Injury Rates of Red King Crab, *Paralithodes camtschaticus*, Passing Under Bottom-trawl Footropes

CRAIG S. ROSE

Introduction

Unobserved mortality is a significant concern as one of the incidental effects of fishing. It occurs when organisms are injured by encounters with fishing gear but are not brought to the surface with the catch. Because the injured organisms are not seen, the mortalities resulting from the injuries may not be recognized and are difficult to study and account for.

The inability to accurately estimate unaccounted mortality does not preclude its consideration in management and fishing decisions. Unfortunately, the lack of information on unaccounted mortality means that those participating in such decisions have to combine and weigh a mixture of related knowledge, opinions, and suppositions to substitute for conclusive facts. This can be a source of considerable dispute and reservations about the ultimate decisions.

Craig S. Rose is with the Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Seattle WA 98115. Mention of trade names or commercial firms in this manuscript does not imply endorsement by the National Marine Fisheries Service, NOAA.

ABSTRACT—The rate of injuries sustained by red king crab, Paralithodes camtschaticus, *during passage under several types of bottom trawl footropes was examined using a modified bottom trawl in Bristol Bay, Alaska. Crabs were recaptured and examined for injuries after passing under each of three trawl footropes representing those commonly used in the bottom trawl fisheries of the eastern Bering Sea. Using the injury rate from tows with a floated footrope which minimized crab contact to account for handling injuries, injury rates of 5, 7, and 10% were estimated for crabs passing under the three commercial trawl footropes.*

The effects of bottom trawling on the crab stocks, *Paralithodes* spp. and *Chionoecetes* spp., of the Bering Sea and Gulf of Alaska have been a significant consideration in the management of the bottom trawl fisheries of that area (Donaldson, 1990; Witherell and Pautzke, 1997). In addition to direct bycatch and habitat effects, unobserved mortality has been one of the justifications used by managers for closing large areas to bottom trawling (Armstrong et al., 1993). While bycatch mortality has been estimated and tracked, issues of habitat effects and unobserved mortality have struggled along with little objective information. A promising start on the habitat issue was made by McConnaughey et al. (In press) which detected differences in the macrofauna occupying adjacent trawled and untrawled areas of Bristol Bay.

Estimating the unobserved mortality of red king crab, *Paralithodes camtschaticus*, that encounter bottom trawls is a complex problem. The total width of a bottom trawl presents a range of different obstacles for crabs to pass over, under, or around. By far the largest portion of the area swept by most bottom trawls is covered by the sweeps (which include the bridles), which connect the trawl net to the trawl doors (Fig. 1). These usually consist of 7–12 cm diameter disks strung over cable moving across the bottom at an angle of 10–25° from the direction of travel. The leading parts (wings) of trawl nets are oriented at a greater angle and are equipped with rubber bobbins or disks from 20 to 65 cm in diameter, with smaller diameter sections of varying length in between (see footropes A, B,

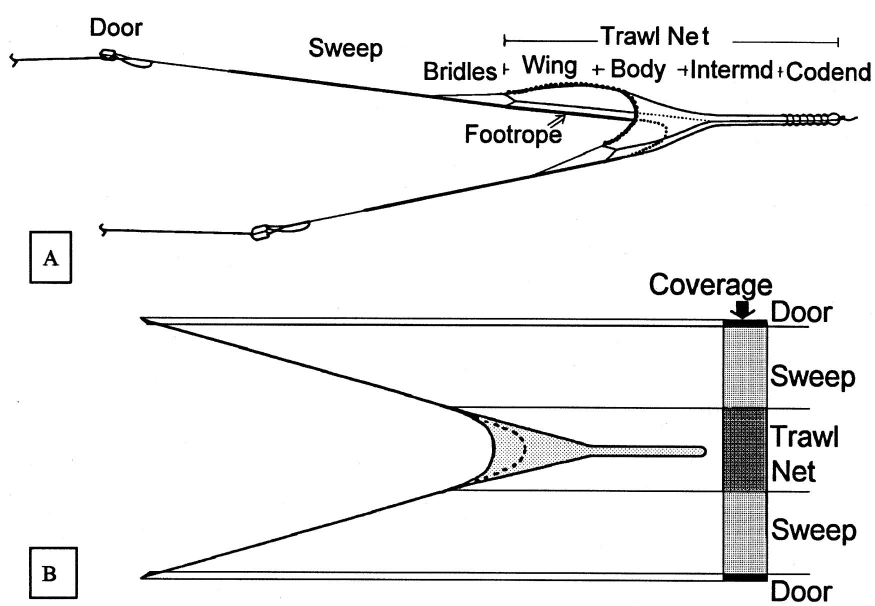

Figure 1.—Parts of a generalized bottom trawl (A) and comparison of the area of seafloor swept by the main components (B).

and C in Figure 2). The center section of the trawl footrope is perpendicular to the direction of travel and is also equipped with larger diameter bobbins or disks with spaces between. Finally, the doors cover a relatively small area of seafloor, but they would be expected to inflict the greatest injuries on crabs which pass beneath them.

Video observations of trawls (Rose, 1995; Highliners Association [1]; Rose[2]) have provided some insight into the interactions of trawls and crabs in the Bering Sea. Crabs were only able to avoid encounters for short distances until they were overtaken. While their mobility may permit avoidance of the doors, it only slightly delayed contact with the sweeps or footrope. Whether a crab passed over or under a trawl component was mostly determined by the relative size of the crab and the component encountered. Contact with the small diameter sweeps generally resulted in the crabs passing over without overt signs of damage (e.g. missing legs). As the footrope diameter increased in size, the more likely it was for a crab to go underneath it, especially if the crab was small or in close contact with the seafloor. While our observations did show crabs passing under trawl footropes, it was not possible to resolve the frequency, nature, or severity of any injuries to these crabs.

Donaldson (1990) provided the first information on the condition of red king crabs remaining on the seafloor after passage of a trawl. Crabs were tethered in the path of a trawl and recovered by divers after a trawl was towed through the area. Of the 169 crabs in the trawl path (doors, sweeps, and net), 21% were captured by the trawl, 46% were recovered by divers, and 33% could not be located. Of the 78 crabs recovered from the seafloor, only two (3%) were injured.

[1] Highliners Association. 1988. Minimization of king and Tanner crab bycatch in trawl fisheries directed at demersal groundfish in the eastern Bering Sea. Project Rep., NOAA Award 86-ABC-0042. Highliners Association, 4055 21st Ave W., Seattle, WA 98199.

[2] Rose, C. S. 1995. Behavior of Bering Sea crabs encountering trawl groundgear. Unpubl. video tape presented at N. Pac. Fish. Manage. Counc. meet. Dec. 1995. Avail. from Alaska Fisheries Science Center, NMFS, 7600 Sand Point Way N.E., Seattle, WA 98115.

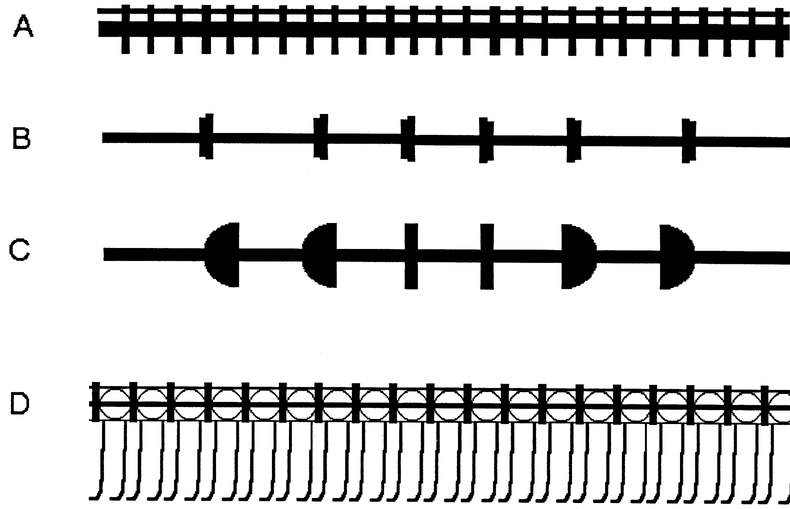

Figure 2.—Footrope configurations tested for red king crab injury rates. A = 38 cm rockhopper disks at 17 cm spacing, B = 36 cm disks at 60–90 cm spacing, C = 48 cm disks and 46 cm cones at 38–46 cm spacing, and D = float and chin suspended footrope. All spacing sections were 16 cm in diameter.

While concerns about the fate of the unrecovered crabs and the small sample size were acknowledged, this experiment provided a “preliminary estimate” of the rate of unobserved injuries.

Methods

To make direct measurements of the rates of injury to red king crabs passing under the center section of a commercial bottom trawl, a secondary trawl was suspended behind three types of commercial trawl footropes to retain the affected crabs. This allowed the rates of injury to these crabs to be directly observed. Tows with a fourth footrope, whose design allowed crabs to pass with minimal probability of damage, were used to account for injuries due to factors other than passing under the footrope.

A two-seam commercial bottom trawl (54 m headrope, 60 m footrope) was fished from the 37.5 m trawler *Columbia* in outer Bristol Bay, Alaska, in August 1996. Four ground-gear configurations were installed in the center section of the footrope (Fig. 2). Three of these configurations (A, B, and C in Figure 2) were selected to represent the range of footrope design commonly used in Bering Sea groundfish fisheries (Fig. 3). Footrope A, a series of closely spaced disks, was rigged as a rockhopper footrope. In this configuration, the netting was attached to a chain that passed through the perimeter of each disk, preventing the disks from rolling around the main chain which passed through the center of the disks. This footrope also had extra weighting in the form of eight 3.8 cm chain links positioned four in the center and two on each side 4.6 m from center. Footrope B had slightly smaller diameter disks spaced farther apart with conventional rigging (netting attached to the center chain). Footrope C used disks and bobbins about 10 cm larger in diameter than the other two configurations and spacing similar to footrope C. Construction and materials used in all footropes followed industry practice. Each configuration was towed twice in red king crab habitat (lat. 56°11'N, long. 162°00'W, 68 m depth) at 3 knots for 15–20 minutes.

A small two seam trawl (11.7 m headrope, 15.1 m footrope) was rigged to fish underneath the main trawl and behind its footrope. This trawl was secured to the main footrope at points 7 m either side of its center with double 6 m bridles. The footrope of the small net was a continuous string of 20 cm rubber disks over 13 mm steel chain. Previous observations with similar foo-

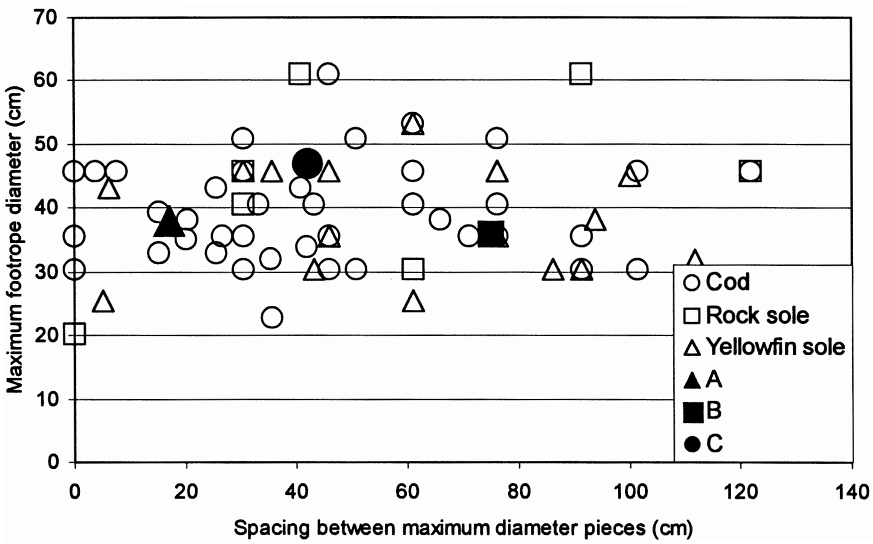

Figure 3.—Comparison of the diameter and spacing of footropes used in this study (solid shapes) with footropes used in the three largest bottom trawl fisheries of the eastern Bering Sea. Source: Unpublished 1996 survey, Craig Rose, NMFS Alaska Fisheries Science Center, Seattle, Wash.

tropes indicated that nearly all king crabs would pass over it and be retained. Thus the small net swept the seafloor just behind the center section of the main footrope and retained crabs which had passed under it.

One of the initial concerns regarding the use of the small trawl was whether crabs captured in this net could be brought aboard the trawler without causing additional damage. The process of initial capture, being towed in the small net's codend, hauled aboard the vessel, and emptied onto the deck might cause injuries that could not be differentiated from footrope injuries. Therefore, a fourth footrope, considered unlikely to cause damage to passing crabs, was used as a control to isolate handling injuries. This fourth configuration (Fig. 2D) was a design (U.S. patent number 5,517,785) provided by Sherif Safwat of Davis, Calif. The footrope section consisted of a curtain of chains dangling from a footrope which floated above the seafloor. In this arrangement, animals passing under the groundgear would displace only a few light chains and thus would experience less damaging force than would be required to pass beneath conventional groundgears. The floatation and chain weight were adjusted so that the main footrope was between 15 and 25 cm off the seafloor, with the chain curtain filling the space below it (0.5 cm diameter galvanized chains, 75 cm long, spaced 10 cm apart and nine 20 cm floats plus one 25 cm float per 2 m of footrope). Previous tests with this gear (Rose, 1995) had shown that all but 1 of 260 crabs that encountered this footrope passed beneath it.

During all tows, an underwater video camera system (Rose, 1995) was suspended above and ahead of the footropes to observe crabs and fish as they encountered each of the footrope configurations. An ultra-low-light camera was used to avoid the need for artificial illumination. A small scanning sonar was mounted with the camera to allow measurements of the gear configuration.

After each tow, all of the crabs were sorted out of the catch of the small trawl. Each crab was examined for injuries, and video images were recorded of its dorsal and ventral sides, highlighting any observed injuries. All injuries were classified and recorded during later review of the video.

Injuries were classified by their location (legs, carapace, abdomen). Because red king crabs can autotomize (drop) injured legs, crabs with a fresh autotomy were classified separately from those with other leg injuries. Healed autotomies, which occurred in 5% of the crabs, were not classified as injuries. Multiple injuries were categorized under the most serious apparent injury. Thus a crab with a shattered carapace and an autotomized leg was coded as a carapace injury.

The results of the observations were examined using two sets of statistical tests. The first examined each pair of tows with the same footrope configuration to see if the observed injury rates were significantly different. The null hypothesis was that these rates were not different between tows (Chi square test for independence: Sokal and Rohlf, 1969). Injury rates for the test configurations (pooled if the rates were tow-independent) were then compared to the control rates with the null hypothesis that the observed injury rates were not different between test and control footropes.

To estimate the injury rates associated with each footrope configuration, the observed rates needed to be adjusted for handling injuries. Injuries during test tows can be caused by either footrope passage or handling. Since the two processes are sequential, not simultaneous, the total probability of injury during test tows (P_{FH}) can be represented by:

$$P_{FH} = P_F + (1 - P_F)P_H, \qquad (1)$$

where P_F = probability of injury by the footrope and P_H = probability of injury due to handling. Because our goal was to estimate P_F and the experiment provided estimates of P_{FH} and P_H (control injury rate), this equation was rewritten as:

$$P_F = \frac{P_{FH} - P_H}{(1 - P_H)}, \qquad (2)$$

providing estimators of footrope injury rates.

In using the control injury rate as an estimate of handling injuries, I assumed that injuries due to the control footrope were negligible relative to those from initial capture, being towed in the small net's codend, hauled aboard the vessel, and emptied onto the deck. While this assumption is believed to be reasonable, considering the mechanisms of potential injury and observa-

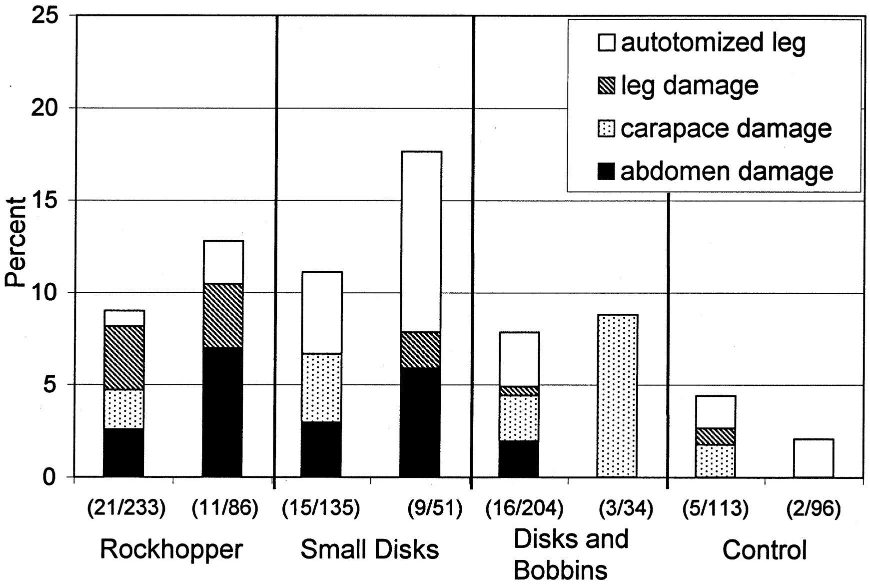

Figure 4.—Rates and locations of injuries sustained by red king crabs passing under four types of trawl footropes. Total injuries over total number of crabs observed from each tow are listed in parentheses.

Table 1.—Statistical tests and estimates of injury rates for red king crabs passing under trawl footropes.

Test	Chi squared	Significance (p value)	Adjusted injury rate (P_F)
Between tows			
Rockhopper (A)	0.99	0.32	
Small disks (B)	1.41	0.24	
Large disks (C)	0.04	0.85	
Control (D)	0.88	0.35	
Control vs. test			
Rockhopper (A)	8.24	0.0004	7%
Small disks (B)	12.42	0.0004	10%
Large disks (C)	4.36	0.037	5%
Between footropes			
A vs. B	0.98	0.32	
A vs. C	0.69	0.41	
B vs. C	2.77	0.10	

tions of crab passing under the control footrope, there was no direct evidence to confirm it.

Results

The eight experimental tows were completed on 8 and 9 August 1996, capturing a total of 870 red king crab. Underwater video showed that the footropes were in contact with the seafloor throughout the tows and that the small trawl contacted and left the seafloor within 10 sec of the main footrope. Therefore, it is almost certain that all crabs in the small trawl had encountered the main trawl's footrope while it was on the seafloor. Sonar detected the small trawl's footrope approximately 6 m behind the center of the main footrope. The control footrope (Fig. 2D) fished with the bottom of the disks approximately 20 cm above the seafloor.

The number of crabs in each tow varied from 34 to 233, and from 82 to 98% of these crabs had no apparent injuries (Fig. 4). No significant differences in the frequency of injuries were detected between any of the pairs of tows with the same footropes (Table 1); therefore observations were pooled for the remainder of the analyses. Tows with the control footrope resulted in low injury rates (3.35%), indicating that handling was not a large source of injuries. Each of the test footropes did have significantly higher injury rates than the control gear. When pooled and adjusted (Equation (2)) for handling injuries, injury rates ascribed to passing under the test footropes were 7, 10 and 5% for the rockhopper, small disk, and large disk footropes, respectively. None of the differences between injury rates from the test footropes were statistically significant.

Discussion

Red king crabs passed under the center sections of full-scale groundfish trawl footropes with relatively low rates of apparent injuries. These rates were slightly larger, but of similar magnitude to the 3% preliminary estimate of Donaldson (1990). There were many differences between these studies that could be related to this small disparity. One notable difference was that the current study focused on the center section of the trawl, while most of the Donaldson (1990) crabs would have been in the paths of the sweeps where injuries may be less likely.

These injury rates do not directly provide an estimate of mortality rates, except perhaps as an upper limit on mortality. No tests were done to determine how much mortality would occur as a result of the observed injuries. Many of these injuries were survivable, particularly the leg autotomies, as evidenced by the 5% of the crabs noted with healed autotomies. In a study of king crabs caught in bottom trawls, Stevens (1990) found that leg and body injuries increased the likelihood of death by 29 and 41%, respectively, while evidence of recent autotomy was not significantly associated with an increased likelihood of death. Those mortalities occurred with the additional stress of holding in an onboard bin with the fish catch for 0.8 to 12.5 hours. While the direct effects of the holding were accounted for in the analysis, any interaction of injury and holding stresses would have increased the mortality rates. It is considered likely that crabs would be better able to cope with most injuries in their normal environment, as would be the case with crabs passing under a footrope. An exception would be increased vulnerability to predators for severely disabled crabs.

The tested footropes were representative of much of the range of gear used in Bering Sea bottom trawl fisheries. Based on video observations of crab-ground-gear interactions (Rose[2]), Footrope C would have the lowest likelihood of causing damage to crabs because the spaces between footrope elements were both wide and tall. Footrope A was expected to have the highest injury rates due to narrow spaces between elements, low diameter, and the additional weighting. The order of the actual injury rate estimates (no statistical difference detected) only partially followed these expectations, with C being lowest, but B being higher than A.

The floated footrope was shown to have an even lower injury rate than these others. Many of these injuries, if not all, could have been due to handling. Combined with its demonstrated ability to keep crabs out of the catch (Rose, 1995), this footrope design may be a useful tool for fisheries where avoiding effects on crabs is crucial. However, if the target species do not rise off bottom during a trawl encounter, as would be the case with many flatfish, the loss of target catch could be too great to allow effective fishing.

It is important to note that these results only represent the center area of the footrope where the gear is almost perpendicular to the direction of motion. Different forces would be experienced by crabs passing over the sweeps or under the wing sections of a footrope, and thus different types and rates of injuries could occur. These results would also not reflect encounters with parts of the gear aft of the footrope. While mesh behind the footrope is generally off the seafloor, a large catch of negatively buoyant fish (such as flatfish) could cause the codend to drag on the seafloor, which could impact crabs which had passed under the footrope.

While this study does not directly address habitat impacts of bottom trawls, it does shed some light on the type and frequency of forces exerted on organisms passing under trawl footropes. Forces sufficient to crack a crab carapace were more the exception than the rule in this study. A common misconception of such forces is evident in a paper by Watling and Norse (1998) who describe footropes weighing thousands of pounds as the instruments of habitat destruction. This obviously ignores the effects of displacement, which dramatically reduces the effective weight of such gear in water. The remaining forces are also distributed across the considerable surface area and length of trawl footropes, leaving a much lighter seafloor contact than would be visualized by experiencing such gear out of the water. Observations made during the Donaldson (1990) study provided an interesting illustration of this difference. As a way of detecting the actual path of the trawl, chicken eggs were placed at regular intervals across the path of the trawl on a firm sand seafloor. Many of the eggs were moved several meters by the trawl and were still recovered intact.

This study is by no means definitive and should be extended in a number of ways. Increased sample sizes might permit the effects of different gear configurations to be differentiated. The connection of the observed injuries to mortalities should also be explored. A full understanding of unobserved crab mortalities will also require similar studies on the other major trawl components that contact the seafloor.

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