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Original Article

Discard mortality rates in the Bering Sea snow crab, *Chionoecetes opilio*, fishery

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Fish and invertebrates that are unintentionally captured during commercial fishing operations and then released back into the ocean suffer mortality at unknown rates, introducing uncertainty into the fishery management process. Attempts have been made to quantify discard mortality rates using reflex action mortality predictors or RAMP which use the presence or absence of a suite of reflexes to predict discard mortality. This method was applied to snow crab, *Chionoecetes opilio*, during the 2010–2012 fisheries in the Bering Sea. Discard mortality in the fishery is currently assumed to be 50% in stock assessment models, but that rate is not based on empirical data and is widely recognized to be in need of refinement. Over 19 000 crab were evaluated using the RAMP method. The estimated discard mortality rate was 4.5% (s.d. = 0.812), significantly below the rate used in stock assessment models. Predicted discard mortality rates from the 2010 to 2012 study were strongly correlated with the air temperature at the St Paul Island airport in the Pribilof Islands. Using this relationship, the discard mortality rate from 1991 to 2011 was estimated at 4.8% (s.d. = 1.08).

Keywords: Alaska, Bering Sea, *Chionoecetes opilio*, discard mortality, RAMP, reflex action mortality predictor, snow crab.

Introduction

The unintentional capture of non-target fish and invertebrates is a common feature of fisheries around the world (Harrington *et al.*, 2005), resulting in major economic and ecological impacts (Kelleher, 2005; Cressey, 2013). For the federally managed fisheries in the United States, the estimated discarded tonnage was 28% of the landed tonnage in 2002 (Harrington *et al.*, 2005). Alaskan crab fisheries are no exception to this phenomenon. For example, in the eastern Bering Sea snow crab fishery from 2007 to 2012, the North Pacific Fishery Management Council (NPFMC) estimated that weight of discarded snow crab (females and undersized males) was 23% of the retained catch (NPFMC, 2011).

The mortality associated with these discarded crab is considered part of the total fishing mortality of the snow crab fishery (NPFMC, 2011), but determining the mortality rates of discarded crab has been technically difficult and expensive (Stoner, 2012; Benoît *et al.*, 2013). The NPFMC assumes 50% mortality for snow crabs discarded from the pot fishery and 80% mortality for trawl bycatch (NPFMC, 2011), but it is widely recognized that more research is needed to estimate both the mean and variation of these values.

Researchers have long studied the impact that fishing operations and low-temperature exposure have on crab survival (Carls and O'Clair, 1990; Watson and Pengilly, 1994; MacIntosh *et al.*, 1995; Zhou and Shirley, 1995; Shirley, 1998; Moiseev *et al.*, 2013). While some studies found negligible effects, other studies found mortality rates of up to 100% (e.g. Warrenchuk and Shirley, 2002). Mortality rates increased with increasing length of exposure time, decreasing temperature, increasing windspeed, and increasing number of injuries (Carls and O'Clair, 1990; Rosenkranz, 2002; Warrenchuk and Shirley, 2002; van Tamelen, 2005). Typically, direct observation of the crab has been used to determine mortality rates (Carls and O'Clair, 1990; Shirley, 1998; Warrenchuk and Shirley, 2002; Watson and Pengilly, 1994). An alternative method is to measure some aspect of crab condition which is closely associated with delayed mortality.

The presence or absence of reflex actions has recently been identified as a method which can accurately predict mortality in crustaceans (reviewed in Stoner, 2012). In Tanner (*Chionoecetes bairdi*) and snow crabs, a suite of six reflex actions was recently developed for this purpose. Known as reflex action mortality predictors (RAMP), the presence or absence of these reflexes can be used to accurately predict mortality rates (Stoner *et al.*, 2008; Stoner, 2009). The RAMP method has the advantage that it can be easily applied at sea on research or fishing vessels without the need for tag recoveries or holding crab in tanks. Also, the reflexes are obvious to detect and the simple presence or absence criteria for scoring greatly reduces subjectivity from the process (Stoner, 2012).

This project applied RAMP to snow crab discarded under actual fishing conditions with the goal of evaluating estimates of discard mortality rates. The estimated mortality rates were also evaluated for their relationship with temperature and windspeed to determine if those conditions could provide a substitute for RAMP scoring. Since it is difficult to routinely obtain the weather conditions from fishing vessels, the use of temperature and wind data from the airport in St Paul in the Pribilof Islands was examined to determine if it could be used as a surrogate for vessel conditions. St Paul Island lies in the centre of the fishing grounds (van Tamelen, 2005) and is a reliable source of weather data for the fishing area. Injury rates observed during the fishery were recorded and compared with injury rates observed historically to determine the potential magnitude of injury-induced handling mortality.

Material and methods

Research biologists from the National Marine Fisheries Service (NMFS) and fisheries observers from the Alaska Department of Fish and Game (ADF&G) Observer Program collected RAMP scores during the 2010, 2011, and 2012 snow crab fishing seasons in the southeastern Bering Sea. The biologists received RAMP training from one of the co-authors of the Stoner *et al.* (2008) paper (E. Munk, NMFS Kodiak Laboratory). Munk also trained the ADF&G staff who would be instructing observers in RAMP. A training video illustrating the six reflexes was prepared and shown to observers to ensure consistency in scoring. The biologists were placed on vessels of the snow crab fleet on a voluntary basis with RAMP scoring being their only task. The ADF&G observers participated in RAMP scoring when they had completed their required observer tasks. They were instructed to sample at least three pots per day and to select pots for sampling before they reached the surface to avoid any bias towards sampling pots with smaller catches.

Temperature and windspeed were recorded by the biologists at the sorting table as the pot was being brought on board using a Kestrel 4000 (use of trade names does not imply endorsement by the NMFS, NOAA) hand-held wind meter that also recorded temperature. The starting and ending times of the sorting process for each crab pot were recorded. Discarded crab were selected from a sampling point as close as practicable to the location where they were returned to the water, usually an outflow shoot. The sex, carapace width, shell condition, female maturity status (Jadamec *et al.*, 1999), and any injuries were recorded (e.g. cracked carapace or smashed leg). Autotomized legs were not recorded as injuries. The presence or absence of six reflexes were then evaluated (Table 1) as described by Stoner *et al.* (2008). Each reflex got a score of one if the reflex was absent and zero if the reflex was present so that a crab exhibiting no impairment of reflexes received a score of zero. A score of 6 meant all reflexes were absent. As soon as sampling was completed on an individual crab, the next crab passing the sampling point was selected.

The discard mortality rate for the RAMP scored crab was estimated using the mortality probability schedule developed by Stoner *et al.* (2008) and Rose *et al.* (2013) for this species where the number of impaired reflexes is associated with a specific predicted mortality (Table 2). The proportions of crabs at each level of impairment were multiplied by its mortality probability and then summed:

$$m_d = \sum_{r=0\text{ to }6} (m_r \times p_{r,d}),$$

where m_d is the discard mortality rate estimate for a catch, m_r the mortality probability from RAMP scoring for a species with missing r number of reflexes, and $p_{r,d}$ the proportion of the discarded catch with reflex score r (Rose *et al.*, 2013).

While mortality rates based on RAMP scoring do not directly incorporate temperature and windspeed, the RAMP predicted mortality and the concurrent weather conditions at the sorting table were evaluated for correlation. Windspeed was aggregated into 3 km h^{-1} bins: (0–3), (3.1–6), ... , (>18.1) and temperature

Table 1. Reflexes identified as useful for predicting discard mortality in *Chionoecetes* spp. (Stoner *et al.*, 2009).

Reflex	Test	Response
Leg flare	Lift crab by the carapace, dorsum up	All legs spread wide and high, near horizontal orientation in strong crabs
Leg retraction	While held as above, draw the forward most walking legs in the anterior direction	Legs respond with a retraction in the posterior direction or present resistance to the motion
Chela closure	Observe for motion or hold the chelae in the fingers	Chelae open and close rapidly without manipulation. Manipulation results in closure. Chelas may close slowly or show resistance to opening
Eye retraction	Touch the eyestalk with a blunt probe, or lift the eyestalk from its retracted position	Eye stalk retracts in the lateral direction below the carapace hood or shows resistance to opening
Mouth closure	If closed, attempt to open the third maxillipeds with a sharp dissecting probe. If open, draw the maxillipeds downwards	Third maxillipeds retract to cover the smaller mouth parts. The maxillipeds may droop or move in an agitated manner in weak crab
Kick	With the crab in the ventrum-up position, use a sharp dissecting probe to lift the abdominal flap away from the body	Immediate agitation of the legs and chelipeds. Males respond more strongly than females. Testing with the females often requires greater extension of the entire abdominal flap. Hind leg motion is retained in weakened crabs

For this study, a weak response was recorded as a positive response.

into 3°C temperature bins: (<-20), (-19 to -17), ..., (>2). The strength of the correlation between windspeed and temperatures on the vessels and at the St Paul airport was then evaluated to determine if the airport conditions, which are readily available, can be used as a surrogate for vessel conditions.

Given a relationship between airport and vessel conditions, the mortality rate based on St Paul airport conditions can be applied to the total number of crab discarded by the fishery as recorded by ADF&G fisheries observers with bins corresponding to the airport conditions at the time the pot was hauled. It was assumed that the daily rate of crab being discarded from the unobserved pots was the same as for the observed pots. The total number of pots being fished daily was determined from the ADF&G fishticket database. An annual discard mortality rate was calculated for the 1991–2011 fishing seasons as the estimated sum of the daily discard mortalities divided by the total number of discards. The overall injury rate was the number of crab with observed injuries divided by the total number of crab observed.

Results

Three biologists and 20 fisheries observers collected RAMP scores from a total of 19 109 snow crab from 23 vessels and 2718 pots during the 2010, 2011, and 2012 fishing seasons (Table 3). The average sorting time per pot was 2.8 min. Only 54 of the observed crab were females, similar to the proportion of females observed during the fishery (W. Gaeuman, ADF&G, pers. comm.). Over 90% of the observed crab had no reflex impairments and the estimated discard mortality rate was subsequently low with an overall rate for the three seasons of 4.8%, ranging from 4.5 to 5.5% per fishing season. The overall injury rate was 1.8% (Table 3).

Wind and temperature readings at the sorting table were collected from 14 449 crab with RAMP observations. Windspeed ranged from calm to 23.5 km h^{-1} [mean 5.7 ± 0.05, 95% confidence interval (CI)] and temperature ranged from −14.7 to 6.5°C (mean −1.5 ± 3.6, 95% CI). No clear relationship existed between windspeed at the sorting table and estimated discard mortality making it difficult to draw conclusions about the effect of windspeed or wind chill on discarded crab. In contrast, temperatures colder than −4°C had a direct effect on predicted mortality with increases of ∼2–3% in the mortality rate with each 1°C decrease in temperature (Figure 1). At temperatures warmer than −4°C, however, there was no evidence of temperature effect on predicted mortality (Figure 1). Temperatures colder than −4°C were relatively rare during the 2010–2012 fisheries, occurring on only 15% of the observed fishing days (Figure 1). For the period 1981–2011, 20% of the days when fishing was occurring had a mean St Paul temperature colder than −4°C (NOAA, National Weather Service; Figure 2). Backdeck temperatures and the temperatures at the St Paul airport were correlated ($r = 0.84$), indicating that airport temperatures can be used as a surrogate for backdeck temperatures. Data from the established weather history of the airport (mean daily temperature) and the daily ADF&G observer data on crab discards available from the 1991 snow crab fishery onwards produced estimates of discard mortality rates that fluctuated within a narrow range from 3.0 to 8.1% (Figure 3), comparable with those observed directly during the 2010–2012 fisheries.

Table 2. The mortality predicted at each level of reflex impairment (Rose *et al.*, 2013).

Reflex impairment	Predicted mortality (%)
0	1.4
1	20.5
2	30.0
3	43.9
4	75.9
5	88.1
6	100.0

Reflex impairment is measured as the number of six defined crab reflexes whose function has been lost.

Table 3. Summary of snow crab RAMP sampling and results from the 2010 to 2012 fishing seasons.

Fishing season	Number of vessels	RAMP observations	Per cent unimpaired	Per cent with injury	Discard mortality rate
2010	18	12 619	91.2	0.1	5.5
2011	1	4 764	90.2	2.3	4.6
2012	4	1 726	90.4	5.6	4.5
Total	23	19 109	90.9	1.8	4.8

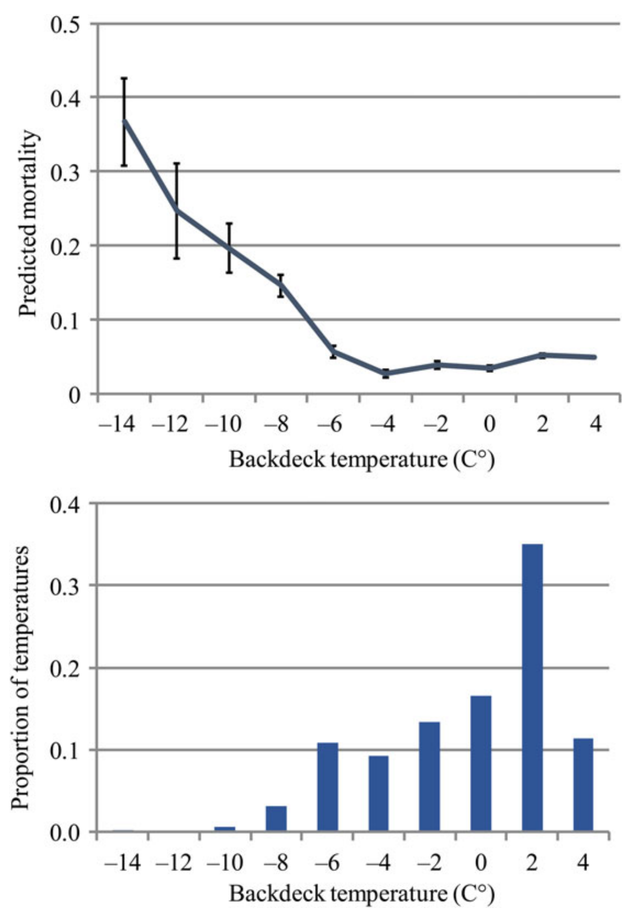

Figure 1. The upper panel shows the relationship between the temperature at the snow crab sorting table and the predicted mortality of snow crab based on reflex impairments. Error bars indicate the 95% CI. The lower panel shows the proportions of the temperatures recorded, while the observations were being made during the 2010–2012 fisheries.

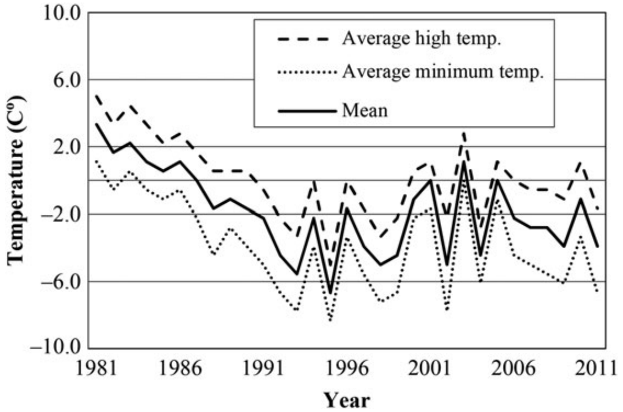

Figure 2. The average daily temperature at the St Paul airport in the Pribilof Islands from 1981 to 2011 for the days when the Bering Sea snow crab fishery was occurring.

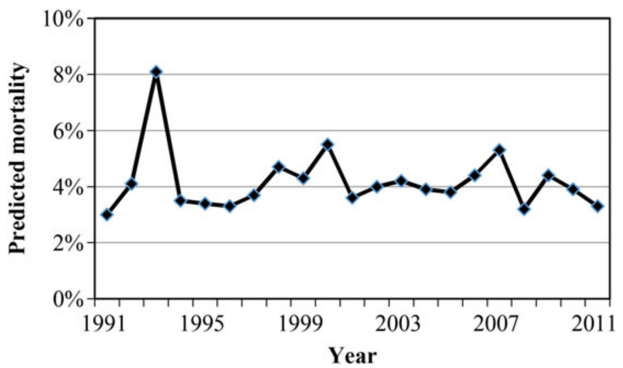

Figure 3. Estimates of historical snow crab discard mortality rates based on the relationship between predicted discard mortality and the temperature at the St Paul airport in the Pribilof Islands when the discards were occurring.

Discussion

Discard mortality experienced by snow crab during the directed pot fishery can take several forms. First, crab can die immediately due to trauma inflicted during the fishing process. Second, mortality can be delayed so that a crab that may be still alive during the sorting process dies in the water column or on the bottom shortly after discard as a direct result of fishing operations or cold exposure. Similar to other studies (Warrenchuk and Shirley, 2002; Stoner, 2009), the effects of exposure on *Chionoecetes* crabs were found to be directly proportional to increasing exposure.

The RAMP method as applied here to *Chionoecetes opilio* has proved effective at predicting short-term mortality induced by varying amounts of trauma and exposure (Stoner, 2009). In that study, Stoner (2012) used holding times of 9 d, but mortality may be significantly delayed when stressors create metabolic imbalances which lead to infections or difficulties in molting. Delayed mortality generally goes unobserved and is difficult to quantify but may comprise a large portion of the total fishing impact (Ridgway *et al.*, 2006). In addition, decompression effects associated with the rapid ascent from the bottom may result in reduced vitality in crab which may subsequently impact the reproductive potential of the crab stock (Moiseev *et al.*, 2013). These effects may not be fully captured by RAMP. Despite its limitations, the results of this study provide empirical evidence that the discard mortality rate of 50% overestimates the actual mortality rate.

Conclusions

In this study, the results of RAMP observations showed that at the range of winter temperatures typically encountered by the Bering Sea snow crab fishery, nearly all discarded crab experienced no reflex impairments. Therefore, we estimate that they should have only a 4.8% chance of short-term mortality. Injuries caused by the fishery occurred at very low levels and so should also have a minimal effect on discard mortality rates. However, because long-term survival rates and the effects of reduced crab vitality are difficult to predict, an estimate of the total impact of discard practices on snow crab stocks is not possible. Even with these uncertainties, the current empirical evidence indicates that the assumed discard mortality rate of 50% is conservative.

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