Estimating bycatch mortality rates of Dungeness crab (*Cancer magister*) in Oregon fisheries
Final Report on Marine Stewardship Council Condition 1.1.2

4th Annual Surveillance of the Oregon Commercial Dungeness Crab Fishery

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Project Overview

The goal of this research is to address Condition 1.1.2 of the General Conditions for Continued Marine Stewardship Council (MSC) Certification for the Oregon commercial Dungeness crab (*Cancer magister*) fishery, which states that the fishery must:

> *Present results of sampling Dungeness crab fishing to determine the rate at which females are caught, whether hard or soft shelled, and time to release. Present an estimate of the mortality rate of released female crabs. Review estimates of recreational catch, by-catch in the trawl fishery and the catch of undersized males. Where data are lacking, conduct the sampling/monitoring necessary for estimates. Present a crude (or better) estimate of recreational catch, by-catch in the trawl fishery and the catch of undersized males.*

Research Objectives
Research to address MSC Condition 1.1.2 for the commercial Oregon Dungeness crab fishery began in October 2011 with the goal of estimating bycatch mortality rates for female and undersized male Dungeness crab that are bycaught in commercial and recreational crab fisheries; and to evaluate the nearshore groundfish trawl fishery with respect to crab bycatch. We also aimed to involve fishermen at all phases of this project.

RAMP
To estimate discard mortality rates we utilized the Reflex Action Mortality Predictor (RAMP) approach. This methodology relates reflex impairment to a probability of mortality (Davis, 2007; Davis and Ottmar, 2006; Stoner, 2012a). The first step of this methodology is to determine reflexes that are present in a minimally stressed animal and that have a consistent response to stimulation. Once selected, the reflexes can then be used to score animals based on whether or not each of these reflexes is present (“0”) or absent (“1”), and summing the responses. If 5 reflexes are being used, an individual that is in the healthiest condition would receive a score of zero (i.e., no reflex impairment) and an individual in the poorest condition would receive a score of five. In order to relate reflex impairment score (“Score”) to a probability of mortality, scored individuals are held for a period of time to determine mortality. The relationship between Score and probability of mortality is then explained with a RAMP, a predictor. A RAMP can either be created with a logistic regression modelling approach or by using the proportion of held crab that died by Score (a “discrete” RAMP). The RAMP approach has effectively determined bycatch mortality rates for fish (Barkley, 2010; Davis, 2007; Davis and Ottmar, 2006; Raby et al., 2011) and invertebrates

(Chilton et al., 2011; Hammond et al., 2013; Rose et al., 2013; Stoner et al., 2008; Stoner, 2012b; Yochum et al., 2014). The RAMP approach has not previously been applied to Dungeness crab; therefore, we determined the RAMP reflexes during experiments at the NOAA Alaska Fisheries Science Center (AFSC) laboratory in Newport, Oregon. The RAMP reflexes we established for Dungeness crab include: (1) eye retraction, (2) mouth defense, (3) chelae closure, (4) leg wrap, (5) leg curl, and (6) abdomen response (Table 1).

Evaluated Fisheries

Commercial Crabbing
The Oregon commercial ocean Dungeness crab fishery is managed with limited entry and by regulations regarding the "3-S's": sex-size-season. Only males with a carapace width larger than 6¼ inches (159 mm; measuring shell edge to shell edge, from in front of the tenth anterolateral spine) are legally retained during the fishing season, which typically runs from December 1 to August 14. There is no catch limit except from the second Monday in June to August 14 when only 1,200 pounds are allowed per vessel per week. Pots, which are used to harvest the crab, are restricted to 13 cubic feet (0.4 cubic meters), must have a minimum of two circular escape gaps with a diameter of at least 4 ¼ in (108 mm; on the top or side of the pot), and must have a mechanism to release animals to prevent ghost fishing if the pot is lost. The Oregon commercial bay fishery is likewise managed by the 3-S's; however, effort is regulated in that each fisherman is restricted to 15 rings (no pots), and the fishery occurs from Labor Day to December 31 (except on weekends or state and federal holidays; and no fishing is allowed when the adjacent ocean area is closed; ODFW, 2011). Effort and landings for these fisheries are recorded by the Oregon Department of Fish and Wildlife (ODFW) through the use of fish-receiving tickets and logbooks. Currently there are no estimates of discard or discard mortality rates for these fisheries.

Recreational Crabbing
For both ocean and bay recreational fisheries (from a boat or shore) each permitted crab fisherman is allowed to use up to 3 pots (or rings) at a time and retain up to 12 male crab that are a minimum size of 5 ¾ in (146 mm carapace width) per day. While the recreational bay crab fisheries are open year round, the recreational ocean fishery is open from December 1st to October 15th. For recreational and commercial fishing, discarded crab (female and undersized males) caught in the ocean must be released within 15 minutes and those caught in the bay must be released immediately (ODFW, 2011). ODFW conducts surveys to assess recreational landings, but does not quantify discard or discard mortality.

Trawling
In addition to directed fisheries for crab, Dungeness are incidentally captured in various bottom trawl fisheries, including: the limited entry bottom trawl fishery for groundfish, and trawl fisheries for both California halibut and pink shrimp. In 2010, discard by weight was highest between 0-125 fathoms (229 m), and, by fishery, was highest in the limited-entry shallow water bottom trawl fishery (265.9 mt of discarded Dungeness crab), which targets a mix of nearshore fishes (flatfish mostly). Following this, the California halibut trawl fishery generates 250.5 mt of discarded Dungeness crab and additional discards come from the pink shrimp trawl and fixed gear fisheries (Bellman et al., 2011). For management purposes, mortality of discarded Dungeness crab for all of these trawl fisheries is assumed to be 100%. However, because the Dungeness crab fishery is

not managed on the basis of catch quotas, bycatch mortality does not figure directly in the management of these fisheries.

Methods

Crab Assessment

Commercial Crabbing

All data for the commercial crabbing portion of this study were collected aboard commercial fishing vessels during regular fishing operations. These "ride-along" trips allowed for the collection of data that are representative of actual fishing practices and provided opportunities to gain feedback from fishermen on project methodology and insight into the fishery. During these trips, we assessed every fifth fished crab pot in a string to avoid slowing down fishing operations and to minimize handling and air exposure beyond typical fishing operations, while maintaining a randomized sampling design. We allowed for changes in this sampling plan when there were logistic constraints that prohibited this sampling regime (e.g., poor weather requiring a pause in sampling, etc.). In these instances, randomization was maintained in determining which pots to assess.

For each assessed pot the following information was recorded: (1) soak time (amount of time the pot was fishing); (2) sea state at the time the pot was brought onto the boat (Beaufort wind force scale); (3) whether or not the crab were removed from the pot using a "slam bar" (a bar that the pot is thrown onto to rapidly release the crab from the pot into a sorting box); (4) how many "keeper" crab were retained (males 6 ¼ inches, 159 mm, or larger); (5) the location of the pot within the string; and (6) the approximate depth where the pot was fished. When a sampled pot was brought on-board, the "keeper" crab were removed and all crab that were intended for discard were put into a sampling basket. Each crab was then measured (carapace width, mm), the sex of the crab was noted, as were shell hardness (soft or hard) and presence of any new (happened during the fishing process) injuries, including cracks or damage to the carapace or abdomen, and broken or autotomized (spontaneously cast off) legs. We also noted air exposure duration for each crab prior to reflex assessment. In addition, all assessed crab were given a RAMP Score based on the number of reflexes that were absent (0-6). We determined that a reflex would be considered absent only if there was no response to stimulation. Although it was determined by Stoner et al. (2008) that including a middle category for the reflex impairment ("weak") was ambiguous and did not significantly improve mortality prediction, we indicated impairment as "uncertain" when reflexes were difficult to discern between present and absent. In addition, in previous RAMP studies, immediate mortalities (i.e., crab that were dead before assessment) were given a Score of six (e.g., Hammond et al., 2013; Yochum et al., 2014). For Dungeness crab, however, to evaluate the discrete contribution to total bycatch mortality by both immediate and delayed mortality, dead crab were analyzed separately from those discarded alive.

Recreational Crabbing

To assess crab discarded from the recreational crab fishery from boats we performed the activities of boat-based recreational crabbing trips in the bay and ocean rather than conducting ride-along sampling given logistic constraints. The trips differed from actual recreational crabbing in that we did not pull the pots as often or move them around as much as a recreational crabber might (based on anecdotal evidence), and we did not retain "keeper" crab (as per ODFW permitting requirements). For these trips, information was collected about fishing gear and bait type, and about the location, depth, sea state, and soak time of the trap or ring. For the shore-side recreational crab fishery we went to the Newport Pier on the Yaquina Bay, Oregon and selected 2-6 groups of people on the pier that were crabbing to sample their catch. We recorded the type of fishing gear and bait that was used, the soak time and number of "keeper" and red rock crab captured. All Dungeness crab that were intended for discard were assessed similarly to sampling for the commercial fisheries.

Trawling

To evaluate discard for trawling in Oregon we assessed bycaught crab in the limited entry nearshore groundfish trawl fishery ("beach dragging") because of the reported high levels of Dungeness crab bycatch. For the trawl ride-along trips, haul duration, water depth, catch size, and information about the gear and fishing operations were recorded for each haul. Crab intended for discard were sorted out of the catch, assessed by the on-board fisheries observer, and then put into a sampling basket. All crab were then assessed similarly to those from the directed crab fishing trips.

Delayed Mortality

To relate probability of mortality to reflex impairment Score, a subsample of the assessed crab during commercial ocean and recreational crab fishing were tagged and taken to the NOAA Alaska Fishery Science Center in Newport, OR for holding. We tagged each held crab with a double T-bar anchor tag (Hallprint). This tag type was selected because the second t-bar prevents the tag from being pulled into the body cavity. In addition, this tag is highly visible and does not need to attach to the crab's leg, which can cause the crab to autotomize. This can lead to injury and/ or the inability to identify the crab. Another benefit of this tag type is that it can be retained through the molting process.

For each fishery, our objective was to hold crab that represented all Scores and combinations of Scores and variables of interest (sex, shell hardness, etc.; Table 2). Crab intended for holding from the commercial ocean fishing trips were kept in a plumbed insulated fishing tote (interior dimensions: 36 inches x 21 inches x 21 inches; 91 cm x 53 cm x 53 cm) during fishing operations. At the completion of the fishing trip the water was drained, the crab were placed into an ice chest with wet burlap sacks, and then were driven to the AFSC laboratory (approximately two miles from the port) where they were placed in plumbed, temperature regulated (approximately 6 degrees Celsius) tanks. Crab from the recreational fishing trips were put directly into the ice chest with wet burlap sacks and similarly taken to the AFSC for holding (< 1 mile away from the port). Captive holding lasted for approximately one month, during which time the crab were fed and the tanks were cleaned once a week. Daily checks for dead crab were completed. Dead crab were removed and the number of days until death (the difference between the date of sampling and of death) was noted. Due to limited deck space, long duration of the fishing trips, and limited access to laboratory holding facilities we were unable to hold crab from the trawl trips. We were also unable to hold crab from commercial bay trips due to the small vessel size.

While crab were held in the laboratory for approximately one month, a crab was only considered dead if it died within the first 5 days of holding, not after. This was done in response to the findings by Yochum et al. (2014) that 5 days was an optimal holding duration for Tanner crab (*Chionoecetes bairdi*) when determining mortality. Holding longer than 5 days has the potential to confound negative effects from captive holding with the stressors being tested. Moreover, we found that mortality of control and Score-zero Dungeness crab increased over time indicating a captivity effect over long holding duration. To minimize this effect we held most crab individually to reduce agonistic interactions among the crab, maintained a low water temperature, kept the tanks cleaned, and fed the crab once a week. Regardless, we believe that 5 days is an appropriate cut-off point for determining mortality.

<u>Drop Experiment</u>

One fishing stressor that is not represented by RAMP is the impact from being dropped or thrown back into the water. We conducted a laboratory based experiment to evaluate this variable in isolation. On two occasions we collected and held crab from recreational bay fishing trips for two weeks to allow them to recover. We then dropped them into a tank of sea water from three distances. During the collection trips, sex, size, and shell hardness were noted for each crab and they were tagged similarly to the crab held to determine delayed mortality.

During the first experiment, which was conducted in November 2013, 62 crab were dropped, a third each from one meter (“low”), 3 meters (“medium”), and 9 meters (“high”). The 60 crab from the second experiment in April 2014 were dropped from the medium and high distances, and, instead of the low distance, were also dropped from 6 meters. The drop distances mimic the free-board from recreational and commercial vessels (“low” and “medium”, respectively), and an approximate range of distances that a crab would be thrown from a pier or dock during shore-side recreational fishing at low tide (6 and 9 meters). For the first experiment we attempted to drop half of the crab, for each distance, so that they would land on their dorsal side, and the other half on their ventral side. This was not replicated during the second experiment. Instead, we did not force the side on which the crab landed. An additional difference between the two experiments was that crab were left out of the water in an ice chest with wet burlap sacks before being dropped for the first experiment; whereas crab for the second experiment were kept in water up to the point that they were lifted to the dropping point. After hitting the water, each crab was assessed for injury, and then held for a month to determine mortality.

<u>Data Analysis</u>

Binary logistic regression was used to determine if there was a relationship for discarded Dungeness crab between the number of impaired reflexes (Score) and mortality (proportion of dead crab), under the assumption of independence among the Scores. We included fishing and biological variables in the model to determine if these influenced mortality. To determine the most parsimonious logistic model for the data we performed model selection in R (R Development Core Team, 2011) using a forward stepwise model selection technique (addterm), and drop in deviance tests. Forward model selection was used given the large number of variables and interactions being tested. Model selection drew from a rich model that included explanatory variables: (1) reflex impairment Score (continuous number of absent reflexes, 0-6); (2) Sex (male or female); (3) shell hardness (soft or hard); (4) carapace width (mm, continuous); (5) fishery type; (6) pot depth; (7) month; (8) presence of new injuries (yes/no); (9) air exposure duration (min); (10) use of the slam bar (yes/no); (11) soak duration (days); and interactions among these variables.

Explanatory variables were included in the logistic model (equation 1):

$$Log_e\left(\frac{p}{1-p}\right) = \alpha + \beta' x,$$

Where

p = proportion of y=1;

y =1 if the crab died and 0 if it survived to the end of holding;

α = intercept;

β' = model coefficients; and

x = explanatory variables tested in the model

The maximum likelihood estimates of mortality (p) were calculated as (equation 2):

$$p = e^{(\alpha+\beta' x)} \Big/ 1 + e^{(\alpha+\beta' x)}$$

To determine overall mortality for each ride-along or simulated trip we applied the selected logistic RAMP to the number of crab assessed at each Score to determine the number of crab that would die (delayed mortality) and added that amount to those that died prior to assessment (immediate mortality). We then divided the sum of the deaths attributed to both immediate and delayed mortality by the total number of assessed crab. These mortality rates by trip were then averaged to estimate a mean value for the fishery.

For the drop experiment we also used binary logistic regression and forward model selection to determine the best predictors of mortality for crab that were dropped. Model selection was similarly completed using a rich model, including variables: (1) drop height (m); (2) side on which the crab landed (dorsal/ ventral); (3) carapace width (mm); (4) sex (male/female); (5) shell hardness (soft/ hard); (6) injury from the drop; and (7) reflex impairment score (0-6).

Results

Crab Assessment

Ride-along trips to conduct crab assessments and holding to determine mortality occurred from February 2012 until April 2014. An objective of this research was to collect data during all calendar months when the fisheries were open in order to look at time of year as a variable in analyzing trends in bycatch and bycatch mortality. This was accomplished for the recreational bay fishing component, but not for the commercial fisheries. Due to logistics we were unable to collect data in August for the commercial ocean crab fishery, and in November for the commercial bay crab fishery. With all fishery types combined, a total of 70 sampling trips were completed and over 10,600 crab were assessed (Table 2). The majority of crab assessed for the crab fisheries (87%) and more than half (64%) of the crab caught during the trawl trips were Score-zero. For all fisheries, both male and female crab were caught; however, the size ranges varied. On average, males caught in the ocean were larger than those caught in the bay; with the largest crab being caught during commercial crabbing operations. Females were also, on average, largest from this fishery. Catch size and composition of the commercial ocean and recreational bay by boat crab fisheries varied by time from fishery opening and trip respectively (Figures 1 and 2). For the commercial ocean fishery, numbers of soft males per pot increased towards the end of the fishing season while the number of keepers decreased. For the recreational bay fishery by boat there are no clear trends over time.

RAMP

A total of 1,086 crab were held at the NOAA AFSC laboratory to determine mortality. The majority of held crab (81%), for all fishery types, were Score-zero (Table 2). Regardless, we were able to hold crab of all Scores for commercial ocean crabbing, and nearly all Scores for recreational crabbing. Given the low impact of these fisheries there were few crab caught with Scores greater than zero. Preliminary model selection on all holding data combined indicated a significant difference between fishery types, namely that recreational bay fishing by boat (RBB) had lower mortality than the other fishery types. We combined recreational crabbing in the ocean (RO) and shore-side (RBS) with commercial ocean crabbing (CO) to determine differences among these fishery types. Model selection did not indicate that "fishery type" was a significant predictor of mortality. We repeated this analysis, but using only recreational data (RBB, RBS, and RO). Again, RBB was significantly different from the other recreational fisheries in that mortality was reduced. We therefore separated the data and only used commercial ocean data to analyze the commercial ocean fishery, and likewise with the recreational bay crabbing by boat. Captive holding datasets for RBS and RO were not large enough to create separate RAMPs. We therefore only created RAMPs for the CO and RBB fisheries. We will assume that the commercial ocean RAMP can be applied to the shore-side and ocean recreational fisheries, however, given that they were not significantly different in the model selection analysis.

Commercial Crabbing

For the commercial ocean crabbing data, preliminary analyses indicated that Score, sex, shell hardness, and injury were variables that seemed to influence morality. We therefore conducted final model selection using only these variables in the rich model, with interactions among them. Data limitations, however, prevented a thorough assessment of some of the variables. For example, there were few soft females held which prevented an extensive evaluation of the differences between hard and soft shelled females and the influence, in general, of shell hardness regardless of sex. In addition, interactions and the role of injury were also limited by sample size and the number of variables being evaluated. The data, however, indicated that there were differences between females and males and, within males, soft and hard shelled. Specifically, hard shelled males had the lowest mortality, followed by females, then soft shelled males. We therefore grouped the data using a new variable: "Sex-soft", with three categories: female, male-hard shelled, and male-soft shelled. The female category could not be broken into "soft' and "hard" given the small sample size for soft shelled females. Model selection and drop in deviance tests indicated that the most parsimonious model includes this variable in addition to Score (Table 3, Figure 3). This model indicates that Score-zero crab have a probability of mortality of 0.05 for females, 0.01 for males with hard shells, and 0.08 for males with soft shells (Table 4). RAMPs for these categories have the same slope, but range in magnitude. Overall, male crab with hard shells have the lowest mortality and those with soft shells have the highest. An alternative model that includes the presence of new injuries was compared to the selected model. The inclusion of this variable did not significantly improve model fit.

Recreational Crabbing

Model selection on captive holding data for the recreational bay fishery by boat indicated that the most parsimonious model included only one variable: whether or not the crab was Score-zero (Table 3). This model indicates that Score-zero crab had no mortality, but those with a Score greater than zero have an 8% probability of mortality (Table 4). While the presence of new injuries appeared to increase mortality, it did not significantly improve model fit.

Bycatch Mortality

Commercial Crabbing

Applying the selected RAMP to the commercial ocean fishery data resulted in the proportion of females in pots expected to die (delayed mortality), averaged over all trips, being 0.08 (SD=0.02), of hard shelled males being 0.01 (SD=0), and of soft shelled males being 0.12 (SD=0.07). All together, discard mortality is 0.06 (SD=0.02); meaning that for every 100 crab discarded, 6 will die, on average, when lumping sex and shell hardness (Table 5). Immediate mortality was, on average, 3% of the bycatch (SD=0.03). Combining delayed and immediate mortality, 9% of bycaught crab has or will die (i.e., for every 100 bycaught crab there will be 9 that die).

The ratio of "keepers" to number of bycaught crab is 1.2 (SD=2.37, range 0.1-11.1). This indicates that, for every 100 "keeper" crab, there are 83 discards. This average is heavily influenced by one trip where catch was high given that it was opening day of the fishing season. If that trip is removed, the average becomes 0.7 (SD=0.82), indicating 143 discards for every 100 keepers. The ratio of keepers to number of dead crab (immediate and delayed combined) is, on average, 23 (SD=53.8, range 0.2-252.2). If the same trip is removed for this analysis the average changes to 12.1 (SD=17.1, range 0.2-72.8). The highest values for this ratio are within the first two months of the fishery opening; indicating that after the first two months of fishing there are fewer keepers per dead crab (Figure 4). For example, if the five highest values are removed, all of which take place in the first two months of the fishery opening, the average number of keepers to dead crab is 5.5 (SD=5.7, range 0.2-23.7).

We did not create a RAMP for the commercial bay fishery. We suspect that the RBB RAMP would likely be more suitable for this fishery than the CO RAMP given the low impact nature of the fishery. Without additional research, however, we do not feel it is appropriate to apply either RAMP. During the 4 ride-along trips, 53 rings were sampled, with 349 bycaught crab and 16 keepers. The number of crab discarded per ring ranged from 2.9 to 10.5. The majority of crab assessed were Score-zero (range for rings: 92%-100%); and hard shelled females were predominant over other sex/shell hardness combinations (35%-92%). There were no immediate mortalities in the rings that were assessed.

Recreational Crabbing

For the 26 recreational crab trips by boat, there were, on average, 75 Score-zero crab (SD=47, range 1-194) per trip; and 6 crab with Scores greater than zero (SD=6, range 0-20). On average there were 5.5 Score-zero (SD=3.6) and 0.5 (SD=0.4) Score greater than zero crab per pot. The average mortality of discarded crab by trip was 0.01 (SD=0.01, range 0-0.04). The trip with the highest mortality was one where there were only 2 crab caught during the trip. There were no immediate mortalities during any trips. The ratio of "keeper" crab to those discarded was, on average, 0.04 (SD=0.04, range 0-0.18; Table 6). The ratio of keepers to the number of crab expected to die after being discarded was, on average (and excluding the four trips that had no mortality for discarded crab), 11.01 (SD=23.74, range 0-106.25). Total number of injured crab was 20 over all trips.

Crab intended for discard was the majority of the catch for the shore-side recreational fishery sampling trips. Fishing gear captured 509 crab that were discarded, and 10 keepers. The majority of the discards were Score-zero (91%; Figure 5). Of the sex-soft categories, the hard shelled males were most commonly caught, followed by hard shelled females. Only 14% of crab caught during RBS fishing were soft.

If the commercial ocean RAMP is applied to the single recreational ocean fishing trip, total delayed mortality for the trip was 6% for females, 2% for hard shelled males, and 14% for soft shelled males. For all categories combined, 6% of all discarded crab from this trip were expected to die after release. There were 40 "keepers" caught during this trip; indicating that for every 100 keepers 17 discarded crab would die; and that for every keeper there were 3 crab discarded. These values should not be applied to the fishery, however, as this was only one trip and therefore should not represent the fishery as a whole.

Trawling

A total of 41 hours of fishing (summed haul durations) were completed during the two ride-along trawl trips, capturing a total of 2,053 crab (Table 7). The majority of crab caught during the trawl trips were Score-zero (64%, Figure 6) and there were 69 and 27 immediate mortalities for the first and second trips, 7% and 3% of total bycatch, respectively. These results indicate that crab bycatch mortality for the trawl fishery is likely less than 100% as currently assumed for fisheries management purposes. We do not feel it is appropriate to apply either the recreational or the commercial crabbing RAMPs to the trawl fishery based on the findings of Yochum et al. (2014) that a RAMP, once created for a species enduring a given set of stressors, should only be applied to animals experiencing similar stressors. Given that and the fact that we were only able to complete two ride-along trips (due to limited available space on these smaller vessels), we will not estimate mortality rates for the bottom trawl fishery. We do, however, feel confident that the rate of mortality is less than 100%. We acknowledge that, unlike the RAMP for the crab fisheries, injury would potentially play a role in mortality prediction for trawling given the nature of the fishery (heavy fishing gear, increased handling, etc.).

Drop Experiment

There were a total of 12 crab that died within five days of holding for the first drop experiment and 4 for the second. Logistic model selection determined that the significant determinant of mortality was whether or not the crab shell cracked upon landing. No crab that were dropped from 1 or 3 meters cracked during either experiment; 1 crab out of 19 cracked from the 6 meter drop (5%) and 14 crab of 42 cracked from the 9 meter drop (33%). Of the crab dropped from 9 meters, 55% of those dropped from 9 meters in the first experiment and 14% from the second experiment cracked. This indicates that shell cracking, and therefore mortality, could be reduced by keeping crab in water before discard. While shell hardness did not significantly improve model fit for the data, we note that 21% of soft shelled crab cracked, whereas only 10% of hard shelled crab cracked. Without even sample sizes among the variables it is difficult to tell if there are confounding factors affecting the differences. However, our results indicate that there is increased mortality for crab dropped from high distances, namely 9 meters, and that shell hardness may influence whether or not the crab shell cracks after being dropped. Further study is needed to evaluate this.

Discussion

Results indicate that bycatch mortality is low for Oregon's crab fisheries, and likely less than previously assumed for trawling. However, this research does not address the potential for repeated capture and discard to have an additive or multiplicative effect on mortality rates. While we aimed to represent actual fishing stressors we acknowledge that the treatment of the assessed crab differed from those not assessed in that the slam bar was used less often, and there was more intentional handling of the assessed crab, which could have reduced instances of the crab being dropped onto the ground or stepped on. In addition, because our results do not incorporate data for the commercial ocean fishery in August, when there are likely higher numbers of soft shelled males being discarded (based on the trends observed), mortality over all months combined may be underestimated. Regardless, we feel that the results are closely representative of actual fishing operations. Along these lines, we also recognize that the mortality rate of soft shelled females may not match the RAMP for discarded commercial ocean females given that we merged hard and soft shelled crab in the analysis and the data were predominantly hard shelled females. To tease this apart an additional experiment would be needed. However, low catch of soft shelled females indicates that this would not largely change overall mortality rate estimates. Also, while the results are based only on a limited number of vessels and ports, we feel that our results can be applied generally to the fleet given that the fishing practices are largely similar by port and vessel size and type. Moreover, we incorporated vessels that are large and small. Lastly, our results do not factor in the potential for mortality to occur after 5 days or for secondary effects of fishing stress (e.g., reduced ability to feed or avoid predators). Further study to address this is needed; however, we found no evidence that would lead us to assume that mortality over long periods of time would be high.

While mortality of crab caught during recreational fishing is low we acknowledge that fishermen who do not adhere to the regulations that mandates immediate return of bycaught crab to the water or who do not use care when handling could increase mortality estimates. In addition, shore-side recreational crabbing mortality estimation does not incorporate mortality that may result from being dropped back into the water. Therefore, actual RBS discard mortality likely depends on drop distance, based on the tide.

ODFW regulates both recreational and commercial crab fisheries with respect to time to discard in that crab caught in the ocean must be released within 15 minutes and those caught in the bay must be released immediately (ODFW, 2011). While we did not quantify this during the commercial fishing trips due to the variable nature of this factor, we can anecdotally state that crab during the ride-along trips were released under the required 15 minutes. Exceptions include crab that are dropped onto the deck and escape the attention of the fishermen; and crab that are left in the sorting box in situations that require urgent attention (e.g., fishing gear, mechanical, or safety issues).

Overall results from this research indicated that discard mortality rates are low for Oregon Dungeness crab fisheries. We feel that, as much as possible, we have successfully acquired data that are representative of fishing practices. The success of this project is largely attributed to the collaborative nature of the research and the investment of Oregon fishermen.

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Tables

Table 1 The Reflex Action Mortality Predictor (RAMP) reflexes that have been established for Dungeness crab (*Cancer magister*; Yochum, in preparation), along with the method for assessing and metrics for determining if a given reflex is "present' or "absent". The reflexes are assessed in this order (1 to 6) and may be applied to either side of the crab.

	Reflex	Method	Present	Absent
1	**Eye Retraction**	A probe is used to tap the top of an eye	Crab retracts the eye downward	Crab does not react, leaving the eye in place
2	**Mouth Defense**	A probe is used to attempt to pull forward the 3rd maxillipeds	Crab defends its mouthparts with its chela making it difficult to access the maxillipeds	Crab allows its maxillipeds to be manipulated
3	**Chela Closure**	A probe is used to stimulate the chela	Crab reacts by closing the chela tightly, then opening it again without manipulation	Crab does not open and close its chela without manipulation
4	**Leg Wrap**	The walking legs on one side of the crab are pulled straight out (i.e., joints at a 180 degree angle)	Crab draws its legs back in (i.e., joints at less than a 180 degree angle)	Crab does not move its legs back without manipulation
5	**Leg Curl**	The 5th leg is straightened and pulled downward	Crab pulls up and curls its leg in a controlled manner	Crab does not move the leg without manipulation
6	**Abdomen Response**	A probe is used to pull the abdominal flap away from the crab's body	Crab exhibits a strong, agitated reaction	Crab does not react

Table 2 The number of sampling trips completed on a given number of fishing vessels for the commercial ocean (CO) and bay (CB), recreational bay by boat (RBB), shore-side (RBS), and ocean (RO), and trawl fisheries to assess bycaught Dungeness crab (*Cancer magister*). Listed are the range of depths (ftm) at which the gear fished, the mean carapace width (mm) of assessed crab, and the number of crab for each reflex impairment score ("Score", 0-6) that were assessed and held at the AFSC laboratory to determine mortality.

	Commercial		**Recreational**			**Trawl**
	CO	**CB**	**RBB**	**RBS**	**RO**	
No. Trips	22	4	26	15	1	2
No. Vessels	4	1	3		1	1
Depth Range (ftm)	3-82	6	1-6		12	56-78
Avg. Width-Male	160 (93-193)	116 (80-160)	125 (61-183)	115 (35-147)	153 (131-173)	146 (114-188)
Avg. Width-Female	152 (52-174)	131 (79-162)	114 (67-167)	127 (41-160)	139 (116-159)	139 (111-177)
No. Crab Assessed	5629	349	2115	509	116	1974
Score 0	4683	336	1957	460	106	1255
Score 1	537	7	118	33	6	276
Score 2	130	2	33	9	1	151
Score 3	46	1	3	3		112
Score 4	14		4		2	49
Score 5	5					13
Score 6	19		1			19
No. Crab Held	672		325	46	43	
Score 0	515		285	42	37	
Score 1	111		30	4	3	
Score 2	22		9		1	
Score 3	16		1			
Score 4	5				2	
Score 5	1					
Score 6	2					

Table 3 Results from binary logistic modeling for the commercial ocean and recreational bay by boat Dungeness crab (*Cancer magister*) fisheries. Estimates, standard errors (SE), and p-values for the intercept and coefficients of the explanatory variables for the most parsimonious models are included, along with the Akaike Information Criterion (AIC). These models were selected based on forward stepwise model selection and drop in deviances tests. The logistic reflex action mortality predictor (RAMP) was created from data that included a reflex impairment score (Score) equivalent to the total number of reflexes absent out of six, and a variable that has three categories: females (hard and soft shelled combined, reference category), males with hard shells, and males with soft shells. For the recreational bay by boat fishery Scores greater than zero are combined such that there are only two categories: Score-zero ("Zero") and Scores greater than zero (reference category).

Commercial Ocean Crabbing

Parameter	Coefficient	SE	p-value
Intercept	-2.98	0.24	< 2e-16
Score	1.12	0.15	0.00
Male-Hard Shell	-1.71	0.62	0.01
Male-Soft Shell	0.49	0.54	0.36
AIC:	277.75		

Recreational Bay Crabbing by Boat

Parameter	Coefficient	SE	p-value
Intercept	-2.48	0.60	0.00
Zero	-3.17	1.17	0.01
AIC:	38.46		

Table 4 Probabilities of mortality by reflex impairment score ("Score") calculated for both the commercial ocean and recreational bay by boat Dungeness crab (*Cancer magister*) fisheries using the selected logistic reflex action mortality predictors (RAMP), which included Score (equivalent to the total number of reflexes absent out of six), and a variable with three categories: females (hard and soft shelled combined), and soft and hard shelled males. For the recreational bay by boat fishery Scores greater than zero are combined such that there are only two categories: Score-zero ("0") and Scores greater than zero (">0"), incorporating both sexes, and hard and soft shells.

Commercial Ocean Crabbing

Score	Female	Male-Hard Shell	Male- Soft Shell
0	0.05	0.01	0.08
1	0.13	0.03	0.20
2	0.32	0.08	0.44
3	0.59	0.21	0.70
4	0.82	0.45	0.88
5	0.93	0.71	0.96
6	0.98	0.88	0.99

Recreational Bay Crabbing by Boat

Score	
0	0.00
>0	0.08

Table 5 Estimates of bycatch mortality for commercial ocean Dungeness crab (*Cancer magister*) research fishing trips (n=22). Mortality, the proportion of assessed crab that were predicted to die based on the applied logistic RAMP (delayed mortality) and those that died in the pot prior to assessment (immediate mortality), is the mean of all trips. Values are estimated for female crab and males with hard and soft shells, and all crab combined. Also shown are the standard deviations (SD), and range of estimates by trip (Min, Max).

Bycatch Mortality				
	Female	**Male- Hard Shell**	**Male- Soft Shell**	**Combined**
Delayed Mortality				
Min	0.05	0.01	0.08	0.02
Max	0.11	0.02	0.26	0.09
Mean	0.08	0.01	0.12	0.06
SD	0.02	0.00	0.07	0.02
Immediate Mortality				
Min				0.00
Max				0.09
Mean				0.03
SD				0.03
Total				
Min				0.02
Max				0.16
Mean				0.09
SD				0.04

Table 6 Estimates for the recreational bay by boat Dungeness crab (*Cancer magister*) research fishing trips (n=26) of the number of Score-zero crab (No. 0) and those with Scores great than zero (>0) per pot (or ring), including the minimum, maximum, mean, and standard devaiation (SD) of trips. Mortality rate, the proportion of assessed crab that were predicted to die based on the applied logistic RAMP and immediate mortalities (those that died in the pot); the ratio of the number of retained crab ("keepers") to the number of discarded crab; and the ratio of keepers to the number of bycaught crab predicted to die. In addition, information about the number of injured crab per trip is listed.

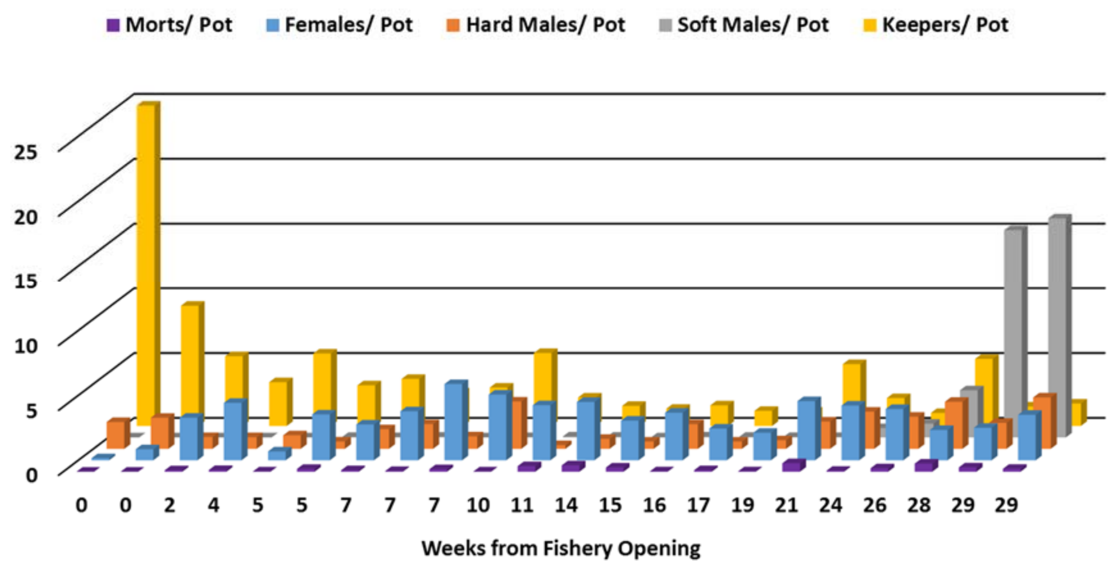
	No. 0/ Pot	No. >0/ Pot	Mortality Rate	Keepers/Discard	Keepers/Morts	No. Injured
Min	0	0	0.00	0.00	0.00	0
Max	15	2	0.04	0.18	106.25	13
Average	5	0	0.01	0.04	11.01	4
SD	4	0	0.01	0.04	23.74	3

Table 7 Information about the ride-along trips for the nearshore groundfish trawl fishery, including the number of hauls completed, total fishing hours (the sum of the haul durations; hrs), the average haul duration (hrs), and the number of bycaught crab caught for each trip.

	Trip 1	**Trip 2**
Month	August	September
Port	Charleston	Charleston
No. Hauls	11	7
Total Hours	24.3	16.3
Avg. Haul (hrs)	2.2	2.3
No. Crab	1051	1002

Figures

a)



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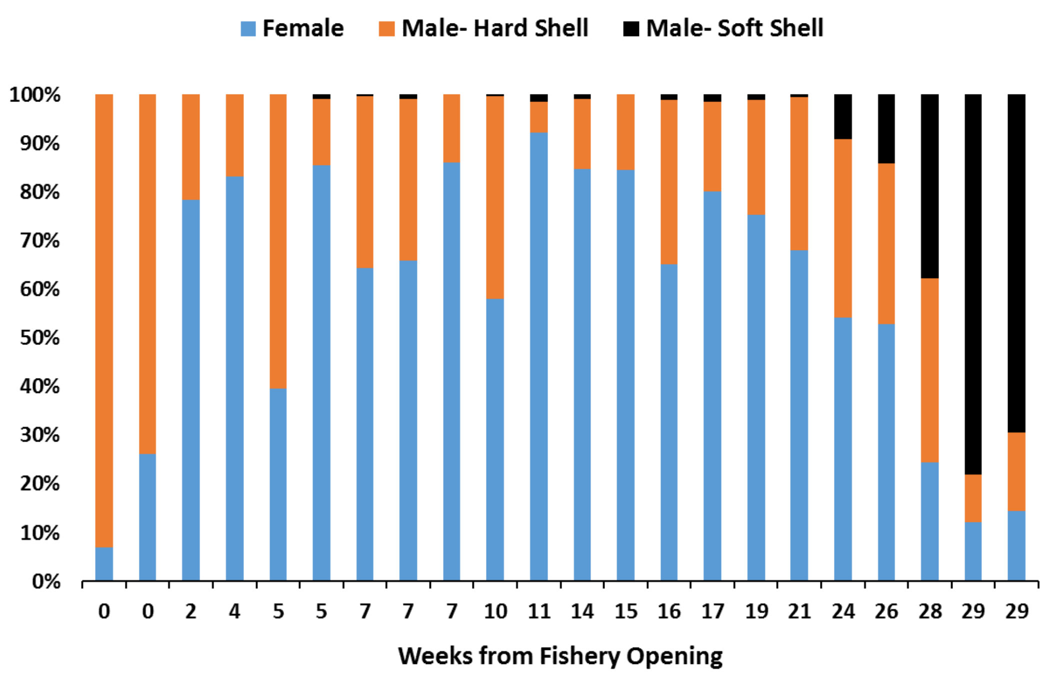
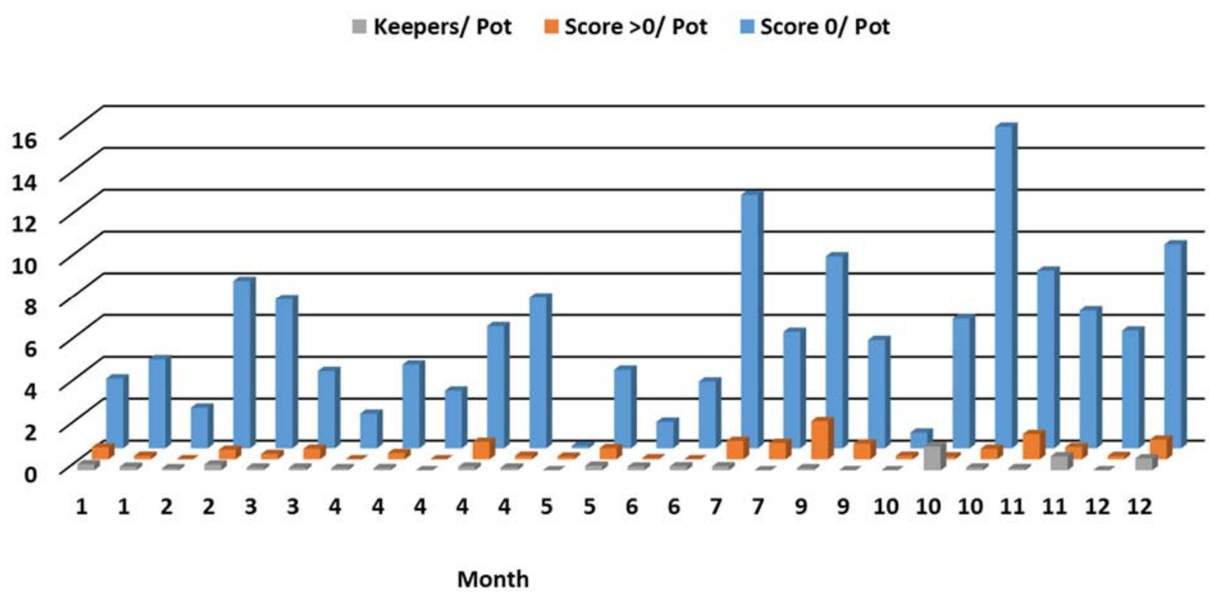


Figure 1 (a) The average number of female, hard shelled male, and soft shelled male Dungeness crab (*Cancer magister*) intended for discard; crab retained ("keepers"); and immediate moralities (i.e., crab that were dead in the pot; "Morts") per pot for each completed commercial ocean crab sampling trip (n=22), listed by the number of weeks past the opening of the fishery. Also shown are the proportions of females, hard shelled male, and soft shelled male crab caught by trip (b).

a)



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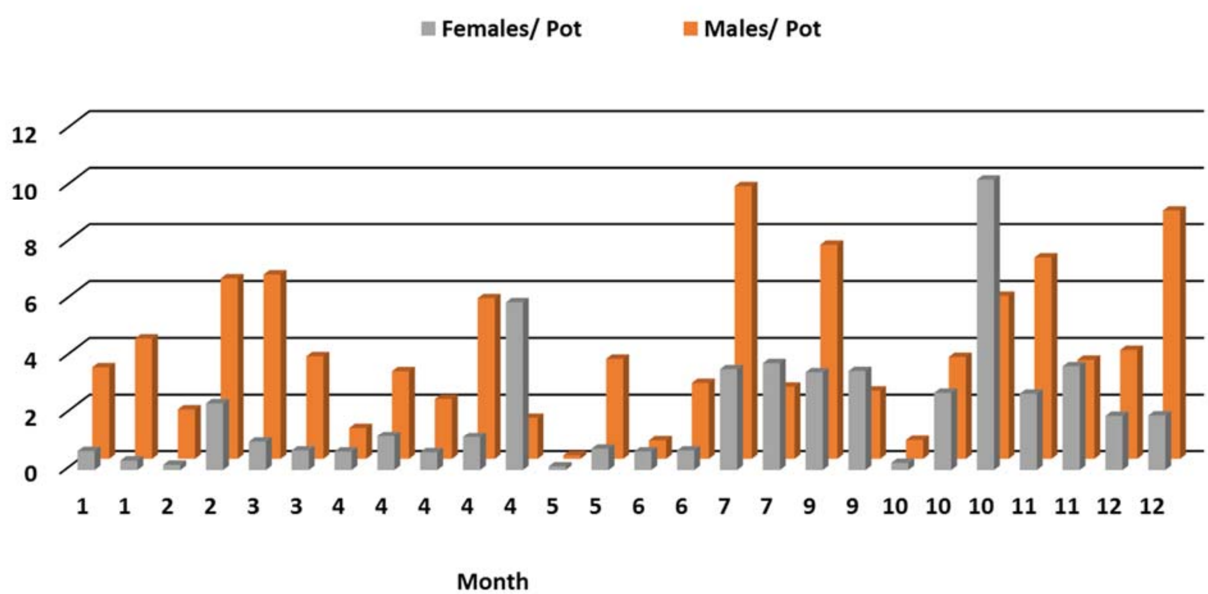


Figure 2 (a) The number of Dungeness crab (*Cancer magister*) intended for discard by reflex impairment score, grouped as Score-zero and those with Scores greater than zero; and crab retained ("keepers"); and (b) the average number of females and males intended for discard per pot for each completed recreational bay by boat sampling trip (n=26), listed by month (January=1).

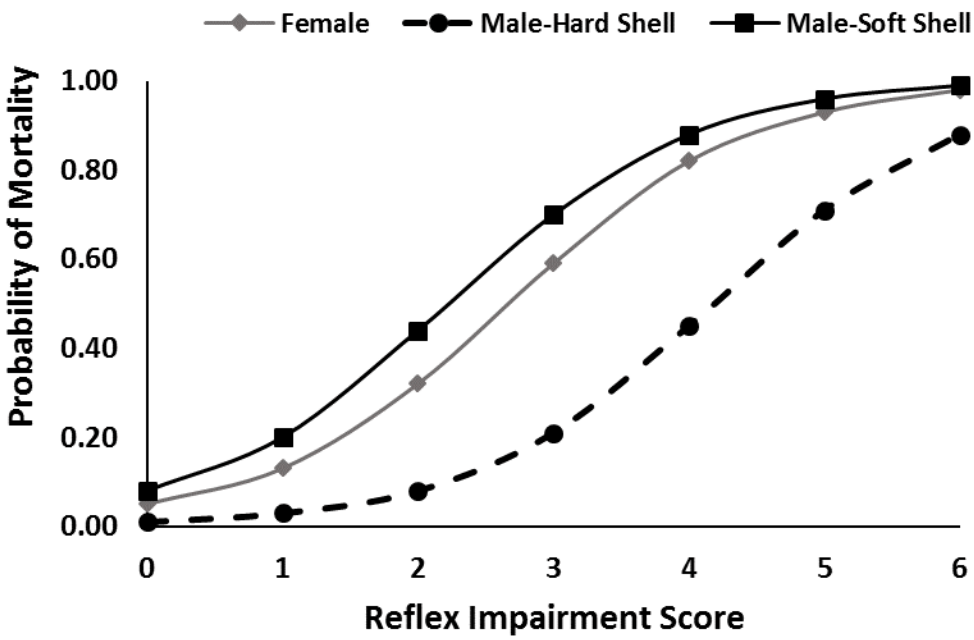


Figure 3 Reflex action mortality predictors (RAMPs) for discarded Dungeness crab (*Cancer magister*) from the commercial ocean crab fishery, including: females (hard and soft shelled combined), hard shelled males, and soft shelled males.

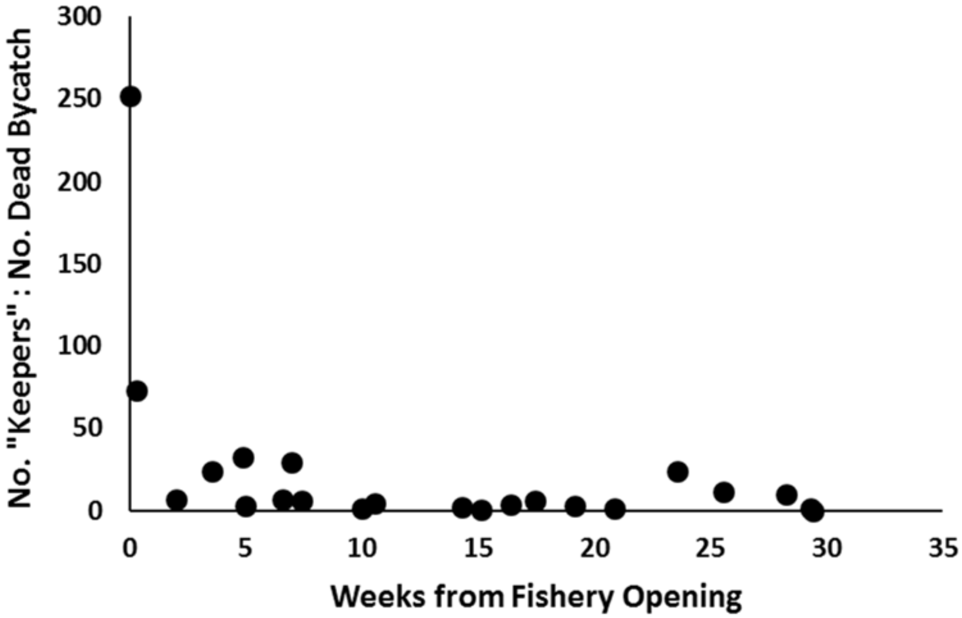
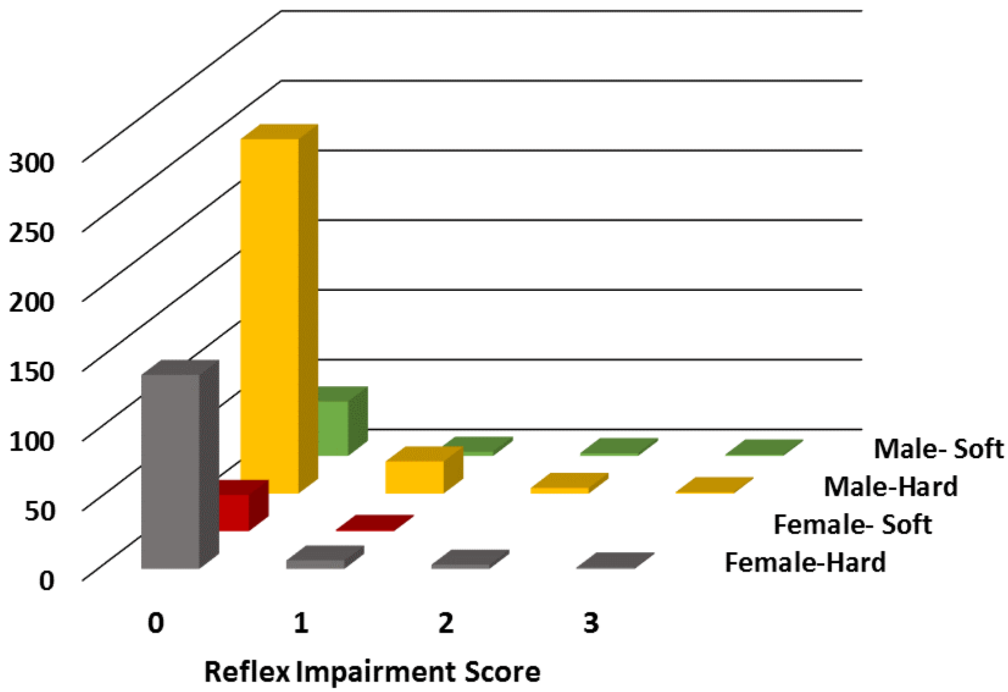


Figure 4 The ratio of the number of legal crab retained “keepers” to the number of bycaught crab predicted to die (sum of delayed and immediate mortality), for each sampling trip (n=22), by the number of weeks past the opening of the fishery for Dungeness crab (*Cancer magister*) in the commercial ocean fishery.

a)



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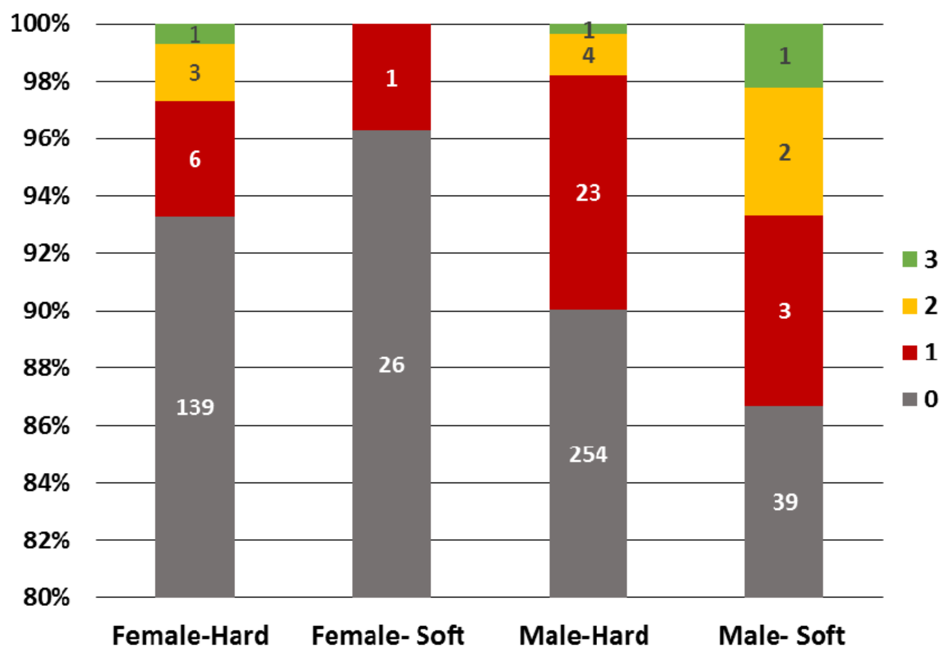
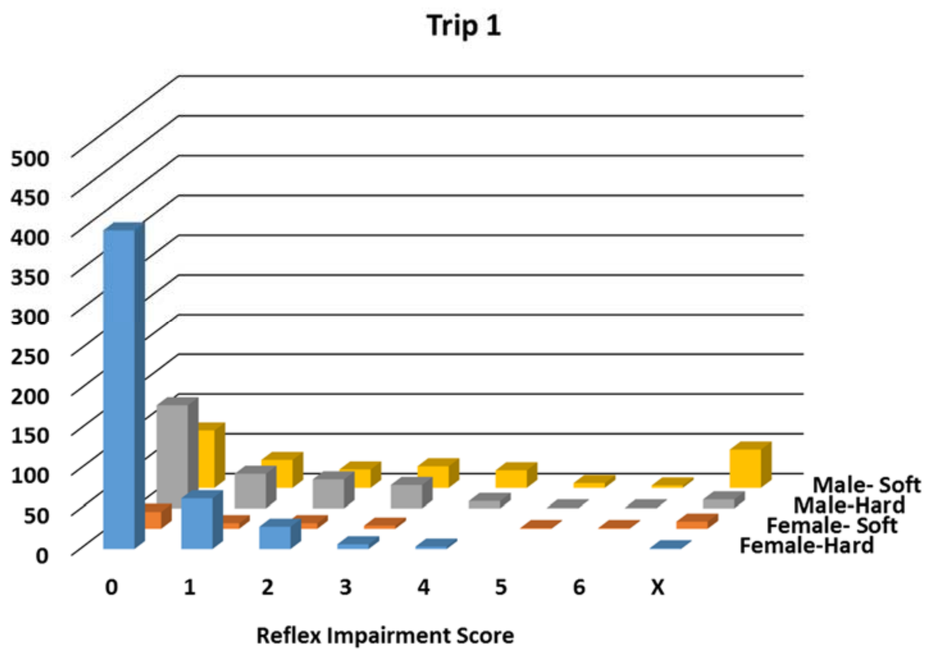


Figure 5 (a) Sum of and (b) proportion of the hard and soft shelled male and female Dungeness crab (*Cancer magister*) intended for discard, sampled from the shoreside recreational bay fishery at the Newport Pier in Yaquina Bay, Oregon by reflex impairment score (0-3).

a)



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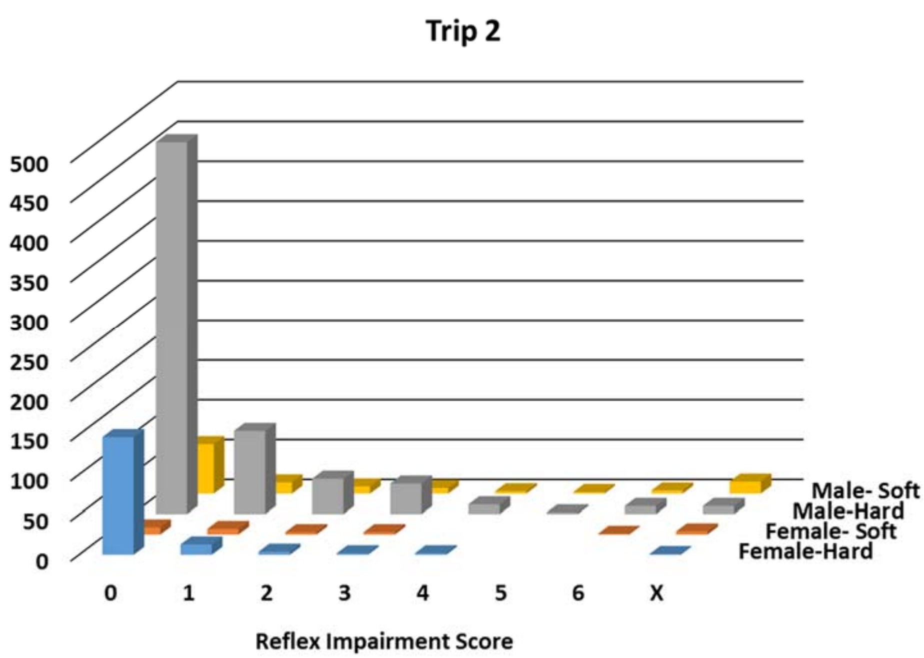

Figure 6 The number of Dungeness crab (*Cancer magister*) bycaught during two nearshore bottom trawl ride-along trips by sex and shell hardness for each reflex impairment score (based on the number of missing reflexes, 0-6), and of crab that were dead (X) before assessment (immediate mortality).