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ABSTRACT: Effects of carapace hardness and air exposure duration on mortality were studied on Dungeness crabs *Cancer magister* off Kodiak Island, Alaska. We captured 516 legal male crabs and marked them with spaghetti tags. Carapace condition was recorded, and crabs were randomly selected for exposure to air for 5, 15, 30, and 60 min. Crabs were then returned to the sea. Subsequent recoveries from commercial catches included 11% of the tagged softshell crabs and 20% tagged hardshell crabs; these differences were statistically different. No statistical difference was found among exposure periods for hardshell crabs; low statistical power due to small sample size precluded similar tests for differences among exposure periods for softshell crabs. Low recovery rates of softshell crabs in Alaska is consistent with previous mark-recapture studies of Dungeness crabs conducted off Oregon and Washington. Previously published results from controlled experiments support our conclusion that differential recovery rates were primarily due to elevated handling mortality of softshell crabs. Our data suggest that softshell crabs experienced 45% higher mortality than hardshell crabs. However, this rate may not be representative of handling mortalities experienced during commercial fisheries because (1) during molting periods fisheries catch crabs much softer than those we encountered, (2) we handled crabs much more carefully than would normally occur during commercial operations, and (3) we were unable to derive separate estimates of differential natural and handling mortalities among softshell and hardshell crabs. Findings of handling mortalities of softshell crabs, coupled to considerations of cannibalism in crab pots, indicate that Dungeness crab fishing seasons in Alaska should be structured to avoid major molting periods as is the general practice along the coasts of California, Oregon, Washington and British Columbia. Such regulations will reduce mortality and commensurately increase the abundance of harvestable males and spawning biomass. Extended fishery closures until several months after molting will result in some economic benefits, as well. Meat yield and wholesale value are lowest during molting and increase until peaking several months later. These factors, plus other socioeconomic tradeoffs, should be weighed to determine net benefits to changes in fishing seasons for Dungeness crabs.

INTRODUCTION

This paper examines experimental effects of carapace hardness and air exposure duration on rates of recovery of tagged Dungeness crabs *Cancer magister* in the commercial fishery off Kodiak Island, Alaska, and discusses the associated management implications. The field investigations for this study were conducted, initially analyzed, and reported by Hicks and Murphy (1989). Further analysis of their data led to a different conclusion about statistically significant differences in tag recovery rates among hardshell and softshell crabs due to handling mortality. These revised findings are presented here.

In Alaska, Dungeness crab fisheries are managed primarily by size, sex, and season (3-S) regulations (ADF&G 1993). Typically, fishing seasons extend from June 15 through December 31, but significant variation in season dates occur among management areas. Only male crabs 6.5 in carapace width may be retained. Width is measured by the straight line distance across the carapace immediately anterior to the tenth anterolateral spine, not including the spines.

Significant quantities of softshell Dungeness crabs may be handled during commercial fisheries in Alaska because seasons are protracted (ADF&G 1993) and crabs molt virtually year-round (Koeneman 1985). Further, with exceptions of Prince William Sound (Donaldson 1990) and Cook Inlet (Kimker

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1991), fishing seasons do not necessarily avoid periods of heaviest molting that appear to occur from April (Koeneman 1985) through August (Kimker 1991). If handling lowers survival of softshell crabs returned to the sea, fishery productivity could be reduced by direct mortality of discarded males: legal softshell males are discarded because of low product quality and both hardshell and softshell sublegal males are discarded due to size limits. Excessive handling mortality of softshell females could reduce population egg production and subsequent recruitment strength.

Although we are unaware of studies on effects of air exposure on Dungeness crabs, several investigators have studied effects of carapace hardness on handling mortality. In these studies crabs were classified based on subjective measures of carapace hardness. Some investigators (e.g., Cleaver 1949) used terms such as *new hard*, *new slightly soft*, *new soft*, and *old shell*. Many others (e.g., Waldron 1958; Tegelberg 1972; Barry 1984) classified crabs as *grade 1* or *hardshell*, those having little or no flexibility in carapace; *grade 2* or *medium hardshell*, those having a somewhat flexible carapace; and *grade 3* or *softshell*, those with a very flexible carapace.

Two of these studies examined mortality directly through controlled experiments designed to mimic commercial fishing operations. In one study in Willapa Bay, Washington, Tegelberg (1972) captured and handled crabs, sorted them by grade, tagged them with Petersen disc tags, and placed 25 crabs for each hardness grade into separate Dungeness crab pots that had tunnels and escape rings wired shut. Pots were submerged in 5–13 m of water. Four-day mortality was approximately 9% for grade-1 crabs, 17% for grade-2 crabs, and 23% for grade-3 crabs. In the other study, Barry (1984) captured, handled, and placed crabs into holding pots in 16–20 m of water in Grays Harbor, Washington. In one set of trials, grade-1 crabs experienced 1% mortality, grade-2 crabs 7%, and grade-3 crabs 11% after 4 d. In another trial conducted during a major molting period, grade-1 and -2 crabs were not collected, but 30% of grade-3 crabs died and an additional 9% were moribund after 5 d.

Two other studies examined recovery rates of Dungeness crabs that had been marked with Petersen disc tags and were subsequently sampled from commercial catches. In the first study conducted off Washington (Cleaver 1949), the recovery rate of tagged new, slightly soft crabs was 7% lower than new, hard crabs, whereas new soft crabs were recovered at a rate 68% lower than that of new, hard crabs. However, rather than resulting from differences in handling mortality, Cleaver attributed different return rates to higher tag loss among softshell crabs than hardshell crabs. In the second study off Oregon (Waldron 1958), the tag recovery rate for grade-2 crabs (20%) was half that for grade-1 crabs (40%); differences in recovery rates were statistically significant, but Waldron did not attribute these differences to specific cause.

METHODS

Field Methods

Dungeness crabs were captured with commercial pots in Alitak Bay (approximately 56° 50' N, 154° 10' W) at the southern end of Kodiak Island during June 6–15, 1987, using the Alaska Department of Fish and Game vessel *R/V Coho*. Females and sublegal males were not studied and were returned quickly to the sea. Captured legal male crabs were measured for carapace width, and objective estimates of carapace hardness were obtained with a model 307LCRB4 durometer using methods described by Hicks and Johnson (1991). The durometer measures the relative units (0–100 durometers) of pressure that must be applied to result in an indentation of the carapace. For frame of reference, using nonlinear regression of carapace hardness on time since molting for laboratory animals, Hicks and Johnson (1991) predicted that legal males average 19 durometers one month after molting, 46 durometers at 3 months, and 66 durometers at 5 months.

Legal male crabs were tagged with spaghetti tags using methods of Snow and Wagner (1965) and randomly assigned, regardless of carapace hardness, to treatment groups of 5, 15, 30, or 60 min of air exposure. After the prescribed period of air exposure, crabs were returned to the sea. During these procedures, all crabs were handled with great care; handling was not intended to simulate treatment experienced during the commercial fishery. Due to good cooperation by fishermen, tagged crabs were recovered by ADF&G biologists from dockside catch samples from the commercial fishery that opened on June 15 and closed on December 31, 1987. See Hicks and Murphy (1989) for more detail on field methods.

Our study is similar to the field studies conducted by Cleaver (1949) and Waldron (1958), but we believe that we made some notable advances. Unlike these earlier studies in which carapace hardness was subjectively classified, our study employed a durometer (Foyle et al. 1989; Hicks and Johnson 1991) to obtain objective measures of carapace hardness. A spaghetti tag, applied to the epimeral suture line of the crab, was chosen rather than the Petersen disc tag used by Cleaver and Waldron. Spaghetti tags are superior to Petersen disc tags for study of differential mortality among softshell and hardshell crabs because (1) during molting spaghetti tags are retained (Snow and Wagner 1965), but disc tags are shed (Waldron 1958); (2) Petersen disc tags are lost at greater rates from softshell than hardshell crabs (Tegelberg 1972); (3) crabs marked with Petersen disc tags experienced higher short-term (6 d) mortalities than untagged crabs receiving identical handling treatments (Tegelberg 1972); and (4) there is no evidence of significant tag loss nor differential mortality among Dungeness crabs marked and unmarked with suture line tags (Tegelberg 1972; Smith and Jamieson 1989). Unlike earlier studies with Petersen disc tags, we dismissed the importance of differential tag loss and tag-induced mortality in our investigation for these reasons. Last, we studied tag return rates for effects of air exposure — a factor not investigated previously for Dungeness crabs.

Analytical Methods

Tag recovery data were aggregated into two carapace-hardness categories (<70 and ≥70 durometers) and four exposure durations (5, 15, 30, and 60 min). Hicks and Johnson (1991) reported that 92% of the crabs with carapace hardness <70 durometers are "new soft shells." For notational shorthand, we refer to crabs with carapace hardness <70 durometers as *softshell* and those with hardness ≥70 durometers as *hardshell hereafter.*

Confidence intervals (CI) for recovery rates expressed as proportion recovered were estimated using two methods. For cases with sufficient recoveries (in this case, hardshell crabs), 95% confidence intervals were calculated as

95% *CI* for p_{hd} =

$$\hat{p}_{hd} \pm \left[1.96 \sqrt{\frac{\hat{p}_{hd}\,\hat{q}_{hd}}{N_{hd}}} + \frac{1}{2N_{hd}} \right] \quad ; \quad (1)$$

where:

$\hat{q}_{hd} = 1 - \hat{p}_{hd}$;

N_{hd} = *number of tagged hardshell crabs (h) that were exposed to air for d min;*

$\hat{p}_{hd}$ = *proportion of hardshell crabs exposed to air for d min that were subsequently recovered; and*

$(2N_{hd})^{-1}$ = *correction for continuity (Snedecor and Cochran 1967).*

Because this approximation may be poor in data-limited situations where $N\hat{p} < 5$ *(Sokal and Rohlf 1981), statistical tables calculated by Mainland et al. (1956) and reproduced by Rohlf and Sokal (1969) were used to estimate 95% C.I. of* $\hat{p}_{sd}$ *, or the proportion of softshell crabs exposed to air for d* min.

We subjected results to 2 x 2 and 4 x 2 tests of independence for tag recovery rates among carapace hardness and air exposure treatments. Results of these tests were evaluated with respect to statistical power (1–β). A 2 x 2 *G*-test with Williams' correction (G_{adj}; Sokal and Rohlf 1981) was used to test for independence of tag recovery rates on carapace hardness alone and was compared to tabled values of (1–β) for differences between two proportions with unequal samples sizes (Cohen 1988).

To test for independence of tag recovery rates on exposure treatment, 4 x 2 tests were conducted on hardshell and softshell crabs separately. Hardshell crabs were subjected to a 4 x 2 *G*-test with Williams' correction. Because of the low number of treatments and small expected frequencies, we followed Conahan's (1970) advice and applied a 4 x 2 Fisher's exact test for softshell crabs. Because of difficulty in extending power analyses to more than two classes (Sokal and Rohlf 1981), we constructed Monte Carlo simulations of these two 4 x 2 tests of independence to examine statistical power. These Monte Carlo simulations were used to estimate the sample size in each exposure group that would have been needed to detect biologically meaningful differences in tag recovery rates.

We proposed that biologically meaningful differences in tag recovery rates would occur if the rate from at least one treatment (shortest exposure) was double the rates associated with other treatments. If reduced exposure times resulted in smaller improvements in tag recovery rates than this and presumably smaller reductions in handling mortality, we would not have bothered adjusting field estimates of handling mortality for exposure time, and we would have been disinclined to advocate changes in onboard handling procedures during surveys or commercial operations.

For each hardness category, we tested H_0 *at* $p_5 = p_{15} = p_{30} = p_{60}$ *against* H_a *at* $0.5p_5 = p_{15} = p_{30} = p_{60}$. For the simulations, sample sizes were set equal in each of the four exposure groups. Initial test sample sizes for each treatment were set equal to the average observed sample size for the hardness category. Next, we randomly sampled 1000 times from each of four binomial distributions, three with equal probabilities of tag recapture in the neighborhood of those observed and the fourth with a probability double the others. Then, sample size was systematically changed until statistical power of the test was approximated by the proportion of simulated occurrences in which significant ($\alpha = 0.05$) differences in tag recovery rates occurred. Given this α, we followed Cohen's (1988) suggestion and chose the desired statistical power ($1-\beta_\delta$) to be 0.80. We were satisfied that there were no biologically meaningful effects of exposure on observed tag recovery rates, if Ho was not rejected at $\alpha = 0.05$ and if $(1-\beta) \geq (1-\beta_\delta)$.

RESULTS

During tagging operations, 516 legal Dungeness crabs with carapace hardness ranging from 26 to 98 durometers were captured and tagged. Of these, 116 crabs, all with carapace hardness >52 durometers, were recovered in the fishery. Recovery rates ranged from 9–13% for softshell crabs and 16–25% for hardshell crabs (Table 1). The 95% CI for $\hat{p}_{sd}$ and $\hat{p}_{hd}$ are shown in Figure 1; wider CI for $\hat{p}_{sd}$ reflect lower sample size for softshell ($N_s = 114$) compared to hardshell crabs ($N_h = 516$).

The *G*-statistic from the 4 x 2 test for independence of the four exposure treatments on the number of hardshell crabs recovered and unrecovered (Table 1) was $G_{adj} = 3.381$. Because $G_{adj} < \chi^2_{0.05,3} = 7.815$, we did not reject the null hypothesis that recovery rate of hardshell crabs was independent of exposure period for the exposure periods tested (≤1 h). However, simulated binomial observations of these true hardshell crab recovery rates and numbers of crab released in each exposure group resulted in low statistical power (0.31) for detecting differences among treatments.

To increase power of the test we averaged the observed recovery rates (20%), doubled the recovery rate (40%) for the lowest exposure group (5 min) and set the number of crabs released in each exposure group to the average (129) of all groups. This increased power to 0.97. Additional simulations indicated that sample size for hardshell crabs could be decreased to 75 crabs per exposure group; this sample size would allow us to detect a halving of recovery rates as exposure duration increased while retaining statistical power of 0.80. These results imply that there were no biologically meaningful differences in tag recovery rates among exposure treatments for hardshell crabs.

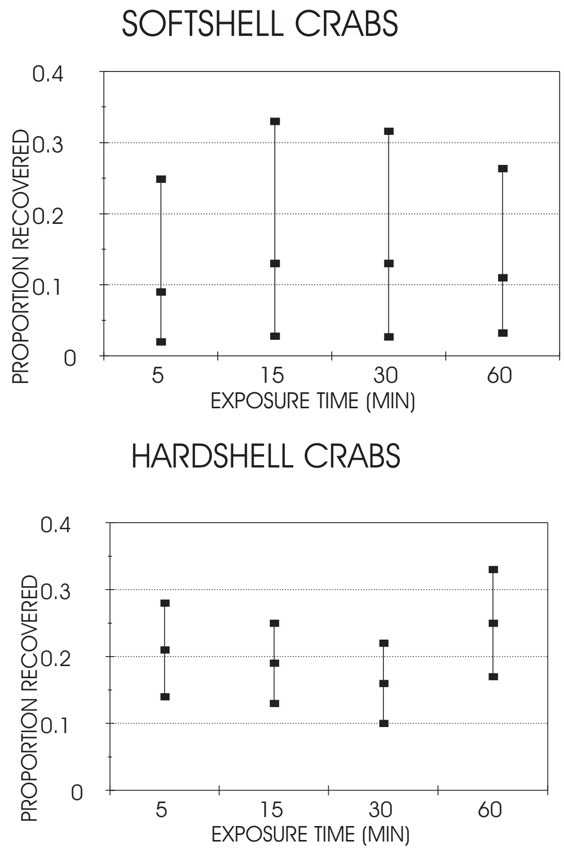

FIGURE 1. Proportion and 95% confidence intervals of tagged softshell (upper panel) and hardshell (lower panel) Dungeness crabs that were exposed to one of four air exposure treatments and subsequently recovered in the commercial fishery by dockside samplers. Methods for calculation of 95% confidence intervals are described in the text.

Fisher's exact test of independence of the number of softshell crabs recovered on the four exposure treatments yielded P = 0.978: the null hypothesis that recovery rate of soft shell crabs was independent of exposure period was not rejected at P = 0.978. Monte Carlo simulation of binomial observations of the number of softshell crabs released and their recovery

Table 1. The number and percentage of recaptured Dungeness crabs for each of four exposure durations and two carapace hardness categories. The four exposure categories and two outcomes (recovered and unrecovered) for hardshell crabs formed the basis of the 4 x 2 *G*-test of independence.

	Softshell Crabs				Hardshell Crabs			
Exposure Time (min)	Number Recovered	Number Unrecovered	Total	Recovery Rate (%)	Number Recovered	Number Unrecovered	Total	Recovery Rate (%)
5	3	29	32	9.4	26	99	125	20.8
15	3	20	23	13.0	27	115	142	19.0
30	3	21	24	12.5	21	112	133	15.8
60	4	31	35	11.4	29	87	116	25.0
Grand Total	13	101	114	11.4	103	413	516	20.0

rates yielded low power (0.078) for detecting differences among treatments.

Statistical power was examined further by (1) setting recovery rates of softshell crabs exposed for 15, 30, and 60 min equal to the average rate (11.6%), (2) setting the recovery rate for the 5-min exposure group to double this level (23.2%), and (3) assuming equal numbers of released crabs for each treatment group. We estimated that a sample size of 155 crabs for each treatment would have been required to detect such differences in recovery rates with a power of 0.8. Thus, small sample sizes prevented conclusions about the existence of biologically meaningful differences in tag recovery rates among exposure treatments for softshell crabs.

Because the effects of exposure period on recovery rates were not evident for hardshell crabs and were unresolved for softshell crabs, we aggregated the tag recapture data into two hardness categories independent of exposure period (Table 2). This permitted a 2 x 2 *G*-test for independence of recovery rate on carapace hardness. For this test we estimated $(1-\beta) \approx 0.90$, given $\alpha = 0.05$, $N_s = 114$, $N_h = 516$, $\hat{p}_s = 0.11$, and $\hat{p}_h = 0.20$. The test statistic for independence of tag recovery rates on carapace hardness was $G_{adj} = 4.955$. Because G_{adj} was greater than the critical $\chi^2_{\alpha,df}$ value ($\chi^2_{0.05,3} = 3.841$; $0.01 < P < 0.05$), we rejected the null hypothesis of independence. That is, the mean recovery rate for softshell crabs (11%) was 45% lower than the mean recovery rate for hardshell crabs (20%), and this difference was statistically significant. If the recovery rate of tagged softshell crabs had been equal to the recovery rate of tagged hardshell crabs, then we would have expected 23 recoveries of tagged softshells rather than the 13 actually recovered.

Table 2. The 2 x 2 table used to test for independence of tag recovery rates among softshell and hardshell Dungeness crabs.

	Number of Tagged Crabs		
Carapace Condition	Recovered	Unrecovered	Total
Softshell	13	101	114
Hardshell	103	413	516
Total	116	514	630

DISCUSSION

In their analysis of the same data reported here, Hicks and Murphy (1989) found no significant differences in tag recovery rates of Dungeness crabs grouped into four exposure periods and six carapace hardness categories. Given total sample size and the number of exposure-hardness treatments considered, they were unable to distinguish handling effects due to low statistical power. We subsequently found that, when data were aggregated into two carapace hardness categories and four exposure treatments, sample size was sufficient to conclude that hardshell crabs showed no statistical evidence of detrimental impact due to air exposure at the four durations (≤1 h) tested. We also found that the number of hardshell crabs tagged in each treatment group was more than adequate to detect a biologically meaningful difference in recovery rates among exposure treatments, had such differences existed.

Sample sizes of tagged softshell crabs were too small to draw meaningful conclusions about effects of air exposure on recovery rates. When pooled across all exposure periods, however, we found that the recovery rate of tagged softshell crabs was lower than that of tagged hardshell crabs. This difference was statistically significant and biologically meaningful, and the power of this test was high. Hicks and Murphy (1989) did not reach this conclusion because they considered the exposure periods as different treatments and did not pool across them. Here, we did not consider the four exposure periods as different treatments for hardshell crabs because no biologically meaningful effects from air exposure were noted. Although statistical power was too low to fully discount exposure effects on recovery rates of softshells, these data were pooled to permit a test for the separate effect of carapace hardness — which we considered to be a primary question. We suspect that if exposures ≤1 have any effects on recovery, these effects would be secondary and would be manifested in crabs with very soft carapaces. Because we had dismissed the importance of differential tag loss and tag-induced mortality, we assumed that differential mortality was responsible for observed differences in tag recovery rates.

Carapace Hardness

Although we were unable to derive separate estimates of differential natural and handling mortalities among softshell and hardshell crabs, we concluded, as did Tegelberg (1972), that handling was largely responsible for the low recovery rates of tagged softshell crabs. Likewise, Smith and Jamieson (1989) surmised that handling of softshells contributed to higher mortality estimates for sublegal males that molted compared to crabs that did not molt. These conclusions are supported by controlled short-term experiments by Tegelberg (1972) and Barry (1984), who found that handling mortality was inversely related to carapace hardness. Even if differential "natural mortality" accounted for a significant portion of observed differences in tag recovery rates among softshell and hardshell crabs, handling may still be implicated. For example, Brown and Caputi (1983) and Gooding (1985) found that handled and released lobsters (*Panulirus*) experienced increased predation due to displacement from home range, lack of shelter at site of release, impairment of activity level, and reduced aptitude for defense against predators.

Unfortunately, our results cannot be used to infer the level of handling mortality of Dungeness crabs during commercial fisheries because (1) fisheries prosecuted during molting periods catch crabs much softer than we encountered, and (2) we handled crabs much more carefully than under commercial operations. For these reasons, estimates of handling mortality may be less than true mortality in commercial fisheries prosecuted on newly molted crabs.

Severity of Handling

Barry (1984) found that, if handled in a manner similar to conditions aboard commercial fishing vessels, crabs experienced higher short-term (4–5 d) mortality than control crabs of the same carapace hardness that were captured and handled very gently. Softshell crabs that were handled three times in 6 d experienced 41% mortality compared to 23% for those that were handled once in 2 d, although sample size prevented tests for significance (Tegelberg 1972).

Impacts of crabs on the deck of a fishing vessel or on the surface of the sea could affect survival rate. In one study, short-term mortality was elevated to 57% for softshell crabs dropped onto the deck of a vessel (Tegelberg 1972). In another study (T. Shirley, University of Alaska Fairbanks, Juneau, personal communication), the commercial catching, sorting, and discarding processes were simulated in the laboratory. Mortality was found to be directly correlated to the number of times per month that Dungeness crabs were captured, handled, and dropped back into the water.

Appendage Loss

Dungeness crabs are vulnerable to appendage injury. Between 18–62% of captured Dungeness crabs were found to be injured along the coasts of Southeast Alaska (Shirley and Shirley 1988) and the Pacific northwest (Cleaver 1949; Waldron 1958; Durkin et al. 1984). Time of year and the level of fishing effort affect injury rates. Shirley and Shirley (1988) found the incidence of appendage injury of Dungeness crabs in Southeast Alaska to increase significantly with the prosecution of the commercial fishery and with the onset of mating and molting.

Dungeness crabs have the ability to survive amputation and regenerate lost limbs (MacKay 1942; Cleaver 1949). However, these crabs may suffer lower survival rates than crabs with all appendages intact. In our study, only three crabs had missing appendages (Hicks and Murphy 1989), so we were unable to analyze the possible effects of this factor. However, in a 2-year study Cleaver (1949) found that tagged crabs missing one appendage were recaptured at 73–93% of the recovery rates of tagged crabs without missing appendages; this fell to 50–65% for crabs missing two appendages. Similarly, data presented by Waldron (1958) reveal that crabs with some lost appendages were recovered at a lower rate (83%) than crabs with all appendages intact, but this difference was not statistically significant.

Air Exposure

Under field conditions — generally cool and overcast or rainy — that we encountered off Kodiak Island during tagging in June 1987 hardshell Dungeness crabs seemed to survive air exposures for up to 1 h. Because of lack of statistical power associated with small sample size, we could not discount possible effects of exposure on softshell crabs. Nonetheless, our finding of no effect for hardshell crabs is consistent with anecdotal observations by Cleaver (1949) that air exposure causes crabs no harm if they are kept cool and moist. However, it seems to us that desiccation could adversely affect survival at longer exposure periods or higher air temperatures especially for softshell crabs.

Management Implications

Handling mortality has significant implications for fishery management. Commercial fisheries prosecuted during molting periods reduce survival of Dungeness crabs returned to the sea. It follows that handling of molting prerecruit crabs reduces the size of the legal population available several months later when crabs are harvestable size. Handling mortality on females reduces population egg production. Unfortunately, it is very difficult to quantify in situ handling mortality and its affect on population dynamics and the commercial fishery for Dungeness crabs.

Fisheries may lead to other sources of mortality aside from handling. Cannibalism, particularly on softshells, occurs when crabs are contained in pots and aquaria (Cleaver 1949; Waldron 1958). Also, deaths occur due to starvation from confinement in pots for periods ≥30 d (Paul et al. 1993b). These mortalities may be problematic in fisheries in which pots are fished with lengthy soak times or in fisheries with significant pot loss. Based on experiments (Kimker 1990; Paul et al. 1993a) and analyses of alternatives (Kruse and Kimker 1993), in February 1993 the Alaska Board of Fisheries adopted new fishing regulations (ADF&G 1993) that require all shellfish and groundfish pots to be installed with a degradable mechanism made of cotton twine or a galvanic timed release device. These provide for escape from lost pots.

Economic considerations are important, as well. Tegelberg (1972) showed that mean percentage picked weight increased from 15% of live weight during peak molting period to 26% three months later for Washington coastal crabs and to 30% seven months after molting for Willapa Bay crabs. Also, he documented a relationship between carapace hardness and product quality. The weight of meat recovered from softshell crabs was lower than that of hardshell crabs of the same size regardless of month of year. For example, in December the picked weight of hardshell crabs (grade 1) was 25% of live weight as compared to only 15% for softshell crabs (grade 3). Additionally, there is a negative linear relationship between percentage of meat yield and percentage of softshell crabs in the catch (PMFC 1978).

Meat yield affects economic rent. Even if wholesale price was fixed, lower product recovery rates reduce gross receipts paid to processors for a given number of crabs (PMFC 1978). Yet, carapace condition may have no effect on unprocessed weight because softshell crabs with low meat yields have high water content (Taylor and Warren 1991). These conditions provide incentives for processors either to refuse purchase of landings dominated by softshell crabs or to offer lower exvessel prices for these catches. Regardless, increased quantities of softshell crabs in landed catches reduce gross earnings of harvesting and processing segments of the crab industry.

Given all of these considerations, we believe that Dungeness crab fisheries in Alaska should avoid major molting periods, as is the general practice off California (Warner 1985), Oregon (Demory 1985), Washington (Barry 1985), and British Columbia (Jamieson 1985). If fixed openings and closures are used, then seasons should be selected that acknowledge extensive interannual variability in molting periods typical of Dungeness crabs (Tegelberg 1972; Snow 1963).

Alternatively, as recommended by Jamieson (1985), fishing seasons could be flexed to avoid major molting periods based on inseason monitoring of carapace hardness. Waldron (1958) reported on a management plan developed in Oregon in the late 1940s in which the fishery was open only when <10% of legal size male crabs were softshell. A similar strategy is employed currently in Washington, Prince William Sound (Donaldson 1990), and lower Cook Inlet (Kimker 1991). The primary advantage over a fixed season is that handling mortality is reduced in years when crabs molt so late that softshells would have occurred in commercial catches despite planned seasonal closures. On the other hand, increased fishing opportunities could be provided in years when the molting cycle is advanced.

CONCLUSIONS

(1) We believe that handling mortality caused the statistically different (0.010.05) tag recovery rate noted between softshell crabs (11%) and hardshell crabs (20%) in the 1987 commercial fishery off Kodiak Island, Alaska.

(2) The 45% lower recovery rate for softshell crabs than for hardshell crabs may have been partially influenced by tag loss or tag-induced mortality, but these influences were believed to be relatively minor. Furthermore, our conclusions about handling mortality for softshell crabs are quite consistent with other Dungeness crab studies.

(3) Hardshell crab survival does not appear to be affected by exposure to air up to 60 min during the cool and overcast or rainy conditions that we encountered off Kodiak Island while tagging. Sample size was too small to test the effects of different exposures on softshell crabs, and no conclusions were possible.

(4) In commercial fisheries severe handling and multiple recaptures will increase handling stress and associated mortality of softshell crabs beyond that indicated by our study, in which crabs were handled only once and with great care.

RECOMMENDATIONS

(1) We recommend a statewide study of Dungeness crabs to estimate molting timing and its interannual variability by area. At present, molting timing is poorly known in most areas of the state.

(2) Dungeness crab fisheries in Alaska should be closed during major molting events. This may be achieved by two methods. Fixed closure periods that account for interannual variability in molting timing may be established for each regulatory area. Alternatively, variable season opening dates could be set based on annual pre-season sampling programs as currently practiced in Prince William Sound and lower Cook Inlet.

(3) A bioeconomic simulation study is recommended to guide considerations of optimal fishing seasons for Dungeness crabs. Relevant factors include results of the proposed molting timing study, handling mortality related to carapace condition, mean percentage picked weight as a function of shell hardness, and seasonal effects of U.S. supply of Dungeness crabs on price paid per pound.

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