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Experimental Effects of Soak Time on Catch of Legal-Sized and Nonlegal Red King Crabs by Commercial King Crab Pots

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ABSTRACT: An experiment was conducted in Bristol Bay, Alaska, to assess the effects of soak time on catch per pot of legal (males ≥165 mm carapace width) and nonlegal (females and sublegal-sized males) red king crabs *Paralithodes camtschaticus*. Soak times of 12, 24, and 72 h were tested because they cover the typical range of soak times in the Bristol Bay commercial fishery. Catch per pot increased with each increase of soak time for both legal and nonlegal red king crabs, but catch per pot per soak-hour decreased with increasing soak time. Additionally, the ratio of nonlegal red king crabs to legal red king crabs decreased with increased soak time, although local conditions were also shown to have a significant effect on bycatch rates of nonlegal crabs.

INTRODUCTION

Effective management of commercial crab fisheries requires an understanding of the influence of pot soak time (the time between the setting and retrieval of a fished pot) on catch per pot. The effects of soak time on the catch rates of red king crabs *Paralithodes camtschaticus* in the Bristol Bay, Alaska, commercial fishery has become of particular interest to the Alaska Department of Fish and Game (ADF&G). Fisher response to 2 regulatory changes in the Bristol Bay fishery since 1996 could lead to reduced soak times. The first was the 1996 establishment of a new harvest strategy for the Bristol Bay fishery that effectively halved guideline harvest levels and the expected season length. Interviews with fishers and data from onboard observers indicated that average soak times decreased from nearly 2 d in the 4 preceding fishing seasons to 1 d in the 1996 season (D. Tracy, unpublished data). Then in 1997 previous pot limits (the maximum allowable number of pots fished per vessel) were halved. Many commercial fishers and industry representatives predicted that the lower pot limits would lead to further soak-time reductions in the Bristol Bay fishery.

Managers of the Bristol Bay red king crab fishery need to understand the influence of soak time on catch per pot of both legal (males ≥165 mm in carapace width [CW]) and nonlegal (females and sublegal-sized males) red king crabs to interpret inseason catch data and judge the effectiveness of pot-limit regulations in meeting management objectives. Many fishers believe that reduced soak times increase the incidental catch or bycatch (fish or shellfish that are not retained for sale or use) of nonlegal red king crabs, which could thereby reduce the long-term productivity of the fishery. By regulation, captured nonlegal crabs must be returned immediately to the sea. A laboratory study simulating the handling of discarded red king crabs in the commercial fishery (Zhou and Shirley 1995) indicated that normal handling produces minimal effects. Nonetheless, some fishers and fishery regulators remain concerned that nonlegal crabs captured and discarded during the commercial fishery may sustain lethal or significant sublethal damage due to cold air exposure (Carls and O'Clair 1990), wind chill, decompression, or dislocation. Moreover, under the Magnuson–Stevens Fishery Conservation and Management Act of 1996, minimization of bycatch is a national standard for development of conservation and management measures for fisheries that are managed under a federal fishery management plan, such as the Bristol Bay red king crab fishery.

Although a variety of mathematical models describe catch per pot of crustaceans as a function of soak time (e.g., Miller 1990; Zhou and Shirley 1997a), we found no controlled experimental studies describing the de-

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pendence of red king crab catch on soak time under current Bristol Bay fishery conditions. Laboratory observations on response of red king crab catch to soak time (Zhou 1996; Zhou and Shirely 1997a) may not directly apply to actual fishery conditions. The only 2 field studies addressing this were conducted near Kodiak, Alaska (High and Worlund 1979; Johnson 1985), and their results have questionable application to the current Bristol Bay conditions because of differences in the gear used, a lack of distinction between legal and nonlegal crabs, and (in the case of Johnson 1985) extremely low density of red king crabs in the study area. Catch as a function of soak time in the red king crab commercial fishery has been estimated for the Kodiak area fishery from logbook data (Rothschild et al. 1970) and could be estimated for the current Bristol Bay fishery. However, because commercial fishers can adjust soak time in response to catch, observational studies using data from commercial fisheries may provide erroneous conclusions on the dependency of catch on soak time (Miller 1990). Using the current standard gear for the commercial fishery, we conducted an experimental study in Bristol Bay to estimate and compare legal and nonlegal red king crab catch per pot at soak times relevant to the current fishery.

METHODS

Study Design and Field Methods

The study was conducted by ADF&G staff from a chartered commercial fishing vessel during 13–19 August 1997 in the traditional commercial fishing grounds of Bristol Bay. The study area was confined to a 12-km by 10-km area centered at 56° 38' N latitude, 161° 37' W longitude. We selected the study area based on exploratory fishing during 3–12 August 1997 that provided catch per pot of legal and nonlegal red king crabs comparable to that encountered during recent commercial fisheries (Tracy 1995). Depths in the study area ranged from 82 to 90 m.

The rectangular king crab pots used in this study measured 2.1 m × 2.1 m × 86 cm and were typical of those used in the commercial fishery. Vertical panels of each pot were fit with 10-cm stretched mesh webbing, except that the lower one-third of one side panel was 23-cm stretched mesh. The 23-cm stretched mesh is required by regulation for commercial king crab pots and is intended to promote escape of captured females and sublegal males. A 20-cm by 91-cm rigid horizontal tunnel opening was fit on each of 2 opposing sides of each pot. Each pot was baited with 1.9 L of chopped, frozen herring.

We used a randomized complete block experimental design (Montgomery 1984). Each block consisted of 36 pots set in a 6×6 square grid and spaced 0.62 km apart. One block of 36 pots was set in a different location on each day for 4 consecutive days to provide a total of 4 uniquely located blocks. Thus, the 4 blocks in this study design confounded the effect of location with the temporal effect of day and time set. Starting time for setting of pots within a block ranged from 1205 hours to 1625 hours (Alaska Daylight Time), and the time required to set a block of 36 pots ranged from 1.6 to 2.1 h.

The treatments for this study were 3 target soak times: 12, 24, and 72 h. The target soak times were chosen on the basis of postseason interviews with vessel skippers following the 1990–1996 Bristol Bay red king crab commercial seasons (D. Tracy, unpublished data). Those interviews indicated a 24-h soak time was average for the 1996 season and that 12 h and 72 h should bracket the average soak times expected for future seasons. Within each block we randomly chose 12 pots for each target soak time. Actual soak time averages for each block were within 0.5 h of the 12-h and 24-h targets and within 2.7 h of the 72-h target; actual soak times for individual pots were within 1.7 h of the 12-h target, within 2.0 h of the 24-h target, and within 5.6 h of the 72-h target.

We recorded species composition of the catch of each pot and for each red king crab the sex, shell age, and carapace length (CL in mm). We also designated all male red king crabs ≥165 mm CW as "legal"; although the relationship between CW and CL is not exact, a 165-mm CW male has an expected CL of 137 mm (Tracy 1998).

Data Analyses

Because only 3 soak times were examined in this study, we did not fit the observed catch per pot to any of the existing models that describe catch as a function of soak time (e.g., Miller 1990; Zhou and Shirley 1997a). Instead, our approach was to test observed differences in catch per pot for different soak times using analysis of variance (ANOVA) and post-hoc comparisons.

We transformed the catch of legal and of nonlegal red king crabs in each pot prior to analysis by adding 1 to the catch and then taking the natural logarithm of that sum. Log-transformation of the catch per pot served to normalize that data and stabilize its variance across treatments and blocks. We added 1 to the catch per pot prior to log-transformation so that the few pots with zero catch of either legal or nonlegal red king crabs could be included in the analyses. The log-transformed catch data were modeled as

$$y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk},$$

where

y_{ijk} = log-transformed catch of legal or nonlegal red king crabs for soak-time target i (i =1,2, 3), block j (j =1,2,3,4), pot k (k =1,2,...,12),

μ = the overall mean of the log-transformed catch of legal or nonlegal red king crabs,

α_i = the effect due to soak-time target i,

β_j = the effect due to block j,

$\alpha\beta_{ij}$ = the effect due to interaction between soak-time targets and blocks, and

ε_{ijk} = random error.

We used ANOVA to test the 2 null hypotheses:

H_{01} — means of the log-transformed catch of legal red king crabs do not differ among the 3 target soak times; and

H_{02} — means of the log-transformed catch of nonlegal red king crabs do not differ among the 3 target soak times.

Dependent upon statistical significance ($\alpha = 0.05$) of the soak-time effect, differences between pairs of mean catches for the soak times were assessed for statistical significance using Fisher's least significant difference (LSD) procedure (Milliken and Johnson 1984).

We also assessed the statistical significance of the effect of soak time on the nonlegal:legal ratio of catch per pot by applying the above ANOVA model to

$$r_{ijk} = \ln[(n_{ijk}+1)/(l_{ijk}+1)],$$

where n_{ijk} and l_{ijk} are, respectively, the catches of nonlegal and of legal red king crabs for soak-time target i (i=1,2, 3), block j (j=1,2,3,4), pot k (k=1,2,...,12).

RESULTS

The 144 pot lifts performed during this study produced a catch of 1,987 legal male, 3,159 sublegal male, and 173 female red king crabs, as well as an incidental catch of 220 Tanner crabs *Chionoecetes bairdi*, 1 snow crab *C. opilio*, and 1 Tanner crab x snow crab hybrid. Because of the low number of females captured, female and sublegal male red king crabs were grouped together as nonlegal red king crabs for our analysis.

Catch of nonlegal red king crabs exceeded that of legal crabs for each of the 3 soak times, and catch per pot tended to increase with soak time for both legal and nonlegal red king crabs (Table 1; Figure 1A,B). For both legal and nonlegal crabs, catch per pot differed more between the 24-h and 72-h soak times than for between the 12-h and 24-h soak times. Although catch of both nonlegal and legal crabs tended to increase with increases in soak time, the catch of legal crabs had the greatest response to soak-time increases. The greater responsiveness of legal crab catch to increases in soak time was most apparent in the medians of catch per pot for soak times. Median catch of legal crabs for the 72-h soak time (22.0) was more than 3 times greater than that for the 12-h soak time (7.0). The difference between the median catch of nonlegal crabs for 12-h and 72-h soak times was slight by comparison: 17.0 for the 12-h soak and 22.5 for the 72-h soak.

The greatest disparity between the catch of legal crabs and nonlegal crabs occurred in the 12-h soak, whereas the least disparity occurred in the 72-h soak (Table 1). The ratio of the mean nonlegal catch per pot to that for legal crabs decreased from 2.4:1.0 for the 12-h soak to 2.0:1.0 and 1.3:1.0 for the 24-h and 72-h soaks, respectively. Likewise, whereas the median catch of legal crabs per pot for the 72-h soak was nearly identical to that for nonlegal crabs, for the 12-h soak the median catch of nonlegal crabs was 2.4 times greater than that for legal males.

The above trends were confirmed by ANOVA. ANOVA of the log-transformed catch per pot of legal red king crabs was significant for the soak-time effect ($F_{2,132} = 41.53, P < 0.001$) and for blocks ($F_{3,132} = 4.14$, $P = 0.008$), but not for the interaction term ($F_{6,132} = 1.48$, $P = 0.191$). All pairwise comparisons (Fisher's LSD procedure) of soak times, with respect to catch of legal crabs, were significant ($P < 0.05$). Soak time and blocks were also significant effects ($F_{2,132} = 3.22$, $P = 0.043$ and $F_{3,132} = 6.73, P < 0.001$, respectively) for the log-transformed catch of nonlegal red king crabs. There was some indication of interaction between soak times and blocks in the catch of nonlegal crabs. Although the interaction term was not judged statistically significant, it was nearly so ($F_{6,132} = 2.07$, $P = 0.061$), and one block (Block 2) was unique in having the lowest catch

per pot of nonlegal crabs in the 24-h soak (Figure 1B). With respect to the catch of nonlegal crabs, only the differences between the 12-h and 72-h soaks were significant ($P < 0.05$) by Fisher's LSD procedure.

ANOVA of the log-transformed nonlegal:legal ratio of catch per pot was significant for the soak-time effect ($F_{2,132} = 15.76, P < 0.001$) and for blocks ($F_{3,132} = 14.04, P < 0.001$). Interpretation of those results, however, was somewhat complicated by the significance of the interaction term ($F_{6,132} = 2.62$, $P = 0.020$). The significance of the interaction term was apparently due to inconsistencies across blocks in the nonlegal:legal ratio for the 24-h soak relative to those for the 12-h and 72-h soaks. The ratio for the 12-h soak was higher than for the 72-h soak in each block (Figure 1C). In 2 blocks the ratio at the 24-h soak was nearly as low as at the 72-h soak and was markedly lower than that for the 12-h soak. In the other 2 blocks, however, the ratio

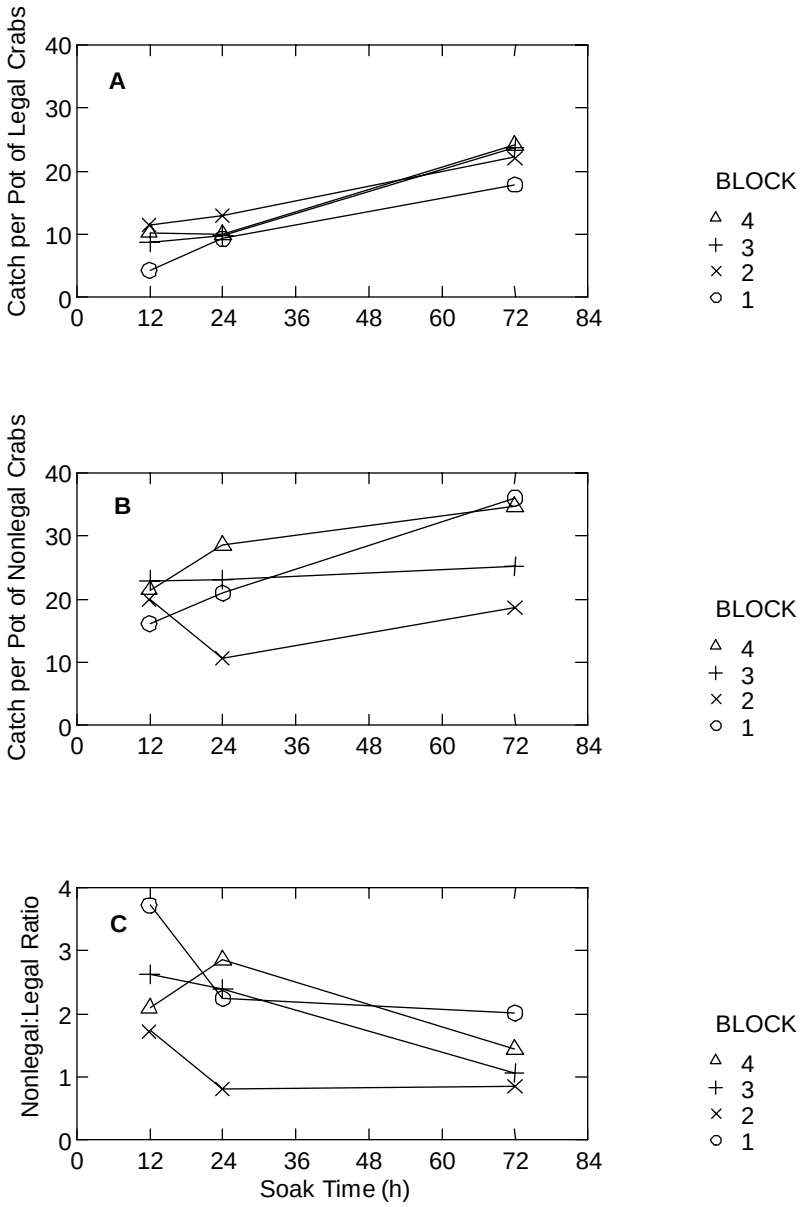

Figure 1. Effects of soak time on catch per pot of legal (males ≥165 mm in carapace width) and nonlegal (females and sublegal-sized males) red king crabs by study block in Bristol Bay, Alaska: (A) catch per pot of legal crabs by block; (B) catch per pot of nonlegal crabs by block; and (C) nonlegal:legal ratio in catch by block.

Table 1. Catch per pot of legal (males ≥165 mm in carapace width) and nonlegal (females and sublegal-sized males) red king crabs by target soak time, Bristol Bay, Alaska.

Soak time	Statistic[a]	Legal	Nonlegal	Ratio[b]
12 h	Mean	8.7	20.1	2.4:1
	Median	7.0	17.0	2.4:1
	SD	6.17	13.22	
24 h	Mean	10.5	20.8	2.0:1
	Median	10.0	19.5	2.0:1
	SD	4.85	11.16	
72 h	Mean	21.9	28.6	1.3:1
	Median	22.0	22.5	1.0:1
	SD	9.57	20.72	

[a] Sample statistics computed from 48 pot lifts for each soak time.
[b] Ratio of statistic for nonlegal crabs to the statistic for legal-sized males.

Table 2. Catch per pot of male red king crabs in 48 pot lifts by size class and by target soak time, Bristol Bay, Alaska. Percentage in parentheses is the relative frequency for the size class.

	Soak time		
Size class	12 h	24 h	72 h
Sublegal ≤109 mm CL[a]	11.9 (43%)	10.6 (35%)	13.5 (28%)
Sublegal ≥110 mm CL	7.1 (26%)	9.4 (31%)	13.6 (28%)
Legal[b]	8.7 (31%)	10.5 (34%)	21.9 (45%)

[a] Carapace length
[b] Males ≥165 mm in carapace width (CW); expected CL at 165 mm CW is 137 mm.

at the 24-h soak was markedly higher than for the 72-h soak and was comparable to or exceeded that for the 12-h soak.

The size-frequency distributions for males captured during soak times of 12 h, 24 h, and 72 h (Figure 2; Table 2) reveals that decreased proportional representation of sublegal male crabs at longer soaks was most pronounced for small males (≤109 mm CL). Catch of small males was relatively stable over the 3 soak times but as a proportion of the total male catch decreased with increasing soak time. In contrast, catch per pot of prerecruits (sublegal males ≥110 mm CL) nearly doubled from 7.1 for 12-h soaks to 13.6 for 72-h soaks.

DISCUSSION

Catch per pot of crabs and lobsters has been variously modeled as (1) increasing with soak time without bounds (e.g., Austin 1977), (2) increasing with soak time to some asymptotic upper bound (e.g., Miller 1983), and (3) increasing with soak time to some maximum value and thereafter decreasing with longer soak times (e.g., Somerton and Merritt 1986; Zhou and Shirley 1997a). We did not fit the catch per pot of red king crabs in our study to any of these models because catch per pot was observed only at 12-h, 24-h, and 72-h soak times. It was clear, however, that catch of legal crabs and, to a lesser extent, nonlegal crabs increased from a 12-h soak to a 72-h soak. That finding differs from laboratory observations indicating that catch per pot of legal and sublegal red king crabs peak at soak times of 7 h and 3 h, respectively (Zhou 1996), but it is in general agreement with field studies of High and Worlund (1979). Another notable result of our study relative to anticipating the effects of soak time on catch per pot was that catch of neither legal nor nonlegal crabs responded proportionately to changes in soak time; that is, doubling the soak time from 12 h to 24 h did not double the catch per pot and tripling the soak time from 24 h to 72 h did not triple the catch per pot. Instead, the catch per pot per soak-hour decreased with increasing soak time over the range of 12 to 72 h.

Although the catch per pot of nonlegal crabs increased from a 12-h to a 72-h soak time, the bycatch rate (i.e., the ratio of nonlegal crabs to legal crabs) tended to decrease. Nonlegal crabs outnumbered legal crabs by a factor of 2.4 in pots soaked for 12 h, whereas that factor was reduced to 1.3 in the pots soaked for 72 h. Hence, our results are consistent with the predictions of some fishers that, for a given harvest of legal crabs within a given time and area, use of longer soak times will produce less catch of nonlegal red king crabs. However, such predictions do not allow for the possibility that shorter soak times may enable fishers to more effectively respond to high bycatch rates by moving their gear to other areas where bycatch is lower.

It must be recognized, however, that trends in the nonlegal: legal ratio with increasing soak times varied significantly among blocks. That result indicates that effects of soak time on bycatch rates are sensitive to local spatial or temporal conditions that can vary, even within our limited study area and period. Data from 2 of our study blocks indicated that reducing soak times from 24 to 12 h would result in no increase in bycatch rates. In the other 2 blocks, however, bycatch rates for 24-h soaks were markedly lower than for 12-h soaks

and were, in fact, comparable to the bycatch rates for 72-h soaks. Likewise, the paucity of female crabs encountered in our study is probably a reflection of the local conditions of our study area; results from the 1997 National Marine Fisheries Service eastern Bering Sea trawl survey, for example, indicate that there are 4 times as many adult-sized (≥90 mm CL) female red king crabs in Bristol Bay as there are legal males (Zheng et al. 1997).

The mechanisms influencing the observed reduction in bycatch rates with increased soak times in our study remains uncertain. The role that escapement of captured crabs may have played here is of particular interest. The current regulation requiring the lower one-

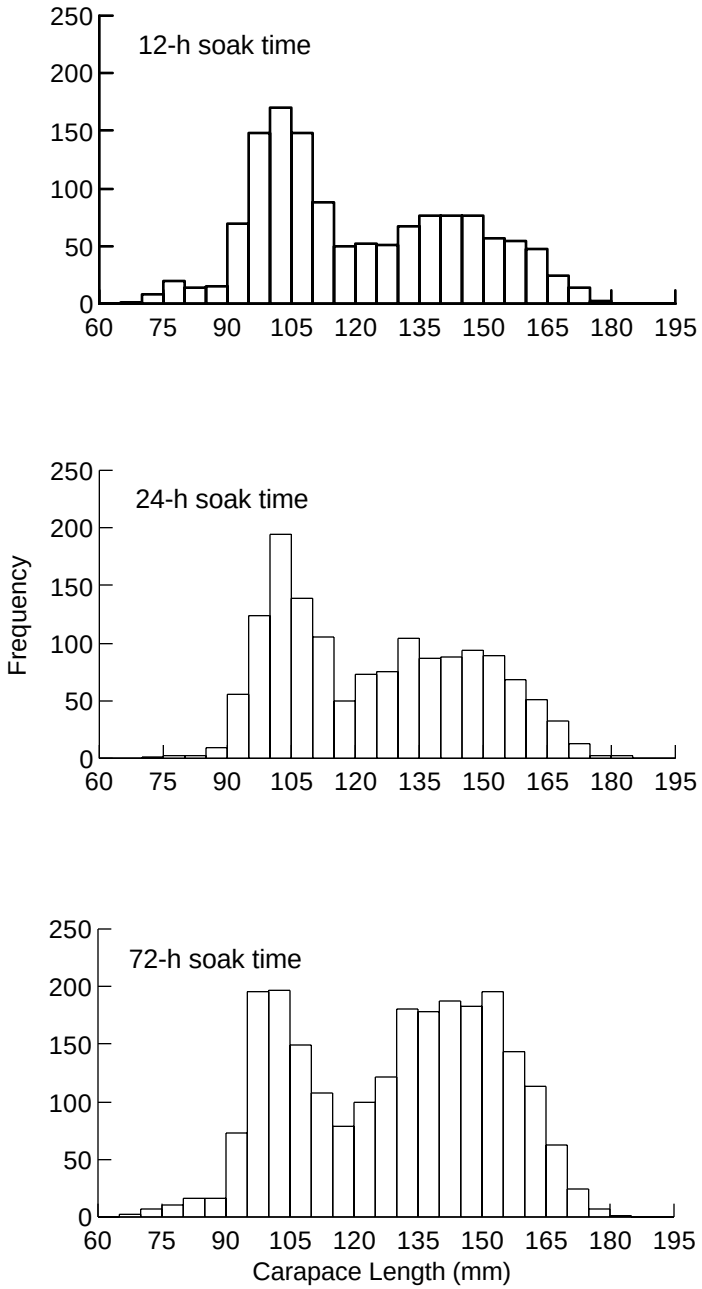

Figure 2. Size frequency distribution by soak time of male red king crabs captured during study of soak-time effects on catch per pot, Bristol Bay, Alaska.

third of one side panel of a king crab pot to be fit with 23-cm stretched mesh is intended to allow female and undersized male crabs to escape while retaining legal crabs. Because longer soak times provide greater opportunity and motivation for captured crabs to escape, the effectiveness of escape panels in lowering bycatch rates should presumably increase with increasing soak times. The relative contribution of the smaller sublegal males ≤109 mm CL to the male catch decreased with increasing soak time in our study. That observation is consistent with an assumption that longer soak times produced lower bycatch rates by affording greater opportunity for smaller crabs to escape. On the other hand, the tunnel-eye opening itself may provide an important avenue for escape of red king crabs and that route is best used by the larger males (Stevens et al. 1993; Zhou and Shirley 1997b). With neither direct observations of escaping crabs nor experimental manipulation of escape devices in our study, other explanations besides escapement could be suggested for the trends in our data. Regardless, it is clear that, with current gear and baiting practices, soak times of up to 72 h are not sufficient to eliminate catch of nonlegal red king crabs in the Bristol Bay fishery.

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