

**Utilizing reflex impairment to assess the role of discard mortality in ‘Size, Sex, and Season’  
management for Oregon Dungeness crab (*Cancer magister*) fisheries**

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## Abstract

We found that crab discarded from Oregon (U.S.A.) commercial and recreational fisheries for Dungeness crab (*Cancer magister*) have lower post-release mortality than previously estimated. This aligns with the goals of the '3-S' management strategy currently employed for these fisheries, to protect discarded sub-legal male (Size), female (Sex), and soft-shell (Season) crab. We found that, for the commercial ocean Dungeness fishery, overall discard mortality rates (five days after release) were 0.080 (95% Confidence Interval 0.061-0.100) for females; 0.012 (95% Confidence Interval 0.002-0.022) for hard-shell males; and 0.092 (95% Confidence Interval 0.026-0.157) for soft-shell males. The overall discard mortality rate for the recreational bay fishery (from a boat) was estimated to be 0.009 (95% Confidence Interval 0-0.018). A Reflex Action Mortality Predictor (RAMP) relationship, which relates reflex impairment to mortality probability, was created and utilized to estimate mortality rates. Our study highlights the importance of looking not only at discard and mortality rates to evaluate '3-S' fishery management, but also the mortality- and bycatch-per-retained ratios, and temporal trends relative to changes in effort, animal condition, and catch composition.

## Keywords

Bycatch, crabs, fishery management, reflex impairment, discard mortality

## Introduction

Dungeness crab (*Cancer magister*) is currently the most valuable crab fishery in the United States, yielding nearly 25 thousand metric tons and \$211 million in 2014 (National Marine Fisheries Service 2015), and has an over \$40 million dollar (CAD 2008) ex-vessel value in Canada (Yonis 2010). In Oregon (U.S.A.), the ocean fishery for these crab is the most valuable single-species commercial fishery, with 300-350 vessels landing 5-15 thousand metric tons each season (Ainsworth et al. 2012), generating up to \$50.2 million (ex-vessel; ODFW 2015a). In addition to the commercial fishery, Dungeness also contribute to local economies as a draw for tourism and recreational fishing (Ainsworth et al. 2012). Despite the economic significance, in the United States there is neither a stock assessment nor a Fishery Management Plan (FMP) for the commercial or recreational Dungeness crab fisheries along the Pacific coast nor in adjacent estuaries. Since 1947, Dungeness fisheries have been managed by state agencies (Demory 1985) that employ, along with effort controls and gear restrictions, a predominately ‘3-S’ management strategy: Size, Sex, and Season.

The size and sex of harvestable crab are regulated within a specified season for commercial and recreational fishing, in the ocean and adjacent bays. In Oregon, commercial and recreational harvest is currently restricted to males with a minimum carapace width of 6¼ inches (159 mm) and 5¾ inches (146 mm), respectively (ODFW 2015b). Because males are mature by 137 mm (MacKay 1942), these size restrictions ensure crab are able to reproduce for one or two seasons before recruiting into the fisheries (Rasmuson 2013). In addition, male-only harvest protects breeding females and increases meat yield (Northrup 1975) given that females produce 42% less meat than male crab (PSMFC 1978).

88

89 The 'Season' component of the '3-S' management regulates the timing of the fishery to avoid

90 capture of recently moulted, soft-shell crab (PSMFC 1978). In Oregon, male crab typically moult

91 from spring to fall (Demory 1985, Rasmuson 2013), with an increasing abundance of moulting

92 crab from April to July, and a substantial number of soft-shell crab in October and November

93 (Spears et al. 1983). Timing of the moult, however, varies geographically, annually, and by sex

94 (Robinson et al. 1977, Demory 1985). Unlike Washington, in both California and Oregon it is

95 lawful to land soft-shell crab (PSMFC 1978), but they are seldom retained because of the poor

96 meat quality and recovery rate (Stewart 1974). For the two to three months that it takes post-

97 moult crab to harden and fill in muscle tissue (Dunham et al. 2011, Rasmuson 2013), the meat

98 yield is approximately 13-14% compared to 25-30% for hard-shell crab (Robinson et al. 1977).

99 Harder crab are preferable in meat quality and value for consumers and processors (Barry 1983,

100 Demory 1985, Kruse et al. 1994), and so yield a higher price (Waldron 1958, PSMFC 1978).

101 While fishermen have little incentive to harvest soft-shell crab, there is a period of time when

102 hard-and soft-shell crab co-occur, resulting in incidental capture and discard of both sub-legal

103 and legal-size soft-shell crab.

104

105 Temporal restrictions on harvest were put in place during the approximate moulting period to

106 mitigate handling mortality of soft-shell crab and, therefore, increase the abundance and quality

107 of legal, hard-shell males in the subsequent season (Waldron 1958). The annual season opener

108 for the Oregon commercial ocean crab fishery is December 1<sup>st</sup>, but is delayed if the crab do not

109 meet the minimum meat weight recovery threshold of 25% (Figure 1; Didier 2002, ODFW

110 2009). Beginning the second Monday in June, as soft-shell crab increase in abundance,

111 fishermen are restricted to landing 1,200 pounds (544 kg) of crab per week. This regulation  
112 remains in effect until the season closes on August 15<sup>th</sup> (ODFW 2009). Despite the regulated  
113 season, the majority of the effort and landings currently occur shortly after the season opens  
114 (Didier 2002), and during the first two months of the season. Post-winter, as catch rate decreases,  
115 fishermen often switch to alternative, concurrent fisheries (Youde et al. 1967, PSMFC 1978,  
116 Oregon Sea Grant 2008).

117  
118 Fishing seasons vary across the commercial and recreational fisheries in the ocean and bays  
119 (Figure 1). The commercial bay fishery occurs from the Labor Day holiday (the first Monday in  
120 September) to December 31<sup>st</sup>, except on holidays and weekends (ODFW 2009). The recreational  
121 bay fishery is open year-round, both from a boat and shoreside. Recreational fishing in the ocean  
122 occurs from December 1<sup>st</sup> to October 15<sup>th</sup> (Ainsworth et al. 2012). Unlike the commercial ocean  
123 fishery, the majority of recreational fishing occurs in the summer and fall (June - October), with  
124 effort depending mostly on weather conditions (when fishing is safer and more enjoyable), catch  
125 rates, and timing of vacations. In addition, crabbing in the bay is influenced by rain and river  
126 run-off, which decreases water salinity and reduces catch (Ainsworth et al. 2012).

127  
128 The objective of this study was to evaluate discard rates (i.e., proportion of the total catch that is  
129 discarded) and quantify discard mortality rates (i.e., proportion of the discarded animals that die  
130 as a result of the capture, handling, and release process) in the commercial ocean and  
131 recreational bay by boat Dungeness fisheries along Oregon's coast and in the Yaquina Bay. The  
132 '3-S' management relies upon these rates being low given that this strategy is largely based on  
133 discarding females, and sub-legal and soft-shell males. To further assess '3-S' management for

Dungeness, we evaluated variation in the mortality- and bycatch- per-retained ratios (MPRR, BPRR) over the fishing season. In addition, we make recommendations toward the goal of reducing both bycatch and discard mortality rates.

The impetus for this project was from commercial Oregon Dungeness crab fishermen and their interest in knowing discard mortality rates for the fishery. This aligns with historic efforts by Dungeness crab fishermen to instigate changes in fishing regulations to protect the crab population (Waldron 1958, Wild and Tasto 1983). This research benefited from collaboration among industry, science, and management partners.

## **Materials and Methods**

### **Dungeness Crab RAMP**

To quantify discard mortality rates for the Dungeness crab fisheries we utilized the Reflex Action Mortality Predictor (RAMP) approach. This methodology relates vitality to mortality probability attributed to a stressor(s) through quantifying reflex impairment (Davis and Ottmar 2006, Davis 2007). Ideally, observations on impaired reflexes (or lack of impairment) can be used to estimate the probability of delayed mortality. While this approach has not previously been utilized for Dungeness crab, it has effectively been used to determine bycatch mortality rates and to evaluate mortality attributed to individual fishing stressors (e.g., air exposure or injury from fishing gear) for several fish (Davis and Ottmar 2006, Raby et al. 2012, Barkley and Cadrin 2012, Nguyen et al. 2014) and crustacean species (Stoner et al. 2008, Stoner 2012a, 2012b, Hammond et al. 2013, Rose et al. 2013, Yochum et al. 2015, Urban 2015).

To apply the RAMP approach to discarded crab from these fisheries, we first established a set of reflexes specific to Dungeness, then assessed reflex impairment in crab that endured the stressors specific to the fisheries, determined delayed mortality for crab with varying levels of reflex impairment through captive holding, and, finally, created a reflex action mortality predictor to model the relationship between reflex impairment and probability of delayed mortality.

### *Establishing a Set of Reflexes*

To create a RAMP relationship for Dungeness crab, we first established a set of reflex actions ('reflexes'; e.g., eye retraction when an eye is tapped) that could reliably be used for evaluating vitality. To accomplish this, we captured male and female crab of varying sizes using recreational crab gear in the Yaquina Bay. After being captured, the test crab were placed in an ice chest with wet burlap sacks to reduce stress from air exposure and captivity (Simonson and Hochberg 1986), and were carried less than 1 km to the Alaska Fisheries Science Center (AFSC) laboratory in Newport, Oregon. After being 'burped' to remove air that might be trapped under the carapace (Snow and Wagner 1965), the crab were placed in temperature-regulated (approximately 6 °C) flow-through sea water tanks (2 m diameter, filled to 1 m depth). In the field and over several days in captivity, the crab were assessed several times to identify reflexes that responded consistently to a stimulus. We began by testing RAMP reflexes established for two *Chionoecetes* species (Stoner et al. 2008), and consulted with fishermen who often use vitality assessments to determine whether or not to retain or sell a crab. The crab were allowed to recover in the holding tanks for a week and were then reassessed. Subsequent assessments were

179 completed after exposing the crab to air and mimicking handling stressors (e.g., dropping on the  
180 ground).

181  
182 Through this process, we established a series of six reflexes to test Dungeness crab vitality,  
183 which gave consistent, involuntary responses to stimulation, and a protocol for assessment. The  
184 reflexes include: (i) eye retraction; (ii) mouth defense; (iii) chela closure; (iv) leg wrap; (v) leg  
185 curl; and (vi) abdomen response (in this order; Table 1). The reflexes are tested by holding the  
186 crab vertically (dorsal side facing away), with the left hand, and assessing the right side of the  
187 crab (assessment can be completed on either side; a video demonstrating the reflexes is available  
188 upon request). A reflex is considered absent only if there is no response to stimulation. Similar to  
189 Stoner et al. (2008), we found that it is too subjective to include additional impairment categories  
190 (e.g., strong, moderate, weak). An overall reflex impairment score ('Score') is calculated by first  
191 assessing each reflex and assigning a '0' to present reflexes (including weak responses) and '1'  
192 to those absent, then summing over all reflexes. Davis and Ottmar (2006) calculated Score as a  
193 proportion (one minus the ratio of the total number of impaired reflexes to the total reflexes).  
194 This approach is advantageous if there are reflexes or individuals that cannot be tested due to  
195 missing or damaged body parts. This is seldom the case for these fisheries; therefore, Score was  
196 calculated as the sum of missing reflexes. In addition, reflex impairment is evaluated for live  
197 crab only. In some previous RAMP studies, immediate mortalities (i.e., crab that were dead in  
198 the fishing gear before assessment) were given a Score indicating maximum impairment  
199 (Hammond et al. 2013, Rose et al. 2013, Yochum et al. 2015). This is an advantageous approach  
200 if it is difficult to differentiate between dead and moribund individuals (Stevens 1990). This is



not the case with Dungeness crab; therefore, the contributions to total bycatch mortality by both immediate and delayed mortality were evaluated separately.

### *Assessing Crab*

We focused on the commercial ocean and recreational bay by boat (here forward referred to as ‘commercial’ and ‘recreational’) fisheries because they account for the vast majority of landed Dungeness crab catch (94-98% and 2-6% respectively; Ainsworth et al. 2012, data from 2007-2011). For the recreational fishery we focused on crab in the Yaquina Bay, as opposed to the ocean, because approximately 60% of annual recreational landings are from Oregon bays, and the Yaquina is both a heavily fished site (Ainsworth et al. 2012) and is the nearest bay to the research facility. Moreover, we focused on fishing in the bay by boat instead of from shore because of the low catch-per-angler-day rates for the latter fishery. Regardless, some data were gathered to evaluate bycatch and discard mortality in these additional fisheries, which are described in the Supplementary Data.

Given that a model for predicting mortality from an assessment of reflex actions can be specific to a set of stressors (Yochum et al. 2015), we were careful to both collect bycatch data that were representative of actual fishing practices and to describe the methods and likely stressors associated with crabbing (e.g., soak duration, the duration of time between when a pot was set and retrieved; Musyl et al. 2009). By doing this we endeavored to establish RAMP relationships that can be utilized in future research. To this end, commercial fishery data were collected during ‘ride-along’ trips aboard fishing vessels, which also allowed us to gain feedback from fishermen on project methodology and insight into the fishery. We were unable, though, to dictate depth

strata, location, and other sampling logistics. To evaluate differences among captains and crew members we aimed to complete trips on multiple fishing vessels and out of several ports. Obtaining ride-along opportunities for recreational fishing was difficult due to small vessel size and research permit restrictions prohibiting crab retention. Therefore, approximately half of the recreational sampling was completed on a research vessel by scientists with recreational crab fishing experience. To incorporate intra-annual variability in stressors (e.g., air temperature), we aimed to conduct at least one sampling trip for each calendar month when the fisheries were open.

### Commercial Ocean

Between February 2012 and January 2014, we sampled all strings (a “continuous line of individual crab pots spaced a given distance apart from each other”, Hicks 1987) during ride-along trips. Within each string, the selection of the first crab pot to sample was randomized and, subsequently, every fifth pot was assessed. This systematic sampling protocol was put in place to maintain consistency of sampling between strings, while not slowing down or interfering with fishing operations, and minimizing handling and air exposure for the crab beyond typical fishing processes. Modifications to this protocol were allowed as necessitated by sampling logistics (e.g., poor weather), under the constraint that each sampled pot be selected before it landed on deck.

For each assessed pot, data were recorded on both the conditions under which the pot was fished, and on the retained and discarded crab within. The following information was recorded per pot: (i) soak duration; (ii) sea state at the time the pot was brought onto the boat (Beaufort wind force

scale); (iii) whether or not the crab were removed from the pot using a 'slam bar' (a bar on which a pot is thrown in order to push crab towards the pot opening); (iv) how many crab were retained; (v) the location of the pot within the string; and (vi) the depth where the pot was fished. In addition, retained crab were counted. All crab intended for discard were measured (carapace width, to the nearest millimeter), and sex and shell condition were noted. 'Soft' crab were described as those with little or no hardening (the crab recently moulted) to moderate hardening post-moult (carapace and legs flexible and soft). Crab designated as 'hard' were those with carapace and legs nearly fully hard to near moulting (i.e., the shell condition that would be acceptable to most fishermen for retention). Crab intended for discard were also evaluated for the presence of any new injuries, including: broken, injured, or missing legs/chela, spines, dactyli, maxillipeds, or abdominal flap; autotomized legs/ chela; smashed carapace (ventral and dorsal); holes or cracks in carapace; and damage to an eye. Warrenchuck and Shirley (2002) found that old injuries did not affect mortality in snow crab (*Chionoecetes opilio*), thus only new injuries were recorded. After one or two days post injury a 'sheath' or scab is visible at the site of injury (Durkin et al. 1984). We therefore considered 'new injuries' those without scabbing. For each crab, we noted total air exposure duration and tested each of the established RAMP reflexes to generate a reflex impairment score. Assessments took approximately 30 seconds per crab.

#### Recreational Bay by Boat

During sampling trips completed between April 2012 and April 2014, all pots and rings were assessed. Recorded information was similar to the commercial fishing trips; however, there were no 'slam bars', soak duration was measured in minutes compared to days, and legal crab were 5  $\frac{3}{4}$  inches (146 mm) or larger. All legal-sized males were marked as 'retained' if they were

considered hard-shell by the definition of this study. Also the trips were executed, when possible, according to advice for maximizing catch from the Oregon Department of Fish and Wildlife (ODFW; ODFW 2015c).

### *Measuring Mortality*

To relate reflex impairment to delayed mortality probabilities for the commercial and recreational fisheries, a total of 655 and 321 crab (respectively) were held in laboratory tanks (described previously) to determine survival. In selecting crab, we aimed to hold as many crab as possible that had impaired reflexes and to fill the remaining tank space with unimpaired crab. Regardless, given the catch composition, the majority of held crab for the commercial and recreational fisheries (77% and 88% respectively) were Score-zero (no impaired reflexes; Table S3). We also attempted to hold crab of varying combinations of sex, size, injury, and shell condition over the temporal extent of the fisheries to look at the potential influence on mortality of and interactions among various biological and environmental variables. For the commercial fishery, 54% of held crab were hard-shell females, and 67% were hard-shell males for the recreational fishery. These percentages similarly reflect catch composition.

For identification purposes, all held crab were tagged with a double ‘t-bar’ anchor tag (TBA-LEVO, Hallprint Fish Tags). This tag type was selected because it has successfully been used and has been proven to last through ecdysis for Dungeness crab (Smith and Jamieson 1989, Swiney et al. 2003, Barber and Cobb 2007), and because it can be used for a large range of sizes and cannot be lost during leg autotomization. Necropsies were performed on over 90% of crab that died in holding, which verified that mortality was likely not tag induced.

293  
294 While crab were held in the laboratory for up to one month, cumulative mortality was evaluated  
295 to determine if holding conditions or tagging were influencing survival over time. To this end, at  
296 the beginning of the study we held minimally stressed crab for a month to monitor survival. For  
297 these crab and those held for this study, we observed that cumulative mortality stabilized by the  
298 second day of holding, but began increasing again after day five, even for Score-zero  
299 (unimpaired) crab. Therefore, crab were only considered discard mortalities if they died within  
300 the first five days of holding to avoid confounding discard mortality with a captivity effect. This  
301 threshold holding duration was also based on findings by Yochum et al. (2015) that five days  
302 was an optimal holding duration for Tanner crab when determining mortality. In previous studies  
303 estimating Dungeness crab discard mortality, crab were held for four (Tegelberg 1972) and five  
304 (Barry 1984) days. Tegelberg and Magoon (1970) found that a captivity effect for Dungeness  
305 was evident after four days of holding. While survival of Dungeness in the laboratory can be  
306 improved with cold water temperatures, a pattern of increased mortality over time remains  
307 (Kondzela and Shirley 1993). For discarded Dungeness crab, there may be more long-term  
308 mortality, but it cannot be accurately determined in a laboratory given the unnatural setting and  
309 potential for a captivity effect to confound results.

310  
311 Given our finding of a captivity effect and evidence from other studies that Dungeness crab can  
312 be difficult to keep alive in captivity (Barnett et al. 1973), we determined ways to reduce stress  
313 and injury attributed to captivity and transport. We found that the captivity effect was  
314 ameliorated by holding crab in individual containers. Similar to Jacoby (1983), we found  
315 agonistic behaviour primarily between females. Therefore, the majority of crab were held in

individual compartments. We also cleaned the holding tanks weekly, maintained cold water temperatures to reduce stress (approximately 6 °C; Burton 2001, Bellchambers et al. 2005), and periodically checked the oxygen and ammonia levels (Barrento et al. 2008). We also fed the crab weekly and performed daily checks to monitor for (and remove) dead crab. To reduce impact from at-sea holding and during transfer, crab from commercial fishing trips were placed, after assessment, into an insulated fishing tote (interior dimensions: 91 cm x 53 cm x 53 cm) equipped with flow-through seawater during fishing operations (Basti et al. 2010). They were transported in ice chests with wet burlap sacks approximately 3.5 km to the holding facility. Crab from recreational trips, following assessment, were placed directly into ice chests with wet burlap sacks that were periodically re-soaked with seawater before taking the crab to the same holding facility (<1 km away).

### *Predicting Mortality from Impaired Reflexes*

Binary logistic regression was used to determine if there was a relationship between the number of impaired reflexes (Score) and mortality, measured as the proportion of the 655 crab that died in holding for the commercial ocean fishery, and 321 for the recreational fishery. Model coefficients were estimated using maximum likelihood (Ramsey and Schafer 2002) based on the fate (mortality or survival) of individual crab that were held, as shown in Table S3. ‘Score’ was treated as a continuous and categorical variable (in separate analyses), and with individual reflexes as predictors. We also included fishing, environmental, and biological explanatory variables in the model to determine their role in predicting mortality.

*Equation 1*      $\text{Log}_e \left( \frac{p}{1-p} \right) = \alpha + \beta_o \text{Score} + \beta_i x_i$ , where:

$p$  = probability that a crab died during the holding period

$\alpha$  = intercept

$\beta_0$  = model coefficient for reflex impairment score ('Score')

$\beta_i$  = model coefficients for the explanatory variables ( $x_i$ ) tested in the model

To determine the most parsimonious logistic model for the data, we performed forward stepwise model selection in R (R Development Core Team 2011) using a function (addterm) that allowed us to determine significance of individual predictors based on Akaike Information Criteria, and through drop-in-deviance tests. Model selection drew from a rich model that included a large number of possible explanatory variables: (i) reflex impairment score; (ii) sex; (iii) shell condition; (iv) carapace width (continuous); (v) fishery type; (vi) month; (vii) air exposure duration; (viii) number of crab retained; (ix) presence of new injuries; and interactions among these variables. Model selection was completed with several categories of injury, as well as the presence (non-specific) or absence of injuries. When analyzing the fisheries separately, (i) use of the slam bar; (ii) soak duration (days), (iii) depth (fathoms), and (iv) Beaufort wind force scale were included for the commercial analysis; and (i) soak duration (min), (ii) depth (meters), and (iii) gear type (ring or pot) for the recreational analysis.

### Quantifying Discard Mortality Rates

While only held crab were utilized to create the logistic model for predicting the probability of mortality, to quantify the overall fishery discard mortality rates we utilized data on all assessed crab from the sampling trips in the following equation.

Equation 3 
$$P(m) = \sum_{k=0}^6 P(m|s = k) * P(s = k)$$

We summed over all Scores ( $s$ ),  $k=0-6$ , the product of the probability of mortality, given Score,  $P(m|s = k)$ , by the probability of catching a crab with that Score (from ride-along data; Table S2) using the following.

Equation 4 
$$P(s = k) = \frac{n_k}{n_{total}}$$

$P(m|s = k)$  was predicted by the regression model and its prediction variance was estimated using the predict() function in R. For each Score,  $k$ , we calculated the prediction variance of the product  $P(m|s = k) * P(s = k)$  using the delta method (Rice 1988). The prediction variance of  $P(m)$  was then estimated as the sum of variances of these products across all Scores, assuming independence among Scores. Finally, the 95% Confidence Interval for  $P(m)$  was estimated as  $P(m) \pm 1.96\sqrt{(\text{variance of } P(m))}$ .

Bycatch mortality rates (i.e., proportion of bycaught animals- non-target crab and immediate mortalities- that die) were calculated similarly, but included crab that died prior to assessment (immediate mortality). Estimates of mortality-per-retained ratios (MPRR) and bycatch-per-retained-ratios (BPRR) were calculated by dividing the number of mortalities (both immediate and predicted delayed) and bycaught crab (discarded alive or dead) by the number of crab retained.



## Results

### Dungeness Crab RAMP

#### *Establishing a Set of Reflexes*

We looked for patterns in reflex impairment to determine if fewer reflexes could be used for assessment (i.e., if some reflexes were seldom lost or linked, or others were primarily lost). We found that, for the majority of assessed males, if only one reflex was lost (Score-one) it was Chela Closure (64%), followed by Leg Wrap (26%). Similarly, for females, Chela Closure was most frequently the first reflex to be lost (49%); however, this was followed by Abdomen Response (20%) then Leg Wrap (18%). Of all lost reflexes, for males, 56% were Chela Closure, followed by Leg Wrap (28%), and Mouth Defense (10%). For females, Chela Closure (39%) was followed by Abdomen Response (23%), Leg Wrap (18%), and Mouth Defense (14%). For both sexes, the Leg Curl and Eye Retraction reflexes were seldom lost. Despite patterns in reflex loss, we could not determine reflexes that could be linked or eliminated given the low numbers of impaired crab (only 242 assessed live crab, both fisheries combined, had more than one impaired reflex).

#### *Assessing Crab*

We completed 26 sampling trips for the recreational and 22 for the commercial Dungeness crab fisheries, assessing 7,685 total crab. More information on sampling trips, catch composition, and size distributions can be found in the Supplemental Data (Tables S1 and S2, and Figure S1). Catch size and composition of the commercial and recreational fisheries varied by time from fishery opening and trip, respectively (Figures 2 and 3). Over all sampling trips (not factoring in sampling frequency by month), 57% of discarded crab from the commercial fishery were hard-

shell females, and 28% were hard-shell males. Conversely, for the recreational trips, 53% were sub-legal, hard-shell males and 26% were hard-shell females. There were few soft-shell females caught during trips for either the commercial or recreational fishery (1% and 8% respectively), nor soft-shell males (11% and 12%).

### Commercial Ocean

Two ride-along trips were completed for each calendar month of the fishing season except for December (one trip) and August (no trips). Sampling was completed aboard four different vessels from two fishing ports (Newport and Florence, Oregon). One trip was completed on the opening day of the fishing season, and in another season on the second day. Soak duration ranged from 1.5 to 30 days (6 days on average), and sea state from 1 to 6 (3 on average; Beaufort wind force scale). Pots were fished in depths ranging from 5.5 to 150 meters. Of all assessed crab, 83% were Score-zero, 10% were Score-one, 3% had Scores greater than one, and 3% were immediate mortalities (Table S2).

The data revealed temporal trends in catch composition. This included that the number of immediate mortalities and soft-shell males per pot increased towards the end of the fishing season (Figure 2). While few soft-shell females were caught throughout the season, the percentage of legal-size males (both discarded and retained) that were considered soft-shell ranged from 0-2% for the majority of the season, then increased in June to 23% and up to 87% in July. Similarly, 0-10% of caught sub-legal males were soft until July, when the percent increased to 50%. In addition, females were uncommon during the trip taken on opening day and were approximately a quarter or less of the discarded catch during the first week of the season and in

July. For trips completed during the middle of the fishing season, however, females comprised the majority of discards. Moreover, the portion of the catch retained decreased over the fishing season. When sampling was completed on the first trip of the season, 92% of the catch was retained (25 retained per pot), 74% two days after the opening in the previous season (9 retained per pot), 55% two weeks after the opening (five retained per pot), then from four weeks to 28 weeks after the season opened, the range of retention was between 11-76% (1-5 retained per pot). In July, 29 weeks after fishing began, only 6-7% of the catch was retained (1-2 per pot). Additionally, 32% of discarded hard-shell males were legal size in July, indicating high-grading for crab with minimal superficial damage and both chela was potentially occurring coincident with when the pound limit was in effect.

#### Recreational Bay by Boat

Two recreational trips were completed during each calendar month with the exception of April (five trips), August (no trips), and October (three trips). During these trips, on average, there were 14.8 pot/ring pulls per trip (range: 8-33). Of assessed crab, on average by trip, there were 6.0 Score-zero (range 0.1-17.2) and 0.5 (range: 0-1.8) crab with Scores greater than zero per pot/ring. There were, on average by trip, 0.2 (range: 0-1.1) crab retained and 5.9 (range: 0.3-15.9) crab discarded per pot/ring. Of all assessed crab, 92% were Score-zero, 6% were Score-one, 2% were Score-two, 5% had new injuries, and there were no immediate mortalities. There were no clear patterns in the number of crab retained or discarded over time; variation was greater among trips (Figure 3). There were, however, slightly more crab discarded per gear for rings than pots (6.61 and 5.25 respectively) and slightly more crab retained per gear for rings than pots (1.98 and 1.56 respectively) when all data were combined.

### *Predicting Mortality from Impaired Reflexes*

Preliminary model selection on all data combined indicated a significant difference (significance in this paper tested at an alpha value of 0.05) between fishery types, namely that recreational had lower mortality probability than commercial. We therefore analyzed the data discretely by fishery type (Table S4) to allow for fishery-specific variables in the analysis (e.g., use of the slam bar).

For the commercial crabbing data, preliminary analyses indicated that Score, sex, and shell hardness were variables that influenced mortality. The data indicated that there were differences between females and males and, within males, soft- and hard- shell. We therefore grouped the data using a sex-shell condition variable: female, hard-shell male, and soft-shell male. Model selection using Akaike Information Criteria and drop in deviance tests indicated that the most parsimonious model included only the 'sex-shell condition' variable in addition to Score (Figure 4). Overall, hard-shell males had the lowest mortality probability for a given Score and those with soft shells had the highest. Alternative models including (i) interactions, and (ii) the presence of new injuries did not significantly improve model fit (p-values 0.08 and 0.20 respectively; Table S4). Moreover, Score best predicted mortality probability when it represented the summation of all six reflexes as a continuous variable rather than as a categorical Score (p-value 0.05), or modeling the reflexes discretely (p-value 0.24). Model selection for the recreational fishery indicated that the most parsimonious model included only one variable: whether or not the crab was Score-zero (Table S4). While the presence of new injuries appeared to increase the probability of mortality, it did not significantly improve model fit (p-value 0.12).

Resultant mortality probabilities, from the data and model, were 0.3% for Score-zero crab, and 7.7% for those with higher Scores.

## Quantifying Discard Mortality in the Fisheries

### *Commercial Ocean*

Delayed discard mortality rates were calculated grouping the data by string, trip, and month, and also combining all data. Differences were observed in these estimated rates for soft-shell males. This was attributed to uneven sample sizes in the different data groupings. We therefore constructed 95% Confidence Intervals for estimates by string, trip, and month to see if there were trends in mortality rates that were overlooked in the logistic regression analysis. This analysis indicated that there were no significant differences by these data groupings, with the exception of grouping female data by month (Figure 5). During one trip in December only four female crab were caught, which heavily influenced mortality rates. No other significant patterns were determined; therefore, we calculated final rates with all data combined.

Predicted discard mortality rates (five days after release, integrated over Scores) were 0.080 (95% Confidence Interval 0.061-0.100) for females; 0.012 (95% Confidence Interval 0.002-0.022) for hard-shell males; and 0.092 (95% Confidence Interval 0.026-0.157) for soft-shell males. While we did not detect significant monthly variations in discard mortality rates, the mortality- and bycatch-per-retained ratios (MPRR, BPRR) increased over the fishing season (Figure 6). During a ride-along trip on opening day of the 2013/14 season, MPRR was 0.001 (688 crab were retained per mortality) given high catch of legal crab and low discard rates. On the second day (in the previous season) MPRR was 0.014 (73 crab retained per mortality).

MPRR increased through the season until July when the value, at its highest, was 1.46 (range 0.23-1.46). Likewise, the BPRR was 0.092 and 0.35 for trips conducted on the opening day and two days following the opener of the fishing season, and increased through the fishing season until July when 14.4 crab were bycaught (range 2.016-14.4) for each retained crab.

### *Recreational Bay by Boat*

Delayed discard mortality rates were similarly evaluated with 95% Confidence Intervals when analyzing the data by trips and months. Because there were no significant differences detected, we combined data over all trips. The discard mortality rate was estimated to be 0.009 (95% Confidence Interval 0-0.018). There were no clear spatial or temporal trends in mortalities. With respect to MPRR and BPRR, not including trips when no crab were retained (n=6), there were 39.93 crab, on average, bycaught per retained crab (range 5.53-127.0). Meaning that, on average, only 4% of the catch (by number) was retained (range 0-15%). Moreover, there were, on average, 0.26 predicted mortalities per retained crab (range: 0.00-1.60; i.e., for every 3.8 crab that were retained, a discarded crab was predicted to die).

## **Discussion**

### Dungeness Crab RAMP

The RAMP approach was effective in determining the primary influences on short-term (5-day) delayed discard mortality and quantifying discard mortality rates for Dungeness crab. An advantage of RAMP is that it eliminated possible bias linked with selecting animals for captive observation. If bycaught crab are held in captivity to determine discard mortality without using RAMP and only the healthiest or most impaired animals are unknowingly selected for

523 evaluation, estimates will not be accurate (Musyl et al. 2009). In addition, by applying the  
524 regression models relating mortality with Score to ride-along data for the frequency of the  
525 different Scores collected over the extent of the fishing season, and on a number of trips and a  
526 variety of vessels, our mortality rates were estimated over a broad sample of crab. This allowed  
527 for estimated rates that are more representative of the fishery than if a non-RAMP approach was  
528 applied, given limitations in the number of crab that can be logistically held in captivity.  
529 Moreover, the reflex impairment score incorporated the effects of injury. This was similar to  
530 findings by Stevens (1990) that vitality scoring is a better predictor of survival than presence of  
531 injuries. Without needing to score for injury, there is a reduction in subjectivity bias in  
532 assessment given that it is easy to overlook an injury. Also, it is time-consuming to do a  
533 thorough assessment of injuries for each individual crab and all injuries are not necessarily  
534 external.

535  
536 While we felt the RAMP approach was effective, we acknowledge that there were limitations in  
537 data analysis and collection. When mortality is determined by holding animals in captivity, long-  
538 term survival and mortality attributed to increased susceptibility to predation or inability to eat  
539 cannot be assessed. Therefore, the discard mortality rates from this study should be viewed as  
540 minimum values that do not include possible long-term mortality resulting from capture and  
541 discard. With respect to limitations in analysis, low numbers of impaired crab (i.e., crab with  
542 Scores greater than zero) prevented a thorough assessment of some of the potential explanatory  
543 variables and interactions among them (e.g., mortality rates for soft- vs. hard-shell females). The  
544 infrequency of impaired crab also required us to extrapolate and interpolate mortality rates for  
545 Scores with limited to no data using the logistic curve. In addition, consistent with findings by

Yochum et al. (2015) that a RAMP relationship can be specific to a set of stressors, we determined that separate RAMP relationships are required for the commercial and recreational fisheries. This result could have been influenced, however, by the fact that 67% of crab held for the recreational fishery were hard-shell males, and only 19% had soft-shells. Given that hard-shell males have the highest survival rate, this could have affected our ability to differentiate mortality probabilities between the fisheries, making the recreational mortality rate sensitive to the composition of held animals. For RAMP information related to recreational shoreside and ocean fishing see the Supplementary Data.

#### Quantifying Discard Mortality Rates

Delayed discard mortality rates of sub-legal, soft-shell male, and female Dungeness crab from this study are similar to, yet lower than previous estimates for the commercial fishery. Barry (1984) found that the discard mortality rate for soft-shell Dungeness was 12.9% (and as low as 11.3%), and 0% for hard-shell crab after 3 days of holding. Tagging studies by Cleaver (1949), Waldron (1958), and Kruse et al. (1994) similarly indicated increased discard mortality for soft-shell crab compared to hard-shell. Likewise, a study by Tegelberg and Magoon (1970) found that hard-shell crab had a handling mortality rate of 4%, and 16% for soft-shell. Tegelberg (1972) also found that when tagged with Peterson disc tags (but not with epimeral suture line dart tags that were more similar to those used in our study) these rates increased (23-41%, the latter with increased holding and handling), and that mortality increased to 57% when soft-shell crab were dropped. Alverson et al. (1994) reported that mortality estimates for the coast-wide pot fishery ranged from 22-25% for soft-shell crab and 2-4% for hard-shell sub-legal crab.



569 Previously estimated mortality rates are higher than those estimated from this study, likely due to  
570 differences in study methodology. For example, Tegelberg (1972) held crab together in groups of  
571 25. Given that he estimated cannibalism rates to be 6.8% on soft-shell crab, depredation could  
572 have contributed to relatively high mortality rates from that study compared to ours, in which  
573 crab were held captive individually. Mortality attributed to tagging could have also influenced  
574 estimated rates from previous studies. We were able to improve upon prior methodologies and to  
575 generate discard mortality rates that are more representative of Oregon fisheries. We  
576 incorporated representative composition of the levels of reflex impairment that result from the  
577 fishing process, and detected differences in mortality rates not only by shell condition, but by sex  
578 and fishery. We acknowledge, however, that our estimates and confidence limits may not be  
579 representative of fishermen that are less careful with handling than those with whom we sampled  
580 crab.

581  
582 We note that in comparing soft-shell mortality rates among studies there may be problems due to  
583 inconsistent definitions of ‘soft’. For Dungeness, soft-shell crab have been defined as such based  
584 on meat weight recovery rates (Robinson et al. 1977, ODFW 2009); physical appearance  
585 (encrustation, color, etc.) and flexibility of carapace and legs (Waldron 1958, Tegelberg 1972,  
586 Barry 1983, Hicks 1987, Fisheries and Oceans Canada 2014); and time relative to moulting  
587 (Reilly 1983, Dunham et al. 2011). Other studies have utilized a combination of these descriptors  
588 to define shell condition (Spears 1983, Penson JR and Tetty 1988 from Somerton and Macintosh  
589 1983, Hicks and Johnson 1999, Lippert et al. 2002), and others used durometer measurement  
590 (Hicks and Johnson 1999, Fisheries and Oceans Canada 2014). The durometer is a spring driven  
591 device that measures, in durometer units 0-100, the pressure required to indent the exoskeleton

(Hicks and Johnson 1999). While the durometer has the advantage of generating an objective, measured value for shell hardness, there are limitations to this method. These include that the measurement (i) is subjective to the body part measured as there is variation in how quickly different parts of the crab harden; (ii) cannot be repeated because the device softens and cracks the shell; (iii) varies with how quickly the operation is completed; and (iv) does not factor in decreases in shell hardness with old age (Foyle et al. 1989). In addition to the concern of accurate readings, the terms ‘hard’, ‘intermediate’, and ‘soft’ for some studies were largely undefined (e.g., Northrup 1975), and vary in practice. During our ride-along trips we noted that what was considered ‘too soft’ for retention varied by fisherman, typically by the amount of experience handling crab and the target market for the product, and was influenced by whether or not the crab was caught when the pound limit was in effect (starting the second Monday in June). We therefore highlight the importance of clarifying what is meant by ‘soft’ and the importance for consistency in designation of shell condition, including how ‘soft’ is defined, what part of the crab is assessed, and how much pressure is exerted when testing. Also, dividing ‘soft’ into two categories (very recent moult or ‘jelly crab’, and soft with some hardening) might provide more information on discard mortality. Moreover, we recommend measuring an area of the crab that hardens last, namely the ventral surface of the carapace, halfway between the 10th anterolateral spine and the coxa of the second walking leg (Hicks and Johnson 1999).

### 3-S Management

Previous research has deemed the current management practices for the Oregon Dungeness crab fishery to be conservative “relative to what the population can sustain” (Heppell 2011). Moreover, the commercial fishery was awarded a certification for sustainability by the Marine

Stewardship Council (Daume and DeAlteris 2014). In accordance with these findings, we determined that discard mortality rates are relatively low for the commercial and recreational Dungeness crab fisheries. This finding supports the goals of the ‘3-S’ management strategy to protect sub-legal, female, and soft-shell crab. However, it is important to consider mortality- and bycatch-per-retained ratios (MPRR, BPRR), and occurrence of soft-shell crab when evaluating management for this fishery, especially with respect to temporal trends.

In addition, while Dungeness discard mortality rates are relatively low, the potential suite of stressors experienced by discarded crab could be reduced and future research to determine optimal fishing locations and ways to conduct fishing operations would benefit bycatch and discard mortality mitigation (Figure 7). To determine best practices for reducing discard mortality rates we recommend utilizing the RAMP approach and, where applicable, the RAMP relationships created from this study.

### *Size*

Given the low discard- and immediate- mortality rates for sub-legal males, the ‘size’ component of the ‘3-S’s benefits the population and fishery by allowing male crab to reproduce for one or more additional reproductive cycles, and to grow, yielding more meat weight per individual in future seasons. This study, however, did not evaluate the minimum size nor the potential benefits of adjusting this regulation.

### *Sex*

While females were the majority of discard and discard mortality for the commercial fishery, and discard- and immediate- mortality rates were higher than that for hard-shell males, the relatively low discard mortality rates indicates that it is advantageous to release females. This allows for protection of reproductive females and avoidance of harvesting crab with inferior meat yield. Moreover, current management regulations with the estimated discard mortality rates allow the population to maintain high levels of eggs-per-recruit (Heppell 2011).

#### *Season*

The most evident pattern in discard and discard mortality was in the temporal variation for the commercial fishery. For one, the percent of captured legal-size males that were soft increased from 0-2% from December to May, to 23-87% in June and July (Figure 2). These latter values exceed the 10% threshold used by the Fish Commission of Oregon in 1948 to determine when to close the fishery (Waldron 1958). We note, however, that the percentages from our study were calculated from a limited number of sampling trips that were not stratified by depth or location.

In addition, MPRR and BPRR increased as the season progressed. As available legal-size crab abundance decreased, each retained crab came at an increasing cost in terms of discards and discard mortality. Zhang et al. (2004) found that, for Dungeness, with a handling mortality rate of 5% or 10%, above a BPRR of 40 or 20 (respectively; discarded sub-legal male only to legal-sized crab), there is net loss in long-term yield. The ratio for the commercial fishery (including females, and sub-legal and legal size males) is below these thresholds and, while BPRR is near these levels for the recreational fishery, the mortality rate is lower. We note that our estimates of MPRR and BPRR are based on a limited number of sampling trips, and could be influenced by

fisherman skill level and definition of a ‘soft’ crab, and high-grading when the pound limit is in effect. Regardless, the trend of increasing MPRR and BPRR is apparent and reflects a decrease in catch of legal crab and an increase in non-target catch as the season progresses. In contrast, when monthly values of MPRR and BPRR (average of trips by month) were speculatively applied to ODFW commercial landings data for the 2011/12 and 2013/14 fishing seasons (converting pounds to individual landed crab by approximating each crab to weigh two pounds; Waldron 1958), we estimated that approximately half of the total discards and bycatch mortality took place in the first three months of the season. While MPRR and BPRR were lowest for the commercial fishery at the beginning of the season, the fleet-wide effort was highest at this time resulting in higher total mortality and discard than in the subsequent months.

To determine whether the commercial fishery closure is appropriately set on August 15<sup>th</sup> an in-depth assessment is required of the trade-offs between discard, and discard- and natural-mortality rates, while factoring in socioeconomic considerations and fleet dynamics. It should also be considered, given that mortality is a function of effort, how the impact on soft-shell crab would be affected if effort in the spring and summer were to increase in the future due to increased price per pound of crab, or low prices or catch in concurrent alternative fisheries. Moreover, in evaluating efficacy with the current management strategy, high effort with low bycatch and discard mortality rates in the beginning of the season should be weighed against the increase in soft-shell crab, and hence higher mortality rates, and in MPRR and BPRR later in the season.

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Table 1            The established reflexes used to assess Dungeness crab (*Cancer magister*) vitality to create a Reflex Action Mortality Predictor (RAMP), along with the method for assessment and metrics for determining if a given reflex is ‘present’ or ‘absent’.

	<b>Reflex</b>	<b>Method</b>	<b>Present</b>	<b>Absent</b>
1	<b>Eye Retraction</b>	A probe is used to lightly tap the top of an eye	Crab retracts the eye downward	Crab does not react, leaving the eye in place
2	<b>Mouth Defense</b>	A probe is used to attempt to pull forward the 3 <sup>rd</sup> maxillipeds	Crab defends its mouthparts with its chela making it difficult to access the maxillipeds	Crab allows it's maxillipeds to be manipulated
3	<b>Chela Closure</b>	A probe is placed below the chela dactyl	Crab reacts by closing the chela tightly, then opening it again without manipulation	Crab does not open and close its chela without manipulation
4	<b>Leg Wrap</b>	A probe is used to pull pereopods 2-4 to a 180 degree angle	Crab draws the pereopods back in (i.e., joints at less than a 180 degree angle)	Crab pereopods do not move without manipulation
5	<b>Leg Curl</b>	Pereopod 5 is straightened and pulled downward	Crab pulls up and curls its pereopod in a controlled manner	Crab does not move the pereopod without manipulation
6	<b>Abdomen Response</b>	A probe is used to attempt to pull the top of the abdominal flap away from the crab's body	Crab exhibits a strong, agitated reaction	Crab does not react

## Figures

Figure 1 The fishing season for Oregon's recreational (grey) and commercial (black) fisheries for Dungeness crab (*Cancer magister*) in both the Pacific Ocean and adjacent bays.

Figure 2 Catch composition for each commercial ocean sampling trip (n=22), including the number of sub-legal (<159 mm) and legal male (hard- and soft-shell), female (all sizes and shell conditions combined), and dead ("immediate mortalities", including all sex and shell condition categories) crab intended for discard per pot, and number of retained crab per pot. Males without a specified shell condition were not included (n=15). Trips are listed by number of weeks past the opening of the fishing season (\*: the first two trips are listed by days from the fishery opening). Indicated are the calendar months that the trips took place and the sampling year: first (2011/12), second (2012/13), and third (2013/14) sampled fishing seasons correspond to number of bars. For trips in June and July, the numbers above the bars indicate the percent of legal-size male crab (those retained and discarded) that were soft. For the remaining trips, the percentage ranged from 0-2 by trip.

Figure 3 Catch composition for each recreational bay by boat sampling trip (n=26), shown by the numeric calendar month and year sampling took place, of crab intended for discard (hard- and soft-shell sub-legal, <146 mm, and legal male, and female crab) and those retained.

911     Figure 4     Logistic model predictions of the probability of mortality by reflex impairment  
912                   score (‘Score’) for Dungeness crab (*Cancer magister*) discarded from the  
913                   commercial ocean crab fishery by sex-shell condition (‘Predicted Mortality’); and  
914                   the actual proportions of the 392 female (Scores 0-5), 213 hard-shell male (Scores  
915                   0-3), and 50 soft-shell male (Scores 0,1,3, and 6) crab that died during laboratory  
916                   holding (five days of observation; ‘Actual Mortality’) with dot size reflecting the  
917                   number of crab held by sex-shell condition and Score.

918  
919     Figure 5     Estimated delayed discard mortality rates for Dungeness crab (*Cancer magister*)  
920                   with 95% Confidence Intervals for the commercial ocean fishery evaluated by  
921                   month of sampling and sex-shell condition.

922  
923     Figure 6     By commercial ocean sampling trip (n=22), the number of mortalities (discard  
924                   mortality and immediate mortality, those dead in the pot), and the number of  
925                   bycaught crab (discard and immediate mortality) per retained Dungeness crab  
926                   (*Cancer magister*; MPRR and BPRR), and the percent of the total catch retained  
927                   listed by number of weeks past the opening of the fishing season (\*: the first two  
928                   trips are listed by days from the fishery opening). Indicated are the numeric  
929                   months that the trips took place and the sampling year: first (2011/12), second  
930                   (2012/13), and third (2013/14) sampled fishing seasons correspond to number of  
931                   bars.

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Figure 7 The potential stressors experienced by Dungeness crab (*Cancer magister*) in directed recreational and commercial crab fisheries, and recommendations for future research and ways to reduce these stressors.

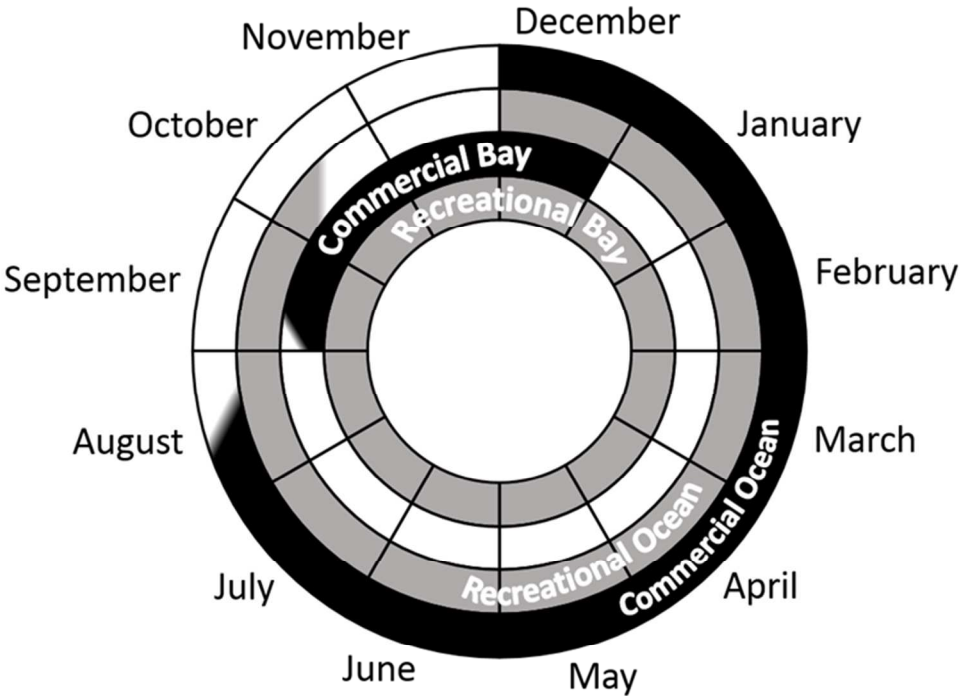


Figure 1 The fishing season for Oregon's recreational (grey) and commercial (black) fisheries for Dungeness crab (*Cancer magister*) in both the Pacific Ocean and adjacent bays.

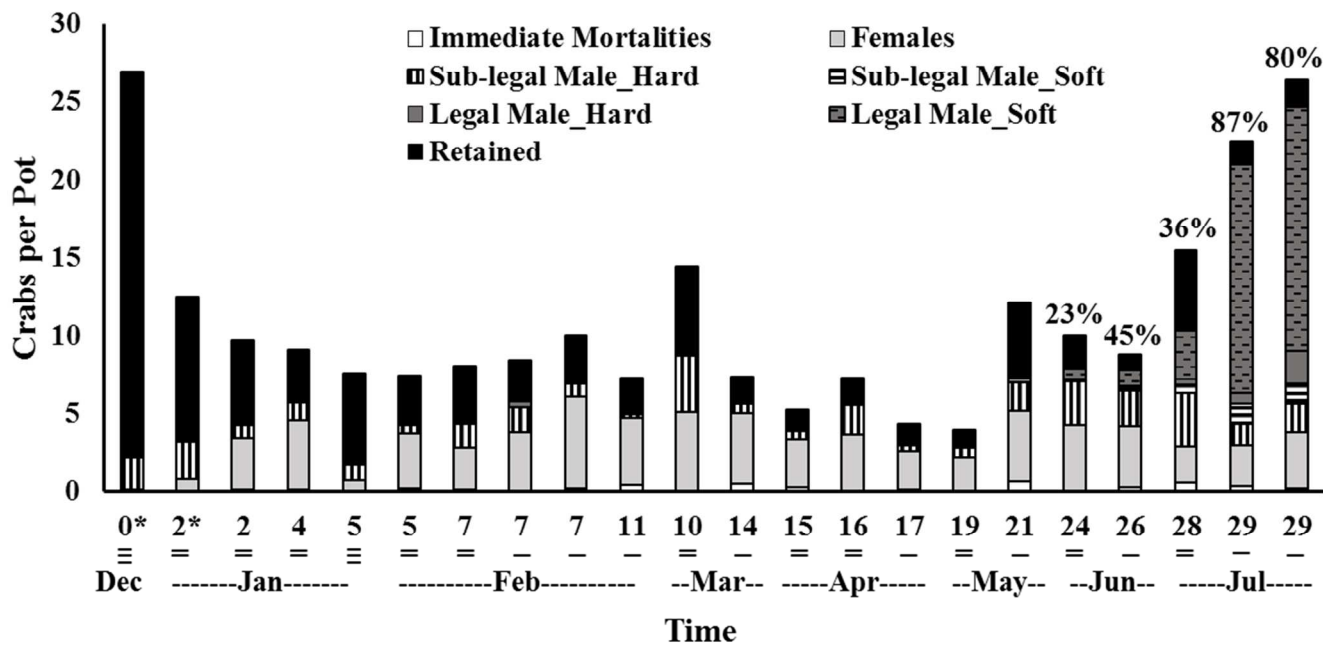


Figure 2 Catch composition for each commercial ocean sampling trip (n=22), including the number of sub-legal (<159 mm) and legal male (hard- and soft-shell), female (all sizes and shell conditions combined), and dead (“immediate mortalities”, including all sex and shell condition categories) crab intended for discard per pot, and number of retained crab per pot. Males without a specified shell condition were not included (n=15). Trips are listed by number of weeks past the opening of the fishing season (\*: the first two trips are listed by days from the fishery opening). Indicated are the calendar months that the trips took place and the sampling year: first (2011/12), second (2012/13), and third (2013/14) sampled fishing seasons correspond to number of bars. For trips in June and July, the numbers above the bars indicate the percent of legal-size male crab (those retained and discarded) that were soft. For the remaining trips, the percentage ranged from 0-2 by trip.

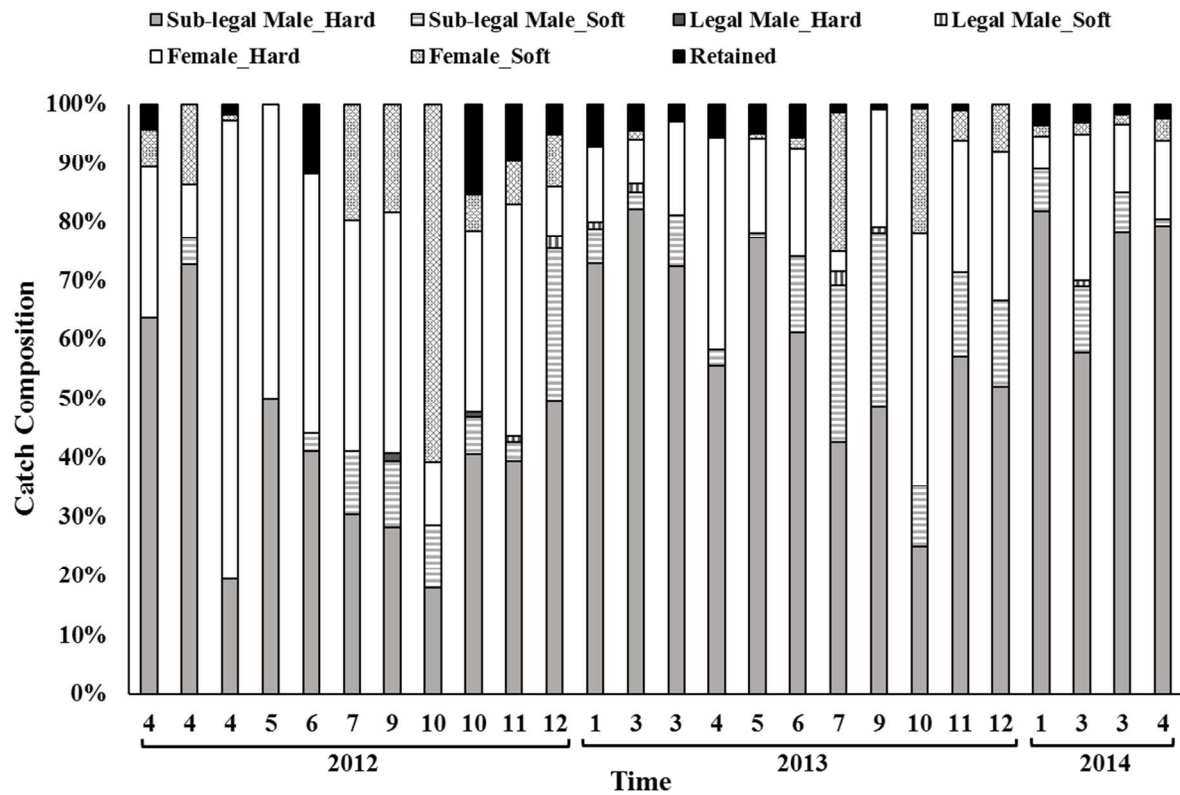


Figure 3 Catch composition for each recreational bay by boat sampling trip (n=26), shown by the numeric calendar month and year sampling took place, of crab intended for discard (hard- and soft-shell sub-legal, <146 mm, and legal male, and female crab) and those retained.



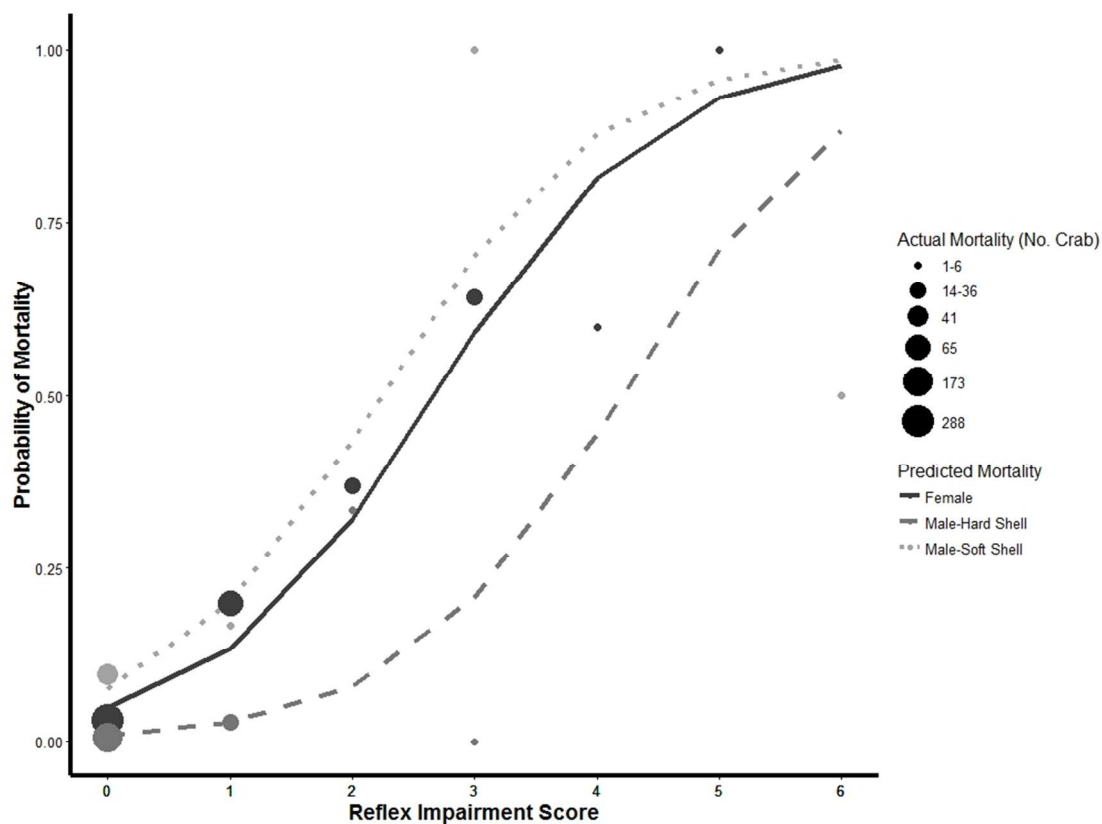


Figure 4 Logistic model predictions of the probability of mortality by reflex impairment score (‘Score’) for Dungeness crab (*Cancer magister*) discarded from the commercial ocean crab fishery by sex-shell condition (‘Predicted Mortality’); and the actual proportions of the 392 female (Scores 0-5), 213 hard-shell male (Scores 0-3), and 50 soft-shell male (Scores 0,1,3, and 6) crab that died during laboratory holding (five days of observation; ‘Actual Mortality’) with dot size reflecting the number of crab held by sex-shell condition and Score.

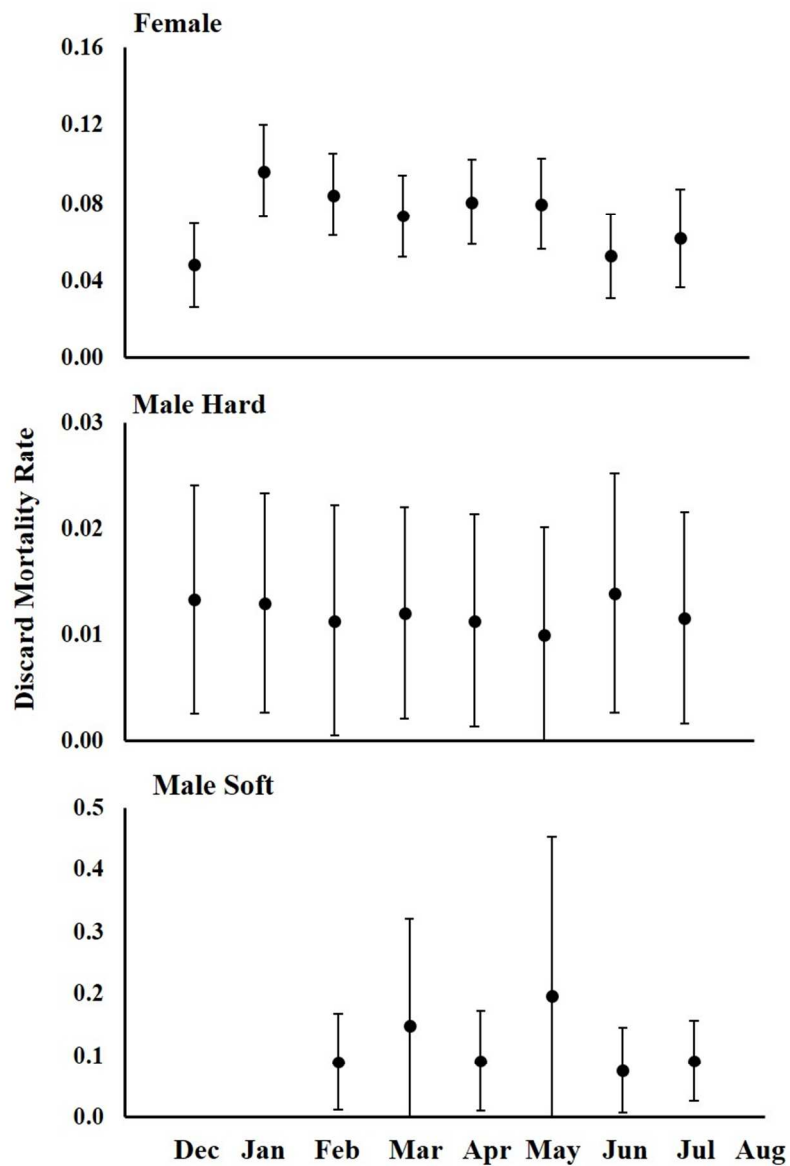


Figure 5 Estimated delayed discard mortality rates for Dungeness crab (*Cancer magister*) with 95% Confidence Intervals for the commercial ocean fishery evaluated by month of sampling and sex-shell condition.

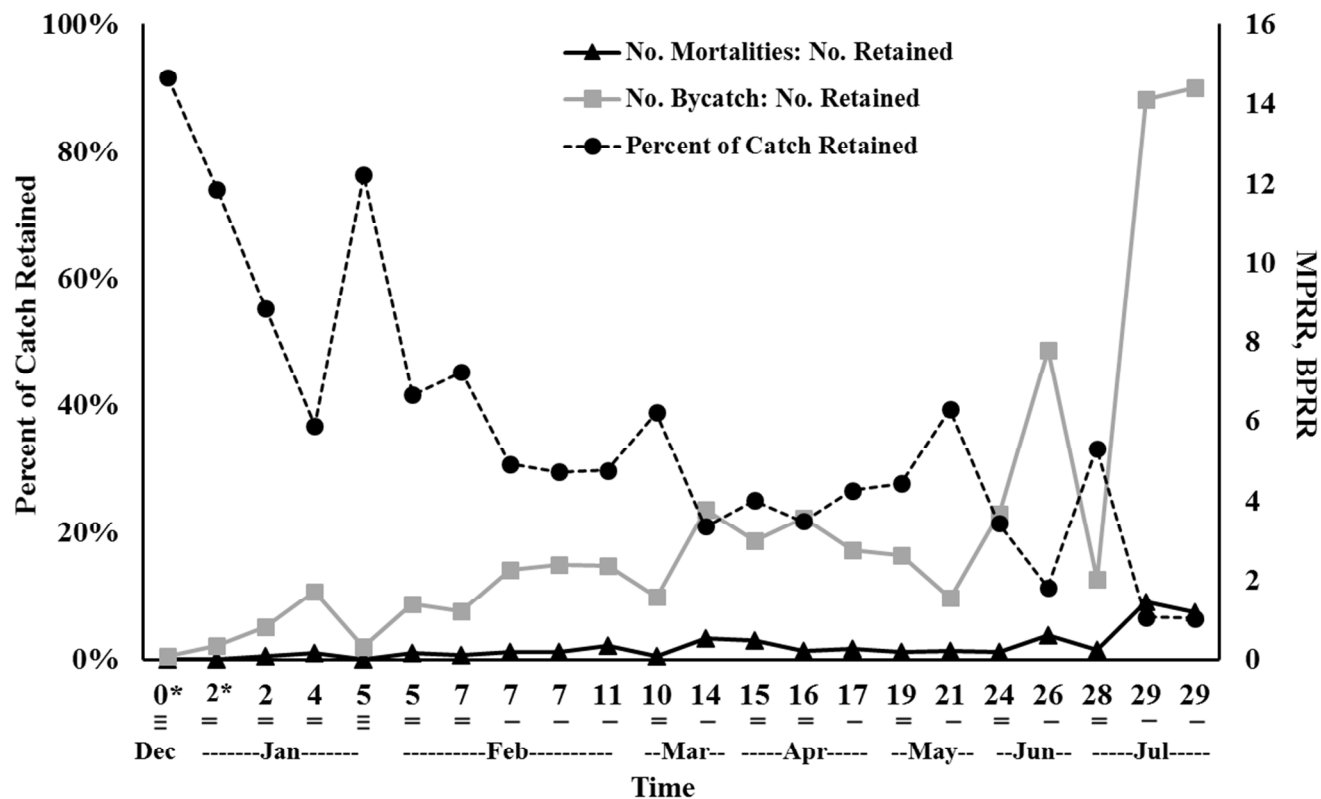


Figure 6 By commercial ocean sampling trip (n=22), the number of mortalities (discard mortality and immediate mortality, those dead in the pot), and the number of bycaught crab (discard and immediate mortality) per retained Dungeness crab (*Cancer magister*; MPRR and BPRR), and the percent of the total catch retained listed by number of weeks past the opening of the fishing season (\*: the first two trips are listed by days from the fishery opening). Indicated are the numeric months that the trips took place and the sampling year: first (2011/12), second (2012/13), and third (2013/14) sampled fishing seasons correspond to number of bars.

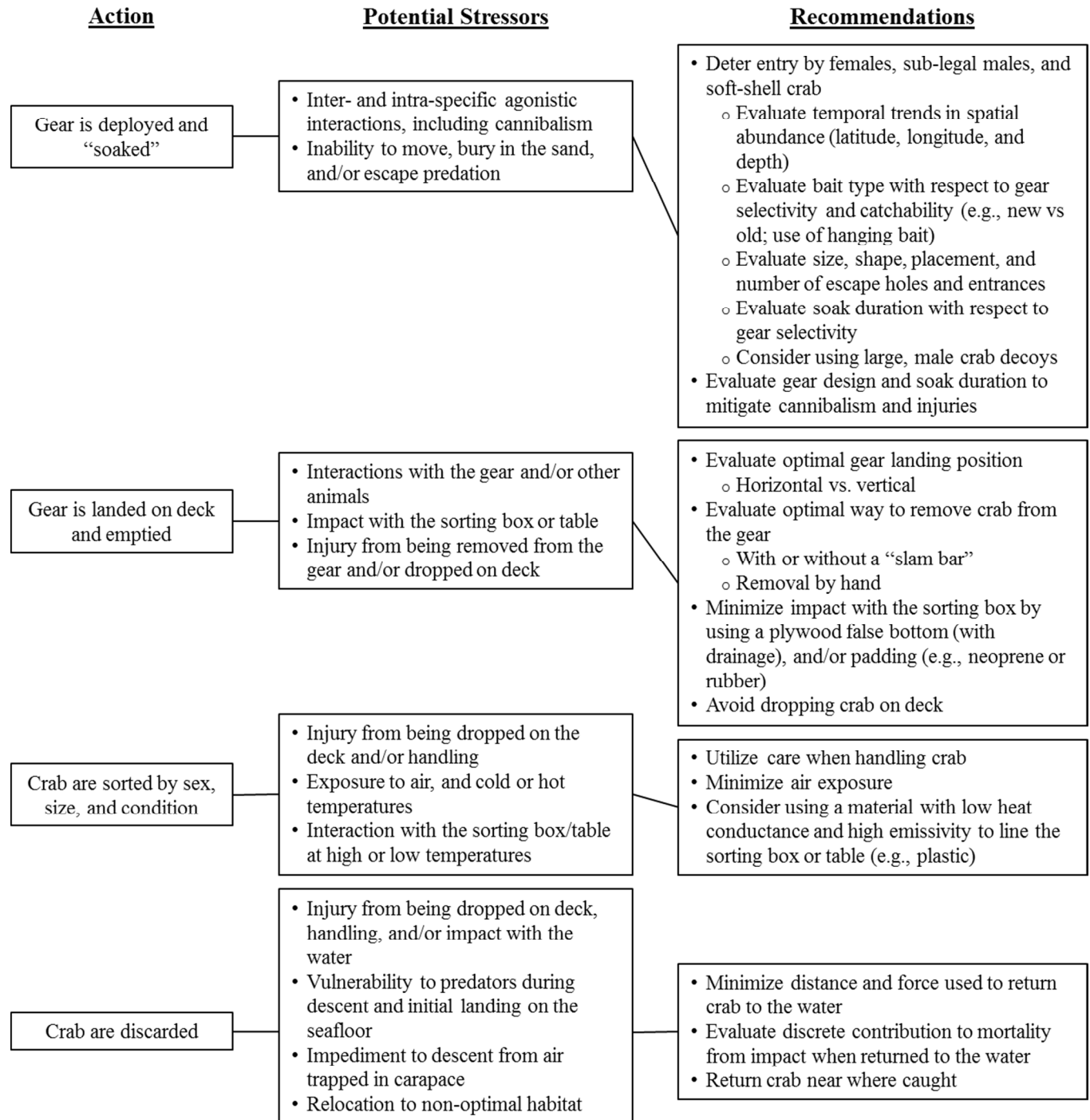


Figure 7 The potential stressors experienced by Dungeness crab (*Cancer magister*) in directed recreational and commercial crab fisheries, and recommendations for future research and ways to reduce these stressors.