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Technical note

Delayed discard mortality of the giant Pacific octopus, *Enteroctopus dofleini*, in the Gulf of Alaska cod pot fishery

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A R T I C L E I N F O

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A B S T R A C T

There is a lack of information available on octopuses in Alaskan waters and because of this lack of data, catch limits are set based on historical incidental catch rates or survey biomass estimates that are likely to be overly conservative. This issue is further exacerbated by the fact that catch accounting for octopuses assumes 100% mortality for all octopuses caught whether retained or discarded. We examined the delayed mortality of the giant Pacific octopus, *Enteroctopus dofleini*, captured in Pacific cod, *Gadus microcephalus*, pot fisheries in the Gulf of Alaska. Octopuses captured as bycatch during commercial fishing operations were held on the vessel and brought back to the laboratory to assess delayed mortality over a period of 21 days. The relationship between survivorship and injury presence, sex, maturity, weight, season of capture, air temperature, water depth, and pot soak time were examined using generalized linear models. In addition, the relationship between injury presence and the same parameters were examined. Survivorship ranged from 77.8% to 93.6% during each of three fishing seasons and was significantly related to injury presence. Injury presence ranged from 10.0% to 63.2% during each season and was related to season with an increase in injuries during the fall. These data indicate the conservative assumption of 100% bycatch mortality for octopus is not appropriate for some fisheries, in particular those utilizing pot gear.

1. Introduction

Catch of octopuses in federal waters off Alaska is assessed biennially by the Alaska Fisheries Science Center (AFSC) and managed by the North Pacific Fishery Management Council (NPFMC). There is currently no directed fishery for any octopus species in federal waters. However octopuses are taken incidentally in several groundfish fisheries. Prior to 2011, octopuses were managed as part of an ‘other species’ complex with catch reported in aggregate with sharks, squids, sculpins, and other non-target species. Since 2011, octopuses have been managed as a separate assemblage that includes all octopus species present within each region. At the present time, data are not available or insufficient to support a model-based assessment for the octopus complex. There are also insufficient data to determine whether the complex is being subjected to overfishing, is currently overfished, or is approaching a condition of being overfished.

At least seven species of octopuses are found within the Gulf of Alaska. The giant Pacific octopus *Enteroctopus dofleini* is the most abundant species in shelf waters and dominates the commercial catch (Conners and Conrath, 2015). Octopuses are taken as incidental catch in trawl, longline, and pot fisheries throughout the Gulf of Alaska, but the highest catch rates are from the Pacific cod *Gadus macrocephalus* pot fishery in the central and western Gulf of Alaska (Conners and Conrath, 2015). Incidental catch of octopuses ranged from 88 to 339 metric tons between 1997 and 2010, with 82–96% of the total octopus bycatch each year caught by fisheries targeting Pacific cod (Conners and Conrath, 2015). The percentage of octopuses captured in pot gear ranged between 69.4 and 97.4% of the total octopuses caught in all gear types targeting cod between 2003 and 2010 (Conners et al., 2011). Once the Annual Catch Limit (ACL) for octopus is reached all octopuses are discarded and these discards are presumed to have 100% mortality. Once the Over Fishing Limit (OFL) is reached for octopus the fishery capturing them is closed. This occurred during 2011, in the Bering Sea/Aleutian Islands region when the OFL for octopus was reached on October 21, 2011 and directed fishing for Pacific cod using pot gear was closed for the remainder of the year in this region.

The assumption of 100% mortality is probably overly conservative and may lead to the premature closure of a fishery. Octopuses have no gas-filled spaces and have only small shell remnants which do not alter buoyancy; therefore they are less likely to experience the effects of

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barotrauma (Boyle and Rodhouse, 2005). If octopus are likely to survive the pressure changes associated with capture, any capture related mortality will be due to how they interact with or are affected by the gear that captures them. It is important that the status of discarded octopuses be established and how it is affected by the capture method. A gear-specific discard mortality factor might be appropriate for estimating total fishery related mortality of octopus; a similar approach is currently used for Pacific halibut *Hippoglossus stenolepis* (Williams, 2016). If a discard mortality factor were included in catch accounting for octopus, the fraction of discarded octopuses that are assumed to survive would not be counted toward the total catch for the assemblage.

Further research is needed to quantify the total mortality of discarded octopuses in relation to condition at the point of discard. Recent studies of short-term mortality of octopuses captured in pot gear indicate a high rate of survivorship at the point of release. A North Pacific Groundfish Observer special project included a visual evaluation of the condition of discarded octopuses throughout Federal fisheries. Immediate mortality rates for octopuses caught in pot gear were very low (< 1% in 2006 and 2007, 4% Dead or Poor condition in 2010–2011). The second part of this study examined the mortality of octopuses incidentally caught during commercial pot fisheries in the Bering Sea and found survivorship rates were greater than 95% for octopus held for over 48 h (Conners and Levine, 2017).

However, it is not known whether there is some delayed mortality due to handling or capture stress. Laboratory experiments are needed to estimate the proportion of octopuses that are alive when discarded, but later die due to the capture and handling process. We collaborated with Pacific cod pot fishers to collect octopuses caught as bycatch and transported them back to the laboratory to examine delayed discard mortality. The primary objective of this project was to provide reliable estimates of delayed discard mortality for octopuses caught as bycatch in the commercial Pacific cod pot fishery in the Gulf of Alaska. In addition, we analyzed mortality and injury data to examine whether there were any correlations with potential explanatory biological and environmental parameters

2. Material and methods

There are two Federal fishing seasons for Pacific cod. Federal A season for pot gear begins on January 1 and Federal B season begins on September 1 (NOAA Fisheries, Alaska Regional Office, 2016). During the 2014 Federal A and B seasons and 2015 Federal A season octopuses were collected by a scientist concurrent with commercial fishing operations on the *F/V Sumner Strait* and the *F/V Ruff & Reddy* (Fig. 1). The location and depth of capture, time out of water, air temperature, and pot soaking time were recorded. An Onset temperature data logger (Tidbit) was attached to one or two pots during each individual collecting trip to record seasonal water temperatures (Onset Computer Company, 470 MacArthur Blvd, Bourne, MA 02532).

After initial capture, all octopuses were placed in individual 18 gallon totes that were strapped closed within a holding tank on board the fishing vessel for a period of up to 72 h. After this period the holding tank containing octopuses was transported either *via* the fishing vessel or a tender to the port of Kodiak where the tank was then transported to the sea water facility at the Kodiak Laboratory. This transport time varied depending on how quickly the vessels could get into the processors to offload and ranged from 8 to 16 additional hours. This timing was consistent on both vessels during each season. The vessel's sea water deck hose, which pumps water from approximately 4 m depth was used to circulate water within the holding tanks; intermittently during fishing operations and constantly between fishing periods and during transport.

During the 2014 Federal A season, 20 octopuses were collected in Uganik Bay in 55–110 m water depth (Fig. 1). The majority (N = 17) were captured in late January and early February. The remaining three of these octopuses were donated by the fishing vessel (no scientist was on board). During the 2014 Federal B season, 19 octopuses were collected in the same region. These collections occurred during late September and early October 2014. These two sets of collections occurred in collaboration with the fishing vessel *F/V Sumner Strait*. The collections during both of these seasons occurred in the same area, on the same vessel, and in the same water depths.

During the 2015 Federal A season, 16 octopuses were collected in the Marmot Bay region in 115–155 m water depth (Fig. 1). The majority of these collections (N = 15) occurred in late January. One octopus was brought into port by the fishing vessel. This set of collections occurred in collaboration with the fishing vessel *F/V Ruff & Reddy*.

Octopuses were held for a period of 24–48 h in the laboratory after which octopus were weighed, sex was determined, and an initial detailed condition assessment was conducted. During this assessment, skin lesions, scratches, or bruises were noted, any open wounds were recorded, and any arm injuries were documented. While it was difficult to determine how recently wounds had been inflicted, whenever possible the openness of the wound was documented. If wounds appeared to be old and completely healed, this was noted as well. During this assessment each octopus was classified as 'injured' or 'not injured'. Injured octopuses were those that had at least one large open wound, bruised area, or area of noticeably different coloration from the rest of the body.

Octopuses were held for a period of 21 days to assess delayed discard mortality. This amount of time was chosen to have a prolonged period to assess survivorship while minimizing any effects on this parameter due to holding octopus in the artificial laboratory environment. Any octopus that experienced mortality during this period was once again examined for condition, the cause of mortality was assessed, and the octopus was dissected to determine reproductive status. At the end of this period a final condition assessment was conducted for each individual octopus. Octopuses in good or excellent condition without injury were defined as 'survivors'. Octopuses in poor condition or with lingering injuries were individually assessed to determine if survivorship seemed likely based on overall condition, coloration, behavior, and the status of injuries. Some octopuses were retained for a period of time for additional studies, but eventually each octopus was sacrificed and maturity status was determined.

Generalized linear models were utilized to examine the relationship between survivorship and several factors including injury presence, sex, maturity, weight, season, location, air temperature at capture, water depth, and pot soak time. A second set of generalized linear models were used to examine the relationship between injury presence and the same factors. Since survivorship and injury presence were binary responses, a binomial model was chosen with a default logit link. A forward step-wise approach was used to populate the models utilizing the parameters that were most statistically significant. The Akaike Information Criterion (AIC) was used to determine which model fit the data most parsimoniously. The generalized linear models were completed using the R statistical package glm in the stats library. Deviance residuals were used to examine model assumptions and the R statistical package usdm was utilized to examine variable inflation factors (R Core Team, 2015).

3. Results

During the 2014 Federal A season, one octopus died while still in the holding tank aboard the fishing vessel. One additional, octopus from the first collection died at the laboratory. Both of these octopuses were clearly injured at the time of capture and both experienced mortality. Octopuses ranged in size from 4.18 to 20.55 kg (mean weight = 9.30 kg, standard deviation = 4.47); all but six were mature and the catch was dominated by male octopus with only six females collected (Table 1). Survivorship of all captured octopuses was 90.0%.

During the 2014 Federal B season, one octopus died upon arrival at the sea water facility. Many of the remaining octopuses (N = 9) had

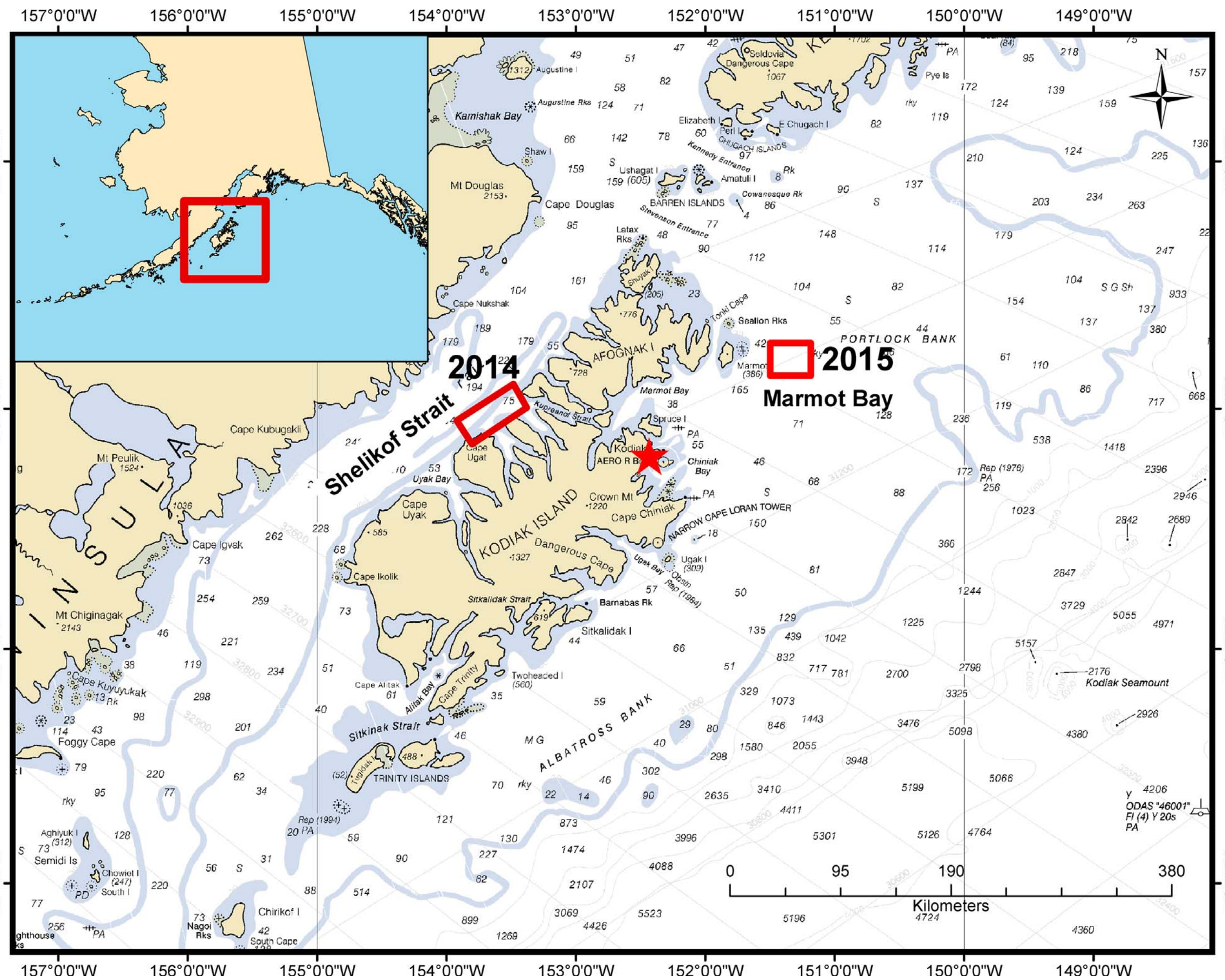

Fig. 1. Fishing locations for giant Pacific octopus during the 2014 Federal A and B season and during the 2015 Federal A season offshore of Kodiak Island in the Gulf of Alaska. The star indicates the position of the Kodiak Laboratory sea water facility.

Table 1
Octopus size range, sex, air temperature, *in situ* water temperature, number of injuries and number of mortalities during each fishing season in which octopus were collected, M = male, F = female, temp = temperature, and Mort = mortality.

Season	Size range (kg)	Sex	Air temp (°C)	Water temp (°C)	Injury	Mort
2014 A	4.18 to 20.55	14 M; 6 F	5.6 to 6.1	5.4 to 5.8	1	1
2014 B	3.90 to 16.98	10 M; 9 F	10.2 to 17.7	7.2 to 9.3	12	4
2015 A	5.48 to 17.53	8 M; 8 F	−1.7 to 6.2	6.9 to 7.0	6	1

injuries of varying severity and the overall condition of these octopuses appeared to be poorer than the condition of octopuses collected during the first fishing season. One mortality occurred at the sea water facility due to a tank malfunction. This octopus was not included in calculations of mortality or survivorship. An additional two octopuses experienced mortality and one octopus was determined to be unlikely to survive. Octopuses collected during this fishing season ranged in size from 3.9–16.98 kg (mean weight = 8.32 kg, standard deviation = 3.28); half of these octopuses were mature, and a nearly even number of males ($N = 10$) and females ($N = 9$) were collected (Table 1). Survivorship of the octopuses brought into the laboratory was lower during this season but still relatively high at 77.8%.

During the 2015 Federal A season one of the collected octopuses was injured and experienced discard mortality. Two other octopuses from this collection had relatively severe injuries and survivorship was questionable but they appeared to be in improving condition at the time of final assessment. Octopuses collected during this fishing season ranged in size from 5.48–17.53 kg (mean weight = 10.67 kg, standard deviation = 3.68), the majority of octopuses were mature (n = 10) and the sex ratio was once again equal with eight males and eight females (Table 1). Survivorship was 93.8% for octopus collected during this season.

The only parameter that was significantly ($P < 0.001$) related to survivorship was injury presence (Table 2). The next three parameters with the lowest P values were air temperature, season, and maturity ($P = 0.0646$, 0.100, and 0.188). These parameters were tested for multicollinearity using the variance inflation factor (VIF) test. Air temperature and season were moderately collinear (VIF = 3.076,

Table 2
Generalized linear model results for survivorship comparing four models utilizing the parameters injury, season, and air temperature. The model determined to have the best fit is italicized.

Model	Parameters	*P* value	AIC score	ΔAIC score
1	*Injury presence*	*< 0.001*	*20.477*	
2	Injury presence	0.004	24.756	4.279
	Air temperature	0.501		
3	Injury presence	< 0.001	21.576	1.099
	Maturity	0.175		
4	Injury presence	0.006	24.724	4.247
	Air temperature	0.253		
	Maturity	0.143		

Table 3
Generalized linear model results for injury presence comparing four models utilizing the parameters season, soak time, and sex. The model determined to have the best fit is italicized.

Model	Parameters	*P* value	AIC score	ΔAIC score
1	*Season*	*0.001*	*65.042*	
2	Season	0.002	66.668	1.626
	Soak time	0.944		
3	Season	0.001	69.609	4.567
	Sex	0.243		
4	Season	0.001	67.639	2.597
	Soak time	0.861		
	Sex	0.320		

3.158) and did represent similar input information into the model so only air temperature was included in the model analyses. The most parsimonious model had the lowest AIC value and was determined to be the best model. All octopuses that were free of serious injury (any open wounding or large bruises/sores) regardless of fishing season, survived during the discard mortality study. Over half (56%) of the octopuses that were deemed to have a serious injury ($N = 16$) survived for the 21 day period, the rest ($N = 7$) either died or were determined to have injuries they were unlikely to survive.

The only parameters that were significantly related to injury presence were season ($P = 0.001$, Table 3) and air temperature ($P = 0.007$). The next two parameters with the lowest P values were soak time ($P = 0.412$) and sex ($P = 0.583$). The season and air temperature parameters were correlated (see above) with the highest temperatures occurring during the fall season (Federal season B) therefore air temperature was not used in the models. The only model parameter that was significant in any model was season and the most parsimonious model had the lowest AIC value and was determined to be the best model. The amount of deviance explained by the parameters in all four models was very low but they do indicate an increase in injury presence during the warmer fall season. Survivorship was lower and injury prevalence was higher in the 2014 season B than either of the other two seasons.

4. Discussion

This study found survivorship of octopuses incidentally captured in pot fishing gear targeting Pacific cod was relatively high. This indicates the development of a gear-specific, discard mortality factor for octopuses would be appropriate. Rates of long-term survivorship were slightly lower but similar to those estimated from the short term studies listed above (Conners and Levine, 2017) with overall survivorship rates of 87.2%. The survivorship estimates derived by this study may be overly conservative as there was no practical way to include a control group within the study and there may have been some holding related stress from being held in captivity for some of these organisms. There were additional stressors involved in the transport of these octopus to the laboratory. Many of these octopuses were mature adults nearing the end of their life span which may also contribute negatively to their survival. It is possible that octopuses returned to the wild may have higher survivorship rates than presented within this study. Alternatively it also possible survivorship of the octopuses may have been inflated by holding them within the predator free laboratory environment. These octopuses did not have to survive a return trip to depth after capture and were fed regularly. This may be particularly true of octopuses that sustained injuries during capture.

Giant Pacific octopuses held during the study that were not injured had 100% survivorship over 21 days, and over half of injured octopuses also survived. This indicates the absence of injuries present on the octopuses may be a strong indicator of survivorship if an octopus is quickly returned to the water. Injury presence may be a conservative way to estimate survivorship and the severity of injury could be incorporated into calculations of mortality rates. However, it is important to note that many injured octopus appear to be in excellent condition at capture and using the condition codes defined for the observer project (Conners and Levine, 2017) may be problematic. Octopuses with severe injuries still often retained both color, muscle mass, sucker response, and movement at capture. Some of these octopuses survived for a period of days or weeks before succumbing to their injuries. Examining octopuses for injury has potential as a point-of-release survivorship indicator but it is important that each octopus is examined closely for injuries and not assumed to be injury free based on overall appearance or behavior.

There were differences in the frequency of injuries between fishing seasons. Octopuses caught in the fall season were overall more injured at capture and a smaller proportion of them survived than during winter fishing seasons. We collaborated with the same vessel during both the 2014 Federal A fishing season (which begins in January) and the 2014 Federal B season (which begins in September). Fishing effort during these two seasons not only occurred on the same vessel but also in the same area at the same depths (Fig. 1). There were some crew changes between seasons, but techniques utilized, experience of fishers, and pot soak time were consistent between the two seasons. Potential reasons for the increased mortality rate in the fall season may include differences in survivorship related to temperature, differences in the behavior of the octopus, and increased injury rates due to the presence of predators within the fall months.

The fall B season temperatures were, as suspected, warmer than both winter A season temperatures. In Prince William Sound, the density of giant Pacific octopuses has been shown to be correlated with sea surface temperature and these correlations may be related to marine productivity during the larval stages of their life history (Scheel, 2015). This would indicate either a difference in movement or survivorship between different temperature regimes. Perhaps more importantly during the fall season air exposure temperatures were at times much higher than recorded *in situ* water temperatures. In some cases air temperatures were 8–9 °C higher than the sea water temperature recorded at the pot. During the 2014 A season air exposure and *in situ* water temperatures were very similar whereas, in the 2015 A season air exposure temperatures were lower than *in situ* water temperatures. Air exposures have been indicated as a cause of additional capture mortality in a variety of invertebrate species. This has been recorded for a variety of crab species where both low air exposure temperatures (Urban, 2015) and high air exposure temperatures (Giomi et al., 2008) have been shown to be problematic. The octopuses' exposure to air, however, was fairly minimal with a maximum exposure time of around 8 min and almost all octopus were placed in a tank within five minutes of capture. Octopuses that were discarded alive would likely experience less than 5 min of exposure to air, so it is likely that there may be another cause for this increased mortality during this season.

Octopuses captured with injuries were either directly injured by contact with the gear, interaction with fishers, or suffered some injury due to interactions with other octopuses or predators present within the region (including the target species cod, halibut, or other large teleosts). The conservative assumption utilized for this project was that injuries were due to the presence and operation of the fishing gear. These injuries could either be due to direct interaction or contact with the fishing gear or more indirect effects created by the fishing gear concentrating organisms within the space of the gear. It is possible that the increased rate of injury is due to biological factors not related to the deployment of the gear. Octopuses may be more active during the fall season due to increased water temperatures (see above). A tagging study in the Bering Sea found that octopus tagged in the fall fishing season had on average larger displacement distances than those tagged in the spring season perhaps indicating these octopus moved more during this period (Brewer and Norcross, 2013). Giant Pacific octopuses in the Gulf of Alaska have a protracted reproductive cycle and the majority of females lay their eggs in the coldest parts of the year (Conrath and Conners, 2014). This spawning pattern may mean that more octopuses are actively seeking mates during the fall months, which may result in a greater number of octopus interactions. Seasonal movements and migration of this species remain poorly understood and differences in spatial distribution may in part also explain some of these differences; however, octopuses were present and captured in high numbers during all three sampling periods and there were minimal differences in the size or sex of individuals captured.

The differences found between seasons are indicative of a need for additional studies to understand the discard mortality of this species in the Gulf of Alaska. Other factors that complicate the assessment of octopus mortality are differences in vessel size, fishing locations and water depth, as well as crew size and experience. Additional studies utilizing more vessels and occurring in additional fishing seasons would add valuable support and robustness to discard mortality estimates for this species in the Gulf of Alaska. In addition, the use of new technologies will aid in providing additional information on movement, mortality, and biomass. The development of new tagging technologies (Barry et al., 2011; Brewer and Norcross, 2012) and the examination of short and long term movement (Scheel and Bisson, 2012) with acoustic studies have begun to provide answers on the short and long term migratory movements of these animals. In addition, these studies have started to examine biomass and mortality of giant Pacific octopus as well. Brewer and Norcross (2013) estimated the biomass of giant Pacific octopus to be 177 tons within a small 25 km^2 study area in the Bering Sea. The large biomass of octopus estimated by this study led the researchers to hypothesize that estimates of biomass and therefore harvest limits for this species within the Bering Sea large marine ecosystem are likely overly conservative. This may be true throughout all the large marine ecosystems of Alaska and more research are needed to understand the population dynamics of octopus within this region.

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