or squid, as the carcasses may attract large predators or scavengers that could prey on caged crab, particularly those crab that were injured or weakened. In the laboratory, similar sized crab were held without food for 28 days at temperatures of -0.5-2.2 °C with no mortalities (Grant et al. 2002). Given the lower bottom water temperatures in the study area during the caging experiments (-1.0--1.2° C), and reduced metabolism of poikilotherms at low temperatures, the risk of starvation was considered minimal.

All 20 holding cages were deployed in close proximity in Conception Bay in an area bounded by approximately from 47°31.59'N to 47°32.71'N latitude and 53°06.16'W to 53°06.68' W longitude and at depths ranging from 174 m to 201 m (mean, 185 m). When a cage was deployed, it was gently lowered into the water to prevent damage to the crab and a hauler was used to slowly (ca. 10 min) lower the cage through the water column for the first 110-145 m. The cage was released from the hauler during the final decent to the bottom, to prevent the vessel from dragging the cage along the ocean floor and allow the anchors to land a sufficient distance away from the cage. Two holding cages were affixed with a thermograph, which recorded bottom water temperatures at the upper and lower boundaries of the cage deployment site.

The holding cages were retrieved after they had remained on the ocean floor for 24-25 days. When a cage was hauled on board it was placed in a large holding tank filled with fresh seawater. The crab in each compartment were counted, mortalities were assessed, and carapace widths were measured using vernier calipers (±1 mm).

2.2 STANDARDIZATION OF HANDLING PROTOCOLS

When conducting experiments with live animals it is important to establish standard handling protocols, otherwise variation in seemingly trivial activities could cause substantial and unaccountable mortality, particularly when the stress associated with these activities is cumulative. For example, on commercial vessels traps may be slid or lifted over the gunwale when they are hauled on board, and sliding may cause protruding limbs to be severed. Once the catch has been dumped, crab are individually lifted for measuring and sorting and the method used to lift crab can result in varying levels of stress and possibly damage. When landed crab are lifted by a single limb, that limb must support the weight of the entire body, which may not only lead to increased stress, but if the limb is damaged it will lead to limb autotomy (MacIntosh et al. 1996) and possibly death. Further, when discards are held out of the water for prolonged periods of time, they may be stowed in a back-up or belly-up orientation, and the latter has been shown to increase mortality (Trenholm and Norsworthy 1999).

In the current study, crab were sorted directly from the trap. Each trap was lifted over the gunwale and gently laid on its side on the deck of the vessel. Crab were always lifted individually by the body and they were gently placed in a back-up orientation in the tote pans during the air exposure treatments.

2.3 DATA ANALYSIS

Instant mortality (IM) was estimated for each drop and air exposure treatment as the number of dead crab removed from a recovery tank. Instant mortality was calculated as follows:

$$IM = \frac{\text{number of dead crab in a recovery tank}}{\text{initial number of crab placed in a recovery tank}} \times 100$$

Delayed mortality (DM) was calculated for each drop and air exposure treatment as follows:

$$DM = \frac{\text{number of crab that died while in a specific compartment of a holding cage}}{\text{initial number of crab placed in that compartment}} \times 100$$

Five cages were used for each experimental trial, therefore up to five estimates of delayed mortality were calculated for each of the four drop and air exposure treatments. Specifically, there were always five replicates of ten crab in the control treatments as there were no instant mortalities in this treatment group. There were however, as few as four replicates of ten crab in the drop treatments, because of instant mortalities. From these data, a two-way analysis of variance (ANOVA; Proc GLM, SAS 1988) was used to determine whether delayed mortality differed within and among treatment groups. To ensure accuracy of the results, and verify whether data transformation was necessary to meet the assumptions of an ANOVA, a two-step examination of the residuals was performed. The first step involved performing a two-way ANOVA on the untransformed delayed mortality data (i.e., DM/100) to obtain the residuals, which were plotted against the explanatory variable to determine whether they were evenly distributed below zero (i.e., homoscedasticity). Secondly, the residuals were examined to determine whether a normal error structure could be assumed. This procedure revealed both homoscedasticity and a normal error structure of the residuals, and therefore the data were not transformed.

A one-way analysis of variance (ANOVA; Proc GLM, SAS 1988) was used to determine whether carapace width and the number of missing limbs differed among drop treatments within an experimental trial. When no significant difference was found the data were combined for each trial and a second analysis was performed to determine whether these factors differed among trials. The carapace width data were $\log_e$ transformed and the missing limb data were $\log_e(n + 1)$ transformed for the analyses.

3.0 RESULTS

3.1 ENVIRONMENTAL CONDITIONS, SNOW CRAB BODY SIZE, AND LIMB AUTOTOMY

Environmental conditions were similar among the experimental trials (Table 1). Bottom water temperatures at both the upper and lower boundaries of the cage deployment site ranged from -1.0° C to -1.2° C and did not differ from the water temperatures where the crab were originally captured (Table 1).

Seven of the mortalities in the holding cages were badly decomposed, which precluded measurements of carapace width. The remaining snow crab exhibited a range in carapace width of 74 to 101 mm (Fig. 1). Analysis indicated that carapace width did not differ among drop treatments in Trial 1 ($F_{204,3} = 1.98$, $p = 0.12$), Trial 2 ($F_{204,3} = 2.14$, $p = 0.10$), Trial 3 ($F_{204,3} = 1.36$, $p = 0.26$), and Trial 4 ($F_{200,3} = 1.15$, $p = 0.33$). Further, when the data were combined and compared among trials carapace width did not differ ($F_{820,3} = 2.46$, $p = 0.061$). Thus, it is unlikely that any within or among treatment differences in mortality were related to body size of the crab tested.

A high proportion (59%) of the 824 crab examined during this study were missing at least one limb when they were captured, and 21% were missing more than one limb (Fig. 2). Limb autotomy occurred in the drop treatments and increased with an increase in drop height. Limb autotomy was highest among crab in the six-foot drop treatments (four to seven limbs per trial) followed in descending order by crab in the four-foot (two to four limbs per trial), two-foot (one limb in three of the four trials), and control treatment (one limb in one trial). Most of the limbs were autotomized during the drop. However, a total of eight limbs were found in the tote pans and recovery tanks, indicating delayed limb autotomy. All limbs were autotomized at the coxa.

Analysis of the total number of missing limbs, which included limbs lost during the drops, indicated that the number of missing limbs did not differ among drop treatments in Trial 1 ($F_{204,3} = 0.76$, $p = 0.52$), Trial 2 ($F_{204,3} = 0.17$, $p = 0.92$), Trial 3 ($F_{204,3} = 1.41$, $p =$ 0.24), and Trial 4 ($F_{204,3} = 1.97$, $p = 0.12$). Further, when the data were combined and compared among trials, the number of missing limbs did not differ ($F_{820,3} = 2.61$, $p =$

0.050). Unfortunately, mortalities and decomposition precluded a reliable assessment of the influence of drop related limb autotomy on delayed mortality.

3.2 CONTROL TREATMENTS

There were no instant mortalities in the control treatment recovery tanks during the four experimental trials, nor were there any delayed mortalities in the control treatments in the 20 holding cages. Absence of mortality in the control treatments, indicates that survival can be maximized (i.e., 100%) when discarded snow crab are handled in a similar manner and under similar environmental conditions as those described in this study. Absence of mortality in the control treatments also provides evidence that any mortalities, or differences in mortality, observed in the drop and air exposure treatments were truly a result of the drop height and air exposure duration.

3.3 INSTANT MORTALITY

Instant mortalities were recorded in all of the drop and air exposure treatments. Mortality increased with an increase in drop height and air exposure duration (Fig. 3). Instant mortality increased substantially (i.e., two fold or greater) with an increase in air exposure duration in all of the drop treatments. For example, there was a 3.3 fold (5.8-19.2%) increase in instant mortality in the two-foot drop treatment, a 2.5 fold (7.7-19.2%) increase in the four-foot treatment and 2.0 fold (11.5-23.1%) increase in the six-foot treatment. Instant mortality increased substantially among drop treatments in both the five and 30 min air exposure treatments, increasing from 5.8 to 11.5% (2.0 fold) and 7.7-21.2% (2.8 fold), respectively. There was a similar marginal (1.2 fold) increase in instant mortality among drop heights within the 60 min (19.2-23.1%) and 120 min (17.3-21.2%) air exposure treatments.

3.4 DELAYED MORTALITY

Considerable mortality occurred even after crab were returned to the ocean floor for 24-25 days (Fig. 4). Overall, mean delayed mortality increased with an increase in drop height and air exposure duration (Fig. 4), and analysis indicated that both factors had a significant negative effect on survival (Table 2). Standardization of the handling and holding procedures, low variability in the environmental parameters monitored, and absence of mortality in all 20 control treatments provide strong evidence that delayed mortality resulted largely from the impact shock and dehydrating effects at each drop and air exposure treatment. Absence of mortalities in the control treatments suggests that short-term starvation did not influence survivorship.

3.5 TOTAL MORTALITY

Total mortality increased with each increase in drop height across all air exposure treatments (Fig. 5). Total mortality among drop treatments was always lowest in the two-foot drop and highest in the six-foot drop. Total mortality within a drop treatment was always lowest in the five-minute air exposure treatment.

Even when crab were dropped from as little as two feet and quickly placed in seawater, a total mortality of 9.8% was observed (Fig. 5). A two fold increase in drop height to four feet resulted in a substantial (2.1 fold) increase in total mortality to 20.2%, and mortality nearly quadrupled (3.7 fold) to 36.6% with a three fold increase in drop height to six feet (Fig. 5). These results indicate that drop height alone had a substantial negative effect on survival of undersized and high graded snow crab. There was also a substantial among drop height increase in total mortality in the 30 min air exposure treatment, as mortality increased by 2.9 fold (16.2-46.2%) with a three fold increase in drop height from two to six feet. There was a similar moderate (1.7 fold) among drop height increase in total mortality within the 60 min (29.2-50.6%) and 120 min (29.8-51.2%) air exposure treatments.

In each drop treatment, total mortality increased with each increase in air exposure duration to 60 min, but showed little change thereafter (Fig. 5), a pattern not unlike that observed in the assessment of instant mortality (Fig. 3). It is unclear why there was no appreciable change in total mortality beyond 60 min One possible explanation is that body surface evaporation and cool body temperatures of the crab (-1.0° C; Table 1) resulted in a relatively high humid and cool air environment in the tote pans during the air exposure treatments. Also, crab were stacked three or four high in a tote pan so that crab in the lower portion of a pan may have received less direct exposure to ambient air temperature. Unfortunately, humidity and air temperature were monitored in the hold only, however, these variables could have stabilized and been less adverse in the tote pans, reducing the long-term effects of air exposure.

In the two-foot drop treatment, there was a 3.0 fold increase in total mortality (9.8-29.2%) when air exposure increased among the five and 60 min air exposure treatments. Over the same time period there was a 2.0 fold increase in total mortality (20.2-41.7%) in the four-foot drop treatment and a 1.4 fold increase in mortality (36.6-50.6%) in the six-foot drop treatment. These results indicate that air exposure duration had a substantial negative effect on the survival of undersized and high graded snow crab that were dropped from two and four feet. Overall, the results suggest that the cumulative effects of dropping and air exposure are more important in the two- and four-foot drop treatments, while drop height appears to be more important in the six-foot drop treatment.

4.0 DISCUSSION

Most of the rough handling practices used in Newfoundland and Labrador's snow crab fishery have developed because many harvesters consider snow crab to be a tough and durable species capable of withstanding physical abuse. This study indicates that mishandling undersized and high graded hard-shelled snow crab by dropping them onto hard surfaces from heights of two to six feet, combined with air exposure durations of five to 120 ± 3 min, has substantial and significant negative effects on survival. Drop heights and air exposure durations vary in the commercial fishery, but for the most part mishandled discards are likely to be dropped onto hard surfaces from heights of two to four feet and held out of the water for 30-60 min This study has demonstrated that when snow crab are dropped from as little as two feet and held out of the water in high humid conditions in the hold for 30 min, total mortalities will be in the order of 16%. Sixteen percent mortality may not seem like a large proportion, however, over time it could accumulate into a very substantial amount, particularly on fishing grounds where large quantities of undersized crab are captured and discarded from year to year. For example, 16% mortality of an initial localized population of 1,000 undersized crab leaves 840 crab, but 16% mortality of the 840 remaining crab leaves 706 crab, while an additional 16% leaves 593 crab, and so on. This scenario is clearly an over simplification, as it is unlikely that an entire localized population of undersized crab will be handled during a fishing season. However, undersized immediate pre-recruits (70-94 mm CW) are vulnerable to capture in the commercial snow crab fishery for two to three years, the period of time required for them to recruit to the fishery (Sainte-Marie et al. 1995). Further, repeat captures in the same season are not uncommon (Taylor et al. 1989), and catchability is high, with discards representing approximately 20 to 90% of the catch in Newfoundland and Labrador's snow crab fishery, depending on time of the year, molt stage of the crab, and previous exploitation history (Miller 1977; FDP 2002a). Overall, based on the levels of mortality demonstrated in this study and the high vulnerability and catchability of immediate pre-recruits, it is concluded that mishandling of undersized crab by dropping and prolonged air exposure can have a substantial negative effect on the quantity of legal-sized crab available to the fishery.

Research trap catches in two of three local inshore fishing areas have shown localized declines in snow crab catch rates, and in recent years several harvesters have indicated that greater effort has been required to catch the same quota (DFO 2001). Although the reasons for localized declines in catch rates are unclear, they could be related to a combination of fishing down the exploitable population and local declines in recruitment, a situation that is bound to worsen if the quantity of discards mishandled in a season increases with an increase in fishing effort. On a broader regional scale, in 1999 and 2000, the DFO fall biomass indices of immediate pre-recruits in NAFO Divisions 2J3KLMNO were about half the level estimated in 1997 and 1998 (DFO 2001). Again, the reason for this apparent decline is unclear. It is conceivable, however, considering the levels of discard mortality demonstrated in this study, that the low pre-recruit biomass estimates were in part at least related to mortality caused by mishandling discarded crab.

Fisheries in the North Atlantic Ocean are inherently rough and physically demanding, requiring varying levels of rough handling of both the capture gear and the catch throughout the course of a day. Newfoundland and Labrador's snow crab fishery is no exception. In addition to injuries and dehydration caused by dropping and prolonged air exposure, the cumulative effects of rough handling of the gear and catch during the capture, sorting, and discard process is also likely to cause injury and weaken crab. In the present study, measures were taken to avoid striking or dragging a trap when it was hauled on board, and crab were handled in a more consistent and careful manner than would normally occur during high volume oriented commercial operations. Further, crab were not thrown overboard or dumped from a tote pan during the discard process, but were gently lowered into the water. Thus, the total mortalities obtained in this study are considered to be conservative estimates of the mortalities that may be expected to occur when crab are dropped onto hard surfaces and held out of the water for prolonged periods of time during commercial crab harvesting operations.

It has been suggested that shrimp trawling on snow crab grounds may negatively impact the snow crab resource in the Newfoundland and Labrador region. Damage to crab in the form of limb autotomy when they are struck by the footgear or doors of a shrimp trawl are the greatest concern expressed by snow crab harvesters. The current study was conducted in Conception Bay, Newfoundland, where shrimp trawling does not occur, yet 59% of the undersized and high graded crab examined were missing at least one limb when they were taken on board. In the present study limbs were autotomized at all drop heights tested, and limb autotomy increased with the height of the drop. These findings have been corroborated by a laboratory study, which also demonstrated that limb autotomy was positively related to drop height (Grant et al. 2002). Overall, the high incidence of limb autotomy in undersized and high graded snow crab observed in Conception Bay in the absence of shrimp trawling, combined with evidence that limb autotomy is related to drop height onto hard surfaces, suggests that mishandling in the snow crab trap fishery may be a considerable factor contributing to harvester observations of limb autotomy where shrimp trawling occurs on or adjacent to crab grounds. It is also notable that a recent study on the impact of shrimp trawling on snow crab fishing grounds did not detect any negative effects on the snow crab resource in the form of limb autotomy (FDP 2002b).

Previous studies conducted in the Newfoundland and Labrador region have also documented drop and air exposure related mortalities of snow crab. Handling experiments revealed that mortality of legal-sized crab increases with tote pan drop height (zero, two, and four feet) and stowage time (six to 72 h) (Trenholm and Norsworthy 1999). Miller (1977) investigated the effect of air exposure duration on discard mortality of undersized hard- and soft-shelled snow crab. Miller's (1977) studies showed mortalities of 11% and 30% in hard-shelled crab and 20% and 64% in soft-shelled crab when both shell types were held out of the water for three and 35 min, respectively. The study was conducted at sea on an unsheltered work deck during August at air temperatures of 16-19°C. Mortality was assessed after crab were placed on the ocean floor at water temperatures of -1.2°C for one to two days. Miller (1977) did not drop these crab, yet mortalities among hard-shelled crab were similar to those obtained in the current study when crab were dropped from two feet and held out of the water for 5 ± 3 min (10% mortality) and 60 ± 3 min (29% mortality). Overall, Miller's (1977) work indicates that when undersized crab are held out of the water on an unsheltered deck, the negative effect on survival can be just as severe as the combined effects of dropping and air exposure in the vessel hold demonstrated in this study.

More recently, a laboratory experiment demonstrated that drop height alone has a significant negative effect on survival of undersized and high graded snow crab (Grant et al. 2002). In the laboratory, groups of ten snow crab were dropped onto a hard surface from two, four, six, and eight feet and quickly placed in submerged four compartment cages similar to those used in the current study. Each treatment was replicated and mortality was assessed at regular time intervals over a 28 day period. The highest total mortality was observed in the eight-foot drop treatment (80%), followed in descending order by the six- (30%), four- (20%), and two-foot (3.3%) drop treatments (Grant et al. 2002). The current findings, that mortality increases with height of the drop, corroborate the laboratory study. In the current study, crab that were subjected to drop heights of four and six feet and the lowest air exposure (5 ± 3 min) exhibited mortalities that were only marginally higher than those observed in the laboratory, while mortalities among crab that were dropped from two feet were three times higher. Higher mortalities in the current study are attributed to cumulative stress associated with harvesting.

Mishandling has recently been suspected to be an important factor contributing to prerecruit and high grade mortality in Newfoundland and Labrador's snow crab fishery because both increased quotas and the number of harvesters entering this fishery in recent years has resulted in widespread discarding of tonnes of crab every year. Although handling practices have reportedly improved in recent years (DFO 2001), many harvesters continue to mishandle snow crab discards because of a lack of sound evidence to warrant otherwise. Overall, the results presented in the current study have strong implications with regard to recruitment and the long-term conservation of the snow crab resource. Specifically, the exploitable biomass of snow crab is recruitment dependent

(DFO 2001), and if harvesters and managers are to maximize recruitment to the fishery there is an urgent need to eliminate dropping and, at the very least, minimize the amount of time discards are held out of water to no more than 5 ± 3 min

The most recent effort to reduce dropping and air exposure duration in Newfoundland and Labrador's snow crab fishery was the introduction of raised sorting tables equipped with discard chutes (FDP 2002a; c). When the catch is emptied onto a raised table the drop height is reduced or eliminated and discards may be quickly returned to the ocean. In the current study, there were no mortalities in the control treatments, which suggests in principle that raised sorting tables and discard chutes could substantially reduce the mortality of discarded crab. However, there are several additional factors that could negatively influence the survival of snow crab once they are removed from the ocean floor.

In the current study, each of the environmental parameters monitored fluctuated within a relatively narrow range of the extremes that discarded crab may be expected to experience in the Newfoundland and Labrador region. Snow crab are harvested from April to the end of August, and ocean and air temperature extremes considerably greater than those experienced by crab in this study may not only increase mortality of crab that are mishandled, but may also cause mortalities in crab that are quickly returned to the ocean (e.g., Miller 1977). Repeat captures throughout a season have been shown to negatively influence survival in Dungeness crab (*Cancer magister*), and repeat captures in the same season have been documented for snow crab (Taylor et al. 1989). The Dungeness crab study demonstrated that mortality is directly related to the number of times crab are captured, handled, and dropped back into the water (Kruse et al. 1994) and it was suggested that thermal shock caused by periodically hauling snow crab to the surface contributed to high mortalities in the Newfoundland and Labrador region (DFO 1995). When undersized snow crab are removed from the water for a short period of time on a hot sunny day, the risk of dehydration is intensified, particularly in soft-shelled crab (Miller 1977; Dufour et al. 1997) and studies also indicate that exposure to sunlight causes eye damage in large bottom-dwelling decapod crustaceans (Meyer-Rochow and Tiang 1981; Gaten 1988; Gaten et al. 1990).

Exposure to sunlight was shown to cause a loss of visual sensitivity in two decapod species, the Norwegian lobster, *Nephrops norvegicus*, (Gaten 1988; Gaten et al. 1990) and western rock lobster, *Panulirus cygnus* (Meyer-Rochow and Tiang 1981). Exposure to one h of sunlight proved to be detrimental to the survival of western rock lobster captured in shallow coastal waters. It caused an inability to see predators, accurate detection of diurnal rhythms was lost, and lobsters with impaired vision were less successful finding shelter (Meyer-Rochow and Tiang 1981). Gaten et al. (1990) demonstrated that the level of eye damage in the Norwegian lobster was highest in individuals from deeper waters. Thus, it is conceivable that snow crab, that reside in much deeper and darker waters than the western rock lobster, may exhibit similar negative responses at even shorter sunlight exposure times. In the current study, snow crab were held in cages that eliminated the threat of predation from large predators that may have otherwise had an impact on survivorship, even in the control treatments, if exposure to sunlight had reduced the ability of discarded crab to detect predators and find shelter.

The current study dealt exclusively with hard-shelled snow crab. However, at-sea studies on the effect of carapace hardness indicate that discard mortality in soft-shelled snow crab may be six times higher (14.3%) than hard-shelled crab (2.2%) in early spring and mortality of soft-shelled crab increased to 88.5% during the summer months (Dufour et al. 1997). Soft-shelled crab have a higher volume of water to be lost to dehydration, and many of these crab are already in a weakened state, the level of which will depend on the period of time elapsed since the molt. In Atlantic Canada, snow crab within the size range used in this study generally molt between April and June, and it may take two to four months for the shell to harden (Dufour et al. 1997). In the Newfoundland and Labrador region, where the commercial fishery encompasses the molt cycle, soft-shelled crab are protected by area closures based on observer programs and reports from harvesters. However, observer coverage is low relative to the number of vessels participating in this fishery, and harvesters are primarily concerned with establishing the incidence of soft-shell in legal-sized crab. Overall, the likelihood of underestimating the incidence of soft-shell in undersized crab discarded in the commercial fishery may be high. This could be a serious concern on fishing grounds where large quantities of undersized crab are captured.

Several gear selectivity devices have been tested in Atlantic Canada's crab fisheries (Chiasson et al. 1993; Hearn and Foster 1998; Hebert et al. 2001). Crab traps may be made more selective by increasing the mesh size (Sinoda et al. 1987) or by attaching barriers that reduce the catch of soft-shelled crab (Chiasson et al. 1993; Hearn and Foster 1998; Hebert et al. 2001) and anecdotal evidence suggests that increasing gear soak time also reduces the catch of smaller crab (Hebert et al. 2001). Currently, the minimum legal stretched mesh size is 135 mm in Newfoundland and Labrador's snow crab fishery. However, some harvesters in the region reduce the time spent sorting and culling small crab by using larger mesh sizes and snow crab studies in the Japan Sea have demonstrated that smaller crab can be protected from the fishery by switching to a larger mesh size (Sinoda et al. 1987). Studies in the Gulf of St. Lawrence have demonstrated that conical crab traps can be modified to be more size selective, capturing significantly fewer undersized and soft-shelled crab without significantly reducing the catch of legal-sized crab (Hebert et al. 2001). The traps were modified by the addition of a plastic panel that serves as a barrier to small and soft-shelled crab. Preliminary studies were conducted using a similar barrier in Newfoundland and Labrador's snow crab fishery (Hearn and Foster 1998). Although the results were promising, there was insufficient data to determine whether catches of soft-shelled and undersized crab differed significantly from catches with unmodified traps.

5.0 RECOMMENDATIONS

This study represents the most comprehensive evaluation to date of the impacts of handling on mortality of discarded snow crab in the Newfoundland and Labrador region. Based on the present findings, it is recommended that the use of recently developed on board handling systems (FDP 2002 a; c) be encouraged in the fishery. These handling systems will reduce drop and air exposure related discard mortality in hard-shelled crab, but the benefits to soft-shelled crab are unclear.

When dealing with cold-water benthic organisms that reside in deep and poorly illuminated waters, the most practical method of reducing harvesting related mortality is to avoid removing them from the ocean floor. Undersized snow crab that are hauled to the surface are subjected to many adverse factors that may weaken and injure them, causing immediate and perhaps long-term stress that may interfere with feeding and normal activities and ultimately result in death. It is strongly recommended that studies continue to determine whether crab traps can be modified to reduce the catchability of undersized and soft-shelled crab without significantly reducing the catch of legal-sized crab.

6.0 ACKNOWLEDGMENTS

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Table 1. Summary of environmental conditions during the experimental trials.

Traial	Date	Surface Water Temp. (°C)	Bottom Water Temp. (°C)	Cloud Cover (%)	Wind Speed (km/h)	Air Temp. on Deck (°C)	Relative Humidity on Deck (%)	Air Temp. in Vessel Hold (°C)	Relative Humidity in Vessel Hold (%)	Recovery Tank Water Temp. (°C)	Recovery Tank Oxygen Saturation
Trial 1	25 June	8.6	-1.0	50-100	5-10	13.5-14.4	60-67	11.9-12.2	86-87	5.8-6.5	81-84%
Trial 2	24 June	8.7	-1.0	80-100 (hazy)	10-15	12.1-13.2	51-64	10.5-11.2	83-85	5.6-6.3	79-85%
Trial 3	20 June	8.6	-1.0	100	5-10	13.8-14.1	61-62	12.0-12.1	84-85	5.8-6.4	79-85%
Trial 4	19 June	8.5	-1.0	nil (hazy)	5-10	13.9-14.3	62-66	11.5-12.0	81-86	5.8-6.2	78-84%

Table 2. Results of analysis of variance performed on the delayed mortality of snow crab in the drop (two-, four-, and six-foot) and air exposure (10-, 30-, 60-, and 120-minute) treatments. df = degrees of freedom; SS = sum of squares; MS = mean of squares. An asterisk (*) indicates a significant difference at the 5% probability level.

Source	df	SS	MS	F-value	Probability value, P
Drop	2	0.2853	0.1427	29.86	0.0001*
Air Exposure	3	0.0581	0.0194	4.05	0.0130*
Drop x air exposure	6	0.0090	0.0015	0.31	0.9256
Error	41	0.1959	0.0048		
Total	52	0.5551			

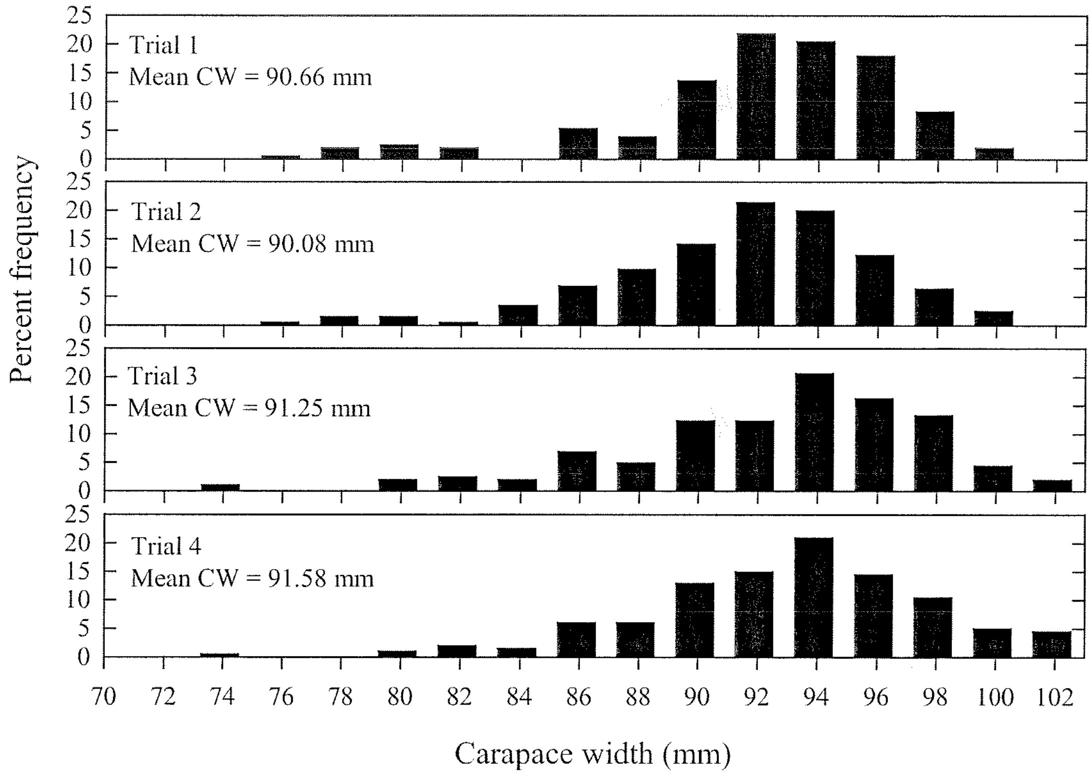

Figure 1. Snow crab carapace width frequency distribution by experimental trial.

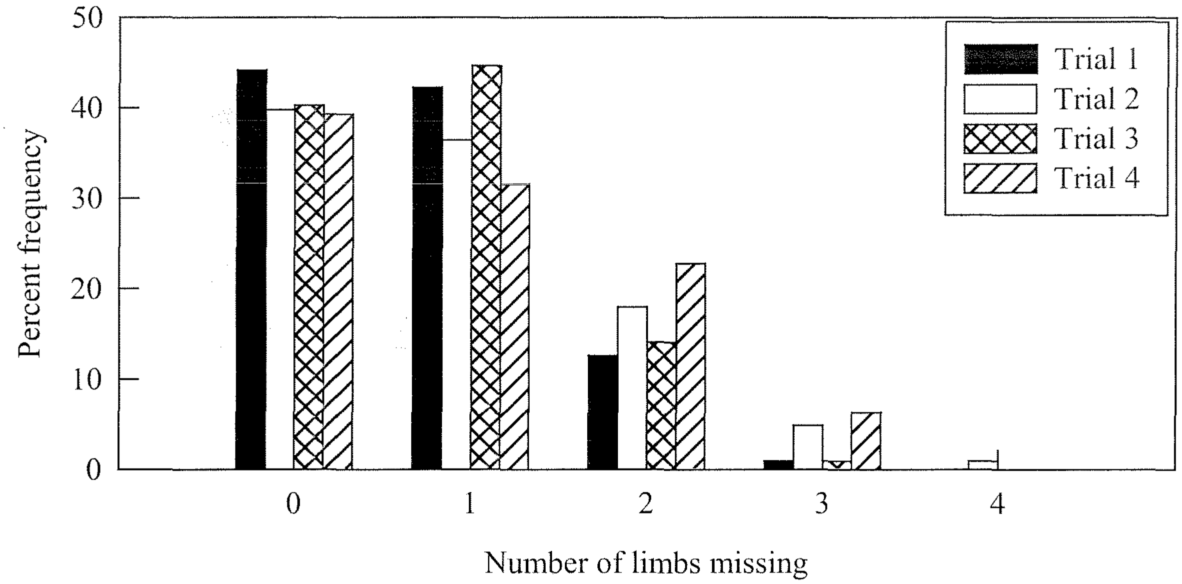

Figure 2. Pre-drop missing limb frequency distribution of snow crab by experimental trial.

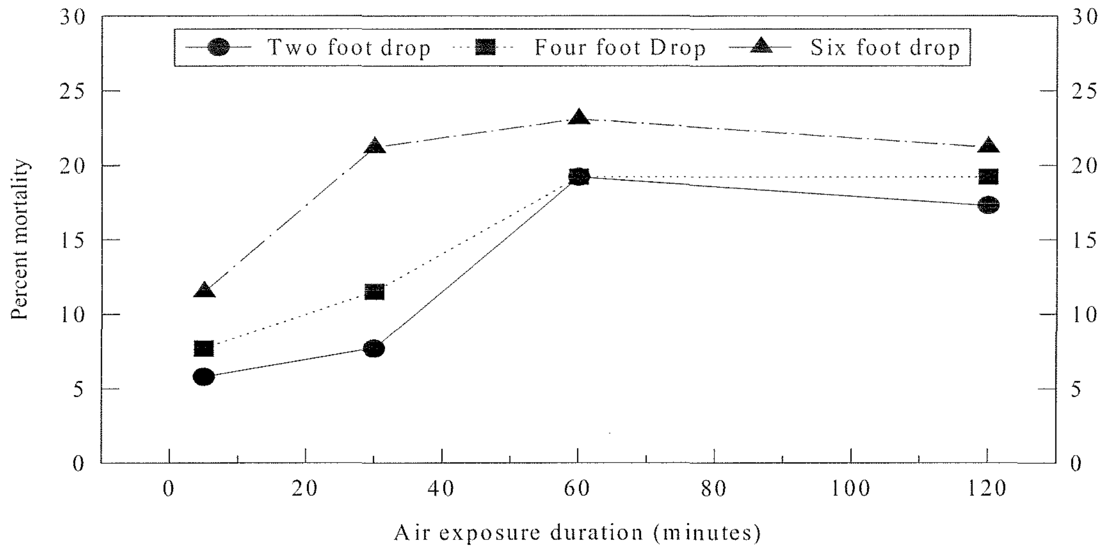

Figure. 3. Drop and air exposure related instant mortality of undersized and high graded snow crab.

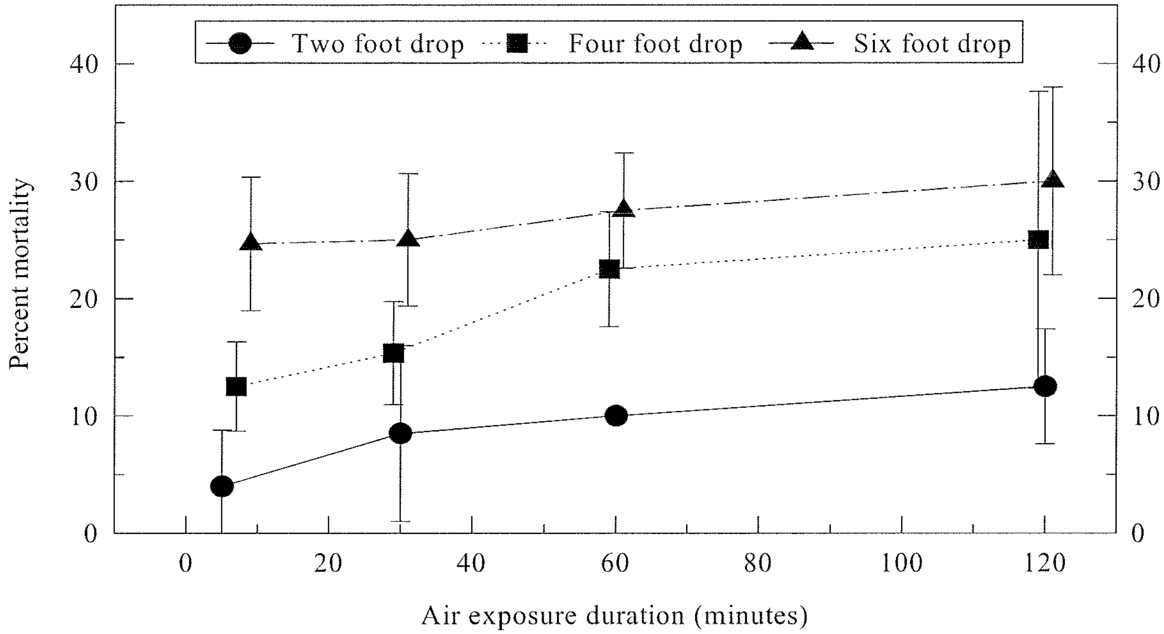

Figure 4. Drop and air exposure related delayed mortality of undersized and high graded snow crab.

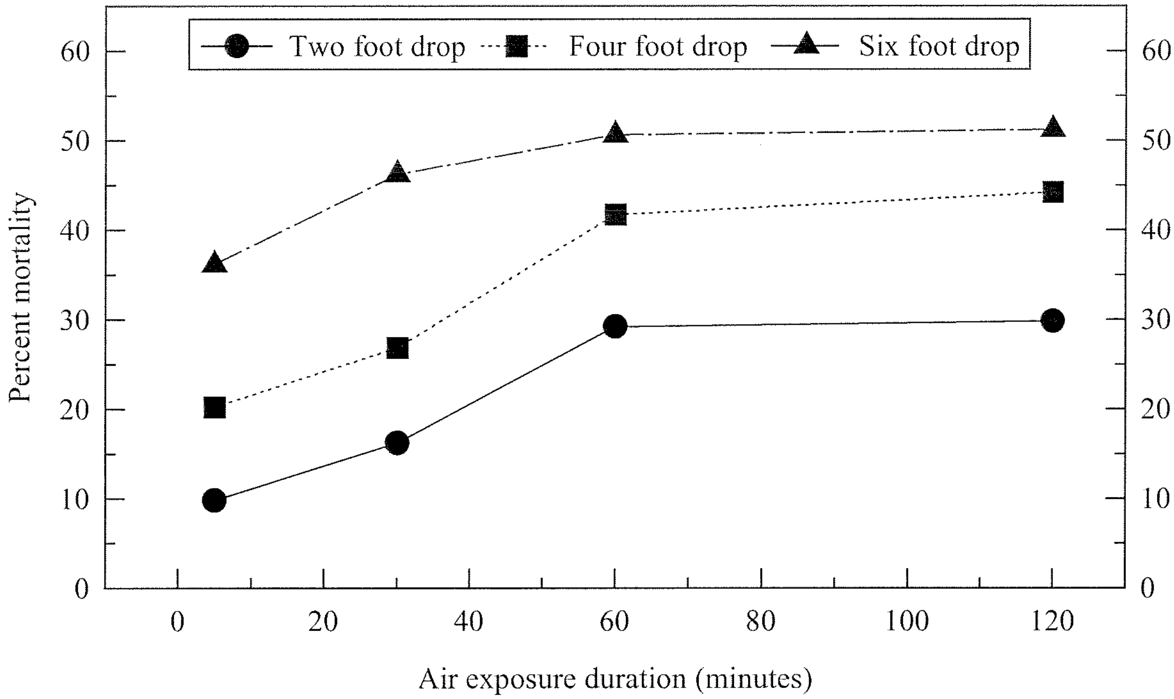

Figure 5. Drop and air exposure related total mortality of undersized and high graded snow crab.