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Long-term Survival and Observable Healing of Two Deepwater Rockfishes, *Sebastes*, After Barotrauma and Subsequent Recompression in Pressure Tanks

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ABSTRACT

We evaluated the long-term survival and observable healing over 6–18 months for two species of deepwater rockfishes that experienced barotrauma followed by repressurization in portable pressure tanks and slow depressurization to surface pressure. Blackspotted *Sebastes melanostictus* and rougheye rockfish *Sebastes aleutianus* were captured at depths from 123 m to 279 m. Barotrauma was assessed immediately after capture and fish were recompressed to 70 psi in pressure tanks on-board the fishing vessel, gradually acclimated to atmospheric pressure at sea-level over a 2- or 4-day period, then held in the laboratory. Others were released from a weighted cage held at ~75 m and observed with a video camera. Survival in the laboratory was highest when fish were given 4 days (78% in 2013) to acclimate to the pressure change, as opposed to 2 days (54–60% in 2011 and 2012, respectively). A longer fish length increased the probability of mortality; however, neither the presence of external or internal barotrauma nor the depth of capture were associated with the probability of survival. Videos taken of fish that were released after capture from the weighted cage showed that fish were not positively buoyant, were oriented upright, and 67% were able to swam away. A previously released fish was recaptured in a bottom-longline fishery 6 months later, 58 km from the release site, demonstrating that fish are capable of surviving in the wild post-barotrauma. This study illustrates the utility of pressure tanks for 1) slowly acclimating fish to surface pressure for transport to a holding facility and 2) as an alternative to underwater cages for short-term observations. Our results indicate that short-term observations of recompressed fish may be adequate for studies of survival. However, long-term observations are required to observe the healing of some injuries.

CONTENTS

INTRODUCTION

Movement patterns and population boundaries of many species are difficult to study because they incur barotrauma, injuries from rapid decompression during capture, which may result in mortality. Although fish brought to the surface from depth may appear moribund and exhibit external signs of barotrauma, there is now evidence that many species can survive after they are released at depth or recompressed. In studies where individual fish were observed after capture, survival rates were species-specific, ranging from 25% to 100% (black rockfish *Sebastes melanops*, Parker et al. 2006 and Pribyl et al. 2012; five species of Pacific rockfishes *Sebastes* spp., Hannah and Matteson 2007; 13 species of Pacific rockfishes, Jarvis and Lowe 2008; yelloweye rockfish *S. ruberrimus*, Hochhalter 2012; snapper *Pagrus auratus*, Butcher et al. 2012; *Argyrosomus japonicas,* Butcher et al. 2013; and yelloweye and canary rockfish *S. pinniger*, Hannah et al. 2014). Despite the growing abundance of information on barotrauma, data on deepwater species are lacking as well as studies of long-term survival and apparent healing from injuries. Also, there is evidence that barotrauma and survival rates sometimes depend on factors such as capture depth and fish size (e.g., Jarvis and Lowe 2008, Hochhalter and Reed 2011, Hannah et al. 2012, Hannah et al. 2014, McLennan et al. 2014, Hall et al. 2014). For these reasons, it is imperative to collect species-specific estimation of survival rates prior to conducting tagging studies.

Short-term survival of individual fish after barotrauma has been studied in underwater cages; in these studies the duration of observations were from 1 to 6 days (Gitschlag and Renaud 1994, Wilson and Burns 1996, Collins et al. 1999, Smiley and Drawbridge 2007, Jarvis and Lowe 2008, Stewart 2008, Butcher et al. 2012, Hannah et al. 2012, Butcher et al. 2013, Hall et al. 2014, Hannah et al. 2014, McLennan et al. 2014). Although these studies have provided data on short-term survival, they do not provide the opportunity to monitor the observable healing of barotrauma (such as injuries to the swim bladder or eyes) or to determine if barotrauma are related to delayed mortality. Hannah et al. (2014) suggest that longer-term studies are "badly needed" to monitor the health of fish post-barotrauma. These data are lacking because long-term holding can be difficult without a method to repressurize multiple fish for transport to a holding facility for monitoring.

Allowable catch of federally managed blackspotted *S. melanostictus* and rougheye rockfishes *S. aleutianus* in Alaska are divided among five management areas: Western/Central Aleutian Islands; Eastern Aleutian Islands/Eastern Bering Sea; and the Western, Central, and Eastern Gulf of Alaska. These two species are difficult to visually distinguish from each other, inhabit the same habitats and depths (100–500 m) (von Szalay et al. 2010), and sometimes hybridize; therefore, they are managed together as a complex in Alaska. Rockfishes have high commercial value in Alaska (ex-vessel value in 2013 was $27 million USD, Fissel et al. 2014); however, information on their movement patterns and population structure are limited. A study of genetic population structure suggests management areas in the Gulf of Alaska may be too large for blackspotted rockfish because their genetic differences show that there may be multiple populations within this management area, potentially making these populations susceptible to over harvest (Gharrett et al. 2007). In addition, in the Aleutian Islands, Alaska, catch and survey abundance trends show there may be local depletion in some areas (Spencer and Rooper 2012). This depletion could be a result of limited dispersal distances and separate populations, indicating that management areas may be too large (Spencer and Rooper 2012). If blackspotted and rougheye rockfish were able to survive barotrauma and be tagged and released, direct measurements of movement among management areas could be used to determine if the geographic boundaries are the appropriate size for management of populations of blackspotted and rougheye rockfishes.

There were four objectives for this study. The first objective was to determine if fish length and capture depth are correlated with the presence of external barotrauma signs. The second objective was to determine if fish length, capture depth, and barotrauma are significantly related to the probability of long-term survival in the laboratory. The third objective was to monitor the observable eye and swim bladder healing over the long-term. The fourth objective was to quantify the percent of fish capable of swimming after release at depth using a video camera. The fifth objective was to tag and release rockfishes for any evidence of survival in the wild post-release.

METHODS

Sample collection

A commercial longline vessel, FV *Seaview*, was chartered to conduct fishing on three sampling trips over 3 years: 10-14 September 2011, 10-14 July 2012, and 3-7 September 2013. Sampling occurred in Port Herbert, a deepwater fjord on the southeast side of Baranof Island, Southeast Alaska, USA (56.38º N, 134.67º E). Small amounts of gear were set at each location (~100 hooks) so the number of fish caught would be manageable for a quick assessment of barotrauma before the fish was either released at depth or recompressed on-board. Soak time was kept short, 2 hours, to minimize potential damage by sand fleas. Gear was set at depths from 123 m to 279 m.

Total fish length (mm) and external barotrauma injuries were recorded immediately after fish were brought on-board. Injuries included exopthalmia ("pop-eye"), ocular emphysema (gas in the corneal tissue), everted esophagus, subcutaneous emphysema by the dorsal fin or between the dorsal fin rays, and subcutaneous emphysema in the pharyngeal-cleithral membrane. The amount of time fish were held at surface pressure while being processed or held in a live well (1 to 10 minutes) was recorded. Surface time was not a significant effect in any models of survival so it is excluded from the Methods and Results sections. All fish were tagged with an external plastic anchor tag for identification. Blackspotted and rougheye rockfish collected in 2013 were genetically identified in the laboratory to species from fin clip tissues using the microsatellite DNA marker uSma6 (modified from Wimberger et al. 1999, Gharrett et al. 2005). The fragment was amplified using an ABI 9700 thermal cycler, variation was visualized on an ABI 3130x DNA Sequencer, and scored using GeneMapper5 (ABI Sequence Detection Software).

Pressure Tanks and Release Cage

A portion of the rockfish were recompressed in three portable pressure tanks on-board the vessel after capture. Pressure tanks were built according to Smiley and Drawbridge (2007); they were constructed out of polyvinyl chloride (PVC) pipe with an internal diameter of 28.6 cm and a length of 91.4 cm and there were acrylic viewing windows on both ends, which were covered the majority of the time to minimize stress and light levels. A flow-through seawater supply maintained a flow of a minimum of 2 liters per minute. One to three fish were placed in each pressure tank, depending on fish size. Fish were provided sufficient space in the pressure tank to keep from touching other fish. Fish were chosen for repressurization in tanks if they were caught close by one another on the longline, minimizing holding time.

Tanks were initially pressurized to 70 psi, which is equivalent to 4.76 atmosphere (atm) or a depth of 47.9 m. We used this pressure because it was the maximum psi that the system would accommodate, given the capacity of the pipe fittings used for outflow from the tanks. Pressure was kept constant for the first 4–6 hours and then slowly reduced, as tolerated by the fish, over the course of 2 days (in 2011 and 2012). Each time there was a pressure change it was reduced until the fish became slightly positively buoyant and then increased until the fish attained neutral buoyancy, similar to Pribyl et al. (2012). In 2013, fish were given 4 days to decompress to surface pressure in pressurized tanks. A 4-day schedule was chosen in an attempt in increase survival. During the longer decompression schedule fish were given more time between pressure adjustments. In all years, surviving fish were transported back to the laboratory for long-term holding in 1 m deep, 2.4 m diameter tanks. The pressure chambers were required to slowly acclimate fish to surface pressure for long-term holding an observation.

In 2011-2013, captured fish not placed in the pressurized tanks were tagged with an external spaghetti tag and released on site. A weighted, bottomless release cage was used to quickly lower fish to ~75 m (250 ft). To facilitate fish escape, the device was held at depth for 1 minute before being pulled to the surface. In 2011 and 2012, an inverted two-ring crab net with an outside diameter of 0.8 m was used for lowering fish. In 2013, a 1 m bottomless cage constructed of stainless steel bars and monofilament mesh was used for descending fish.

In 2013, two LED lights and a GoPro camera in a watertight case rated to 152 m depth were fixed to the top of the cage to record observations of behavior while being descended and during release. The mesh on the top side of the enclosure was 1.5 m from the top of the cage to allow distance between the fish and the camera. The weight of the cage allowed it to sink rapidly (over the course of 2–3 minutes). To facilitate fish escape, the device was held at depth for 1 minute before being pulled to the surface. This depth was chosen so that we could be certain that fish would be repressurized and be either neutral or negatively buoyant, so that the swimming behavior could be observed. The depth of release was deeper than the depth simulated in the tanks, but not as deep as the capture location. The intent was not to compare the results of the underwater behavior to the survival of repressurized fish. The objective was to observe the swimming ability of fish that were released back into the wild.

Long-term Holding in the Laboratory

Fish that survived recompression in pressurized tanks and slow decompression were held in the laboratory at surface pressure (1 atm) for 6-18 months after capture. Fish were all sacrificed in either December or January for gauging maturity status. Because parturition of larvae occurs in March–May in Alaska, fish should show signs gamete development by the winter (Conrath 2017). Maturity was defined easily for all fish because gonads were very small and string-like and could be obviously staged as immature. In the laboratory, eyes were periodically checked for evidence of lasting visible injuries, including exophthalmia, ocular emphysema, and haziness. When sacrificed, visible eye injuries and evidence of healed swim bladder ruptures were recorded.

Barotrauma Presence and Survival Analysis

The relationships between the presence of each barotrauma injury at the time of capture and both fish length and capture depth for all fish caught in all years were analyzed using a logistic regression (JMP software version 9),

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = d_i + l_i \ , \tag{1}$$

where $\hat{p}$ was the expected probability that a certain barotrauma injury was present (one model was run for each injury type): exopthalmia, ocular emphysema, everted esophagus, subcutaneous emphysema by the dorsal fin, subcutaneous emphysema in the pharyngeal-cleithral membrane, or a swim bladder rupture), d_i was the capture depth of the i^{th} fish, and l_i was the length of the i^{th} fish.

A logistic regression model was used to determine the significance of the relationship between survival and fish length and capture depth for fish put into pressurized tanks (equation 2). Here $\hat{p}$ was the estimated probability that a fish survived, d_i was the depth of capture of the i^{th} fish, l_i was the length of the i^{th} fish, and y_j was the sampling year (2011, 2012, or 2013). The year was included in the model because experience using the pressurized tanks increased and the time to acclimate to surface pressure in pressurized tanks increased in 2013,

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = d_i + l_i + y_j. \tag{2}$$

A logistic regression model was used to examine the relationship between long-term survival of fish put into pressure tanks and the presence of barotrauma injuries, where the explanatory variables were the presence or absence of a barotrauma injury and $\hat{p}$ was the expected probability of survival (Equation 3). The full model was run with all barotrauma types (exopthalmia (ex), ocular emphysema (o), everted esophagus (ev), subcutaneous emphysema near the dorsal fin (ed), and subcutaneous emphysema in the pharyngeal-cleithral membrane (ep)) for each fish (i^{th}):

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = ex_i + o_i + ev_i + ed_i + ep_i. \quad (3)$$

RESULTS

Samples for Pressurized Tanks

In total, 246 blackspotted and rougheye rockfish were caught: 186 of these were tagged and released and 60 were recompressed in tanks. In 2013, 87 fish were genetically identified to species: one was a hybrid (of blackspotted and rougheye rockfish), one was a rougheye rockfish, and 85 (98%) were blackspotted rockfish. Although genetics were not analyzed in 2011 and 2012, it is possible that there was a mix of blackspotted, rougheye, and hybrid rockfish. All specimen were pooled in analyses.

In total, 60 fish were recompressed and slowly decompressed in pressurized tanks: 22 fish in 2011, 20 fish in 2012, and 18 fish in 2013. The length of fish ranged from 275 mm to 685 mm (Fig. 1). The three length bins included small (< 400 mm, N = 24), medium (400–450 mm, N = 23), and large fish (> 450 mm, 460–686 mm, N = 13). For blackspotted rockfish our samples were within the range for the species; those genetically identified as blackspotted rockfish in our study were 275–540 mm and fish over 550 mm are rare in trawl surveys in Alaska and the maximum length recorded is 610 mm (J. Heifetz, NOAA-NMFS-

AFSC, pers. comm.). The length range of all specimen in our study (275–686 mm) does not encompass the entire length range for rougheye rockfish; the maximum length for rougheye rockfish is 970 mm, although fish over 800 mm are rare (Love et al. 2002). Although there are no recorded lengths of blackspotted rockfish over 610 mm, it is still possible that the fish over 610 mm that we collected are blackspotted rockfish. The one fish we identified as a rougheye rockfish was 410 mm and the hybrid was 340 mm.

Almost all fish were caught at depths from 123 to 220 m; a single fish was caught at 279 m (Fig. 1). Depth bins were defined as 150 to 175 m (N = 22), 175–200 m (N = 26), and > 200 m (N = 12).

Presence of Observable Barotrauma

In total, 246 blackspotted and rougheye rockfish were caught and barotrauma signs were documented. Several barotrauma signs were common: an everted esophagus occurred in 95% of fish, exophthalmia in 88%, ocular emphysema in 83%, dorsal emphysema in 57%, and subcutaneous emphysema in the pharyngeal-cleithral membrane in 99% of fish. Fish appeared lifeless when brought onboard prior to repressurization in tanks or during release.

In logistic regressions of the presence/absence of each barotrauma type, utilizing equation (1), the only significant relationship identified was between the presence of an everted esophagus and fish length (Fig. 2) (logistic regression model test, $\chi^2 = 6.86$, df = 2, P = 0.03) (logistic regression model test, parameter effect likelihood ratio test for length, $\chi^2 = 5.46$, P = 0.02). The probability of an everted esophagus increased with fish size (Fig. 2). Although there was generally an increase in the prevalence of an everted esophagus with size, fish from 300 to 379 mm had a lower probability of having an everted esophagus (average 86%, N = 97) than smaller and larger fish (Fig. 2). This pattern was consistent for fish caught at shallower depths

(123–170 m) and deeper depths (171–220 m including one fish caught at 279 m) (Fig. 2). However, the difference was most noticeable in the shallower depth range (average difference between moderate-sized fish and other sizes was 23%).

Survival

Of the 60 fish placed into pressurized tanks at-sea from 2011 to 2013, 63% (38/60) survived in the laboratory; 34 were sacrificed and dissected after 6–18 months and others were released in the wild with pop-up satellite archival tags (Rodgveller et al. 2016). All but one mortality occurred while fish were being decompressed in the tanks or within 10 days of capture (Table 1); that is, mortally after 10 days was very low. In 2013 all mortalities occurred while fish were in the tanks. When mortalities occurred during depressurization, the individual fish would first start to flare the operculum more dramatically to force more water through the gills, which may be a sign of stress. Survival increased in each successive year, from 54% in 2011 to 60% in 2012 and increased again to 80% in 2013, when a 4-day decompression schedule was used (Table 1).

We considered our holding times of 6–18 months all long-term because, in comparison to this time period, the literature includes acute studies that are less than 1 week long. There is further justification for pooling these long-term observations of survival because all mortalities, except one, occurred within 10 days of capture, indicating that 10 days encompasses a short-term response to barotrauma for blackspotted and rougheye rockfish. The long-term holding period of 6–18 months also proved to be an adequate time for internal healing of swim bladder tears.

In the logistic model with fish length and capture depth (Equation 2), survival of fish recompressed and slowly decompressed in pressurized tanks was significantly related to fish length and not capture depth (logistic regression model test, $\chi^2 = 6.19$, df = 2, P = 0.052) (logistic regression model test, parameter effect likelihood ratio test for length, $\chi^2 = 4.74$, df = 1, P = 0.01). Smaller fish had a higher survival rate than larger fish (Fig. 3): 75% of fish < 400 mm survived (N = 27), 65% of fish 400–450 (N = 17), and only 31% of fish > 450 mm survived (N = 16). For fish <400 mm, 66% of deaths occurred while fish were being slowly decompressed in pressurized tanks, 86% for fish 400–450 mm, and 78% for fish > 450 mm. Survival was not significantly related to any internal or external barotrauma injuries (utilizing Equation 3).

Long-Term Recovery in the Laboratory

When surviving fish were removed from the pressurized tanks after slow decompression, external signs of barotrauma were visibly reduced. The only apparent external barotrauma that sometimes persisted were eye injuries (Fig. 4). The apparent healing of eyes was tracked for 40 fish in the laboratory. The majority of fish placed into pressurized tanks had both exophthalmia and corneal emphysema immediately after capture (34/40; 85%) (Table 2). Of the fish on the 2-day decompression schedule that exhibited exophthalmia and corneal emphysema immediately after capture (22/27, 81%), 45% were clear after fish were released from the pressure tanks. The remainder had gas in the cornea that cleared after 5 to 6 months, gas that persisted in the cornea throughout holding (Fig. 4), and one fish lost both eyes. All fish with exophthalmia only or clear eyes immediately after capture had clear eyes after being released from the tank. All fish on the 4-day decompression schedule had clear eyes when they were released from pressure tanks, even though 12/13 had both exophthalmia and corneal emphysema immediately after capture (Table 2). These data indicate that exophthalmia is not present after recompression and that corneal emphysema may persist after recompression when the 2-day decompression schedule is used and does not when the 4-day decompression schedule is used.

Previously ruptured swim bladders were observed in 41% (14/34) of fish dissected after long-term holding (6–18 months). Previous ruptures were evidenced by either a scarred area on the swim bladder or by a small portion of the tunica interna that was bulging outward, likely caused by an unhealed tear in the tunica externus, which lacked spotted, black pigment relative to nearby undamaged tissue (Fig. 5). All but one of the fish with ruptures (13/14) had healed and their swim bladders were inflated. In two fish with healed swim bladder ruptures, the scarred swim bladders had attached to the liver. The rupture was surrounded by yellow, apparently necrotic tissue. In a logistic regression of the presence/absence of swim bladder rupture, depth and fish length were not significant predictors of a rupture (logistic regression model test, $\chi^2 = 0.57$, df = 2, P = 0.73) (logistic regression model test, parameter effect likelihood ratio test for length, $\chi^2 = 0.02$, df = 1, P = 0.89) (logistic regression model test, parameter effect likelihood ratio test for depth, $\chi^2 = 0.56$, df = 1, P = 0.40). The average length of fish with a swim bladder rupture was 407 mm (SD = 84 mm) and the average length without a rupture was 394 mm (SD = 57 mm). The average depth for a fish with a rupture was 184 m and without a rupture was 185 m.

Video in Release Cage

In 2013, video was taken of 46 fish while being descended in a cage to ~75 m. During descent fish were pressed against the top mesh panel of the cage and their movement was restricted. During descent, the everted esophagus would shrink due to increased pressure. In some cases, when the fish was at an angle that was captured by the camera, the eyeballs popped back into the socket in one quick motion during descent. When the fish arrived at the release depth they were no longer positively buoyant. At the release depth there was always some current and the fish either passively drifted out of the field of view dorsal side up (i.e., right-side up) over the course of 3 to 10 seconds (15/46, 33%) or actively swam away (31/46, 67%). Before the cage was brought back to the surface, the cage was rapidly raised and lowered to make sure fish were not caught in the cage mesh, which prompted more vigorous swimming.

Tagging

One rockfish tagged with an external spaghetti tag in July 2012 was recaptured in March 2013 in the Pacific halibut *Hippoglossus stenolepis* longline fishery 58 km from the capture/release location. To swim to the recapture location, the fish had to cross over areas as deep as 590 m. Because blackspotted and rougheye rockfishes are closely associated with the bottom, it is possible the fish descended to deeper depths than the capture/release depths in order to reach the recapture location.

DISCUSSION

Survival

We found that with rapid recompression post-capture blackspotted and rougheye rockfish caught in deepwater can survive in the long-term after incurring barotrauma from rapid decompression. In 2013, the third year of the study, fish were decompressed in pressurized tanks more slowly than in 2011 and 2012 and researchers had increased experience operating pressure tanks, likely contributing to the increase in survival in 2013. Smiley and Drawbridge (2007) also found an increase in survival of 13% to 69% with increased experience when repressurizing fish in pressurized tanks. If the goal is to monitor fish condition long-term after capture, it is important to ensure enough time is given for fish to depressurize in pressure tanks without causing increased mortality. Adjusting the decompression schedule for the species of interest will likely be species-specific. For example, in pressurized tanks, black rockfish took 48 hours to show acclimation to surface pressure (1 atm) from 4 atm (30 m) (Parker et al. 2006) and 72 hours to acclimate to 1 atm from 4.5 atm (35 m) (Pribyl et al. 2012) while China rockfish (*S. nebulosus*) took over 250 hours to acclimate to 4 atm from surface pressure (Parker et al. 2006).

Of the fish we tagged and released, there was one recaptured in the Pacific halibut longline fishery, indicating that survival is possible in the wild after capture in deepwater. The fate of all other tagged and released fish is unknown and so no other inferences can be made from this single recapture. Because all the fish we dissected were immature, a high percentage of the fish we tagged may also be immature and thus less likely to move into areas where adults reside and be intersected by the fishery. For example, yellowtail rockfish moved great distances only after reaching maturity (Matthews and Barker 1983). It is possible recaptures will increase in the coming years as the fish mature and move into areas with greater fishing pressure.

There are a couple of reasons why survival after release at-depth in the wild may differ than the survival rates we observed using pressure tanks. One potential benefit of fish being released at depth in the wild is that fish remain repressurized after capture and are not forced to slowly decompress, potentially adding additional stress. The additional time to decompress in pressure tanks increased the survival rate substantially and so we suspect that the survival rate of fish released at depth in the wild would be closer to the higher survival rate we observed in 2013 that the rates observed in 2011 and 2012. However, the survival rate we observed in 2013 does not account for obstacles in the wild such as predation and feeding success, which could substantially affect survival, even if fish are able to function physiologically after incurring barotrauma. Although our results show that the majority of fish are physiologically capable of surviving after recompression, they do not indicate what survival rates would be in the wild.

If the objective of future research is to predict the long-term survival rate of fish that incur barotrauma, and not to observe long-term healing from barotrauma, short-term observations of fish held under a consistent pressure, in pressurized tanks or in underwater cages, are likely good indicators of long-term survival rates after barotrauma. We make this conclusion because we did not observe mortality after fish were decompressed in pressure tanks when the longer decompression schedule was used. If fish are repressurized and held at a consistent pressure, effects of slow decompression in the tank would be removed and species-specific trials to determine an appropriate decompression schedule would not be required. It is important to choose a pressure (or holding depth) where the external signs of barotrauma are reduced and fish are not positively buoyant to reduce physiological stress.

Pressure tanks are a valuable tool for repressurizing and depressurizing fish for studies of short-term and long-term observations. As in our study they were used at-sea so that fish could be transported to a holding facility after depressurization. They also provide a method of repressuring multiple fish in one longer field sampling trip, by completing multiple cycles of repressurization and depressurization on a single trip. As an alternative to underwater cages, they can also be used to repressurize (and not depressurize) fish after capture for short-term observations in the field. Cages may not be practical in all environments or situations (e.g., strong currents, large waves, when observations from divers are not practical, or there are risks of sand flea infestations). Pressure tanks also provide an alternative to cages when repeated visits to cages are not possible.

The probability of survival was not related to any specific barotrauma sign but was higher for smaller fish. For other species length is either not related to survival (Jarvis and Lowe 2008, Sumpton et al. 2010, Brown et al. 2010, Hannah et al. 2012), or, inconsistent with our study, fish have a higher survival rate after incurring barotrauma (snapper, Stewart 2008; yelloweye rockfish, Hochhalter and Reed 2011). Hochhalter and Reed (2011) suggested that in the wild larger fish may have higher survival because they are not as susceptible to predators purely due to size. The increased mortality in larger fish in our study could be explained by differing body morphology, affecting the amount of air in the swim bladder relative to body cavity space. There was a slow increase in mortality associated with length, so changes in the relationship of body cavity volume to swim bladder volume may happen slowly as fish grow. Differences in morphology may also be related to the increased presence of an everted esophagus we observed in larger fish. There are no measurements to support this hypothesis. It is unlikely that the pressure tank size affected survival for larger fish in our study because

Smiley and Drawbridge (2007), using the same pressure tank design, and had high survival rates in rockfishes 52.0 to 74.5 cm long (the largest fish in our study was 65 cm). Because we saw a relationship between size and survival, size will need to be considered in future tagging studies if survival rate is being examined.

The depth of capture was not related to barotrauma or survival rate in our stud. However it affected the presence of barotrauma (Hannah and Matteson 2007, Jarvis and Lowe 2008, Pribyl et al. 2011, Hall 2014) and survival rates in many other studies, when fish were captured at depths from 1 to 194 m (Wilson and Burns 1996, Hannah 2007, Jarvis and Lowe 2008, Stewart 2008, Sumpton et al. 2010, Hannah et al. 2012, Hall 2014, Hannah 2014, Flaherty-Walia et al. 2016). In our study, fish were captured at very deep depths and all fish experienced approximately the same amount of gas expansion during rapid depressurization at capture; the major gas expansion in the swim bladder occurs closer to the water's surface, according to Boyle's Law. This difference between our study and others in the literature may help explain why depth was not a significant effect in our models of barotrauma presence or survival.

Long-term Observations

Long-term holding may be necessary for evaluating recovery of swim bladder ruptures. In dissections after long-term holding, swim bladder ruptures had healed but often had one thin section in the swim bladder wall that was herniated, likely caused by an unhealed tear in the tunica externus, similarly documented in black and China rockfishes (Parker et al. 2006). In one fish a rupture never healed and showed necrotic tissue around the wound. In fish with an unhealed tunica externus, the thin section of the swim bladder could affect its ability to hold gas during changes in pressure. If swim bladder ruptures are only assessed shortly after barotrauma, healing and long-term ability to hold gas cannot be measured. We held fish for 6–18 months; however, it is likely that healing occurred much earlier than the date of dissection. After rapid decompression during capture or simulated capture and 21 days of holding, 77% of black and China rockfish swim bladders were at least partially healed (Parker et al. 2006). These results coupled with ours indicate that a time period longer than 3 weeks but shorter than 6 months is likely adequate for assessing swim bladder recovery.

Unlike swim bladder injuries, short-term observations of eye barotrauma post-recompression may be adequate, as long as the post-capture decompression process is adequately long enough. In our study, apparent healing of eye injuries occurred after 5–6 months in 18% of fish that had corneal emphysema, under a 2-day decompression schedule. However, when fish that had corneal emphysema were decompressed over 4 days, they had clear eyes. If rockfish are released at depth and fish are able to remain recompressed in deepwater, based on our results the reversal of observable eye barotrauma will likely be successful for the species we studied. Also, although exophthalmia causes stretching of the optic nerve chords, a behavioral study showed that vision was functional after barotrauma in rosy rockfish (*S. rosaceus*) (Rogers et al. 2011) and retinal function was normal in black rockfish (Brill et al. 2008). In six species of Pacific rockfishes, histological analysis did not show observable tissue damage in the eye from barotrauma (Pribyl et al. 2011). Given these results, eye function in most rockfishes may remain viable despite barotrauma in the eyes. However, if gases remain trapped in the corneal tissue, as observed in our study when a 2-day decompression schedule was used, the diffraction of light may significantly obstruct visual capabilities. Our results show that observable eye barotrauma can be reversed with adequate time under pressure and a slow decompression process if pressure tanks are used. It is possible this may hold true for other species that incur eye barotrauma.

Behavior After Release

Despite exhibiting external barotrauma injuries and appearing lifeless above water, fish released at depth were oriented upright, no longer had external signs of barotrauma, were not positively buoyant, and two-thirds of the released fish swam away and downward when the cage stopped descending at ~75 m. Like our study, Hannah and Matteson (2007) found that barotrauma signs at the surface were not related to behavior during release at-depth and surmised that behavior during underwater release may be a better indicator of survival. Our data corroborate these results because most of the fish we captured exhibited barotrauma, yet many fish released after capture were able to orient and swim after release at depth and a large proportion of fish held in captivity survived long-term.

Implications

Our data indicate that deepwater rockfishes are capable of surviving after capture and that pressurized chambers are a valuable tool for decompressing fish while at-sea for transportation to the laboratory and also have potential to be used in place of cages for short-term observations for any species that incur barotrauma. Although survival rates are not yet predictable, these results demonstrate that deepwater rockfishes can survive after barotrauma and, therefore, have the potential to survive in the wild after release. There are no data on the health or survival of other rockfishes that are managed in deep, offshore waters by the Federal government (Pacific ocean perch *S. alutus*, northern rockfish *S. polyspinus*, shortraker rockfish

S. borealis, and dusky rockfish *S. variabilis*) because of the uncertainty in their potential to survive post-barotrauma. Our results indicate that there is potential for survival in other deepwater *Sebastes* after capture. Any recovery data from tags would provide the first observation of horizontal movement of a deepwater, offshore rockfish. In the future, tag data could help to define populations, so that no one population is overharvested and provide basic information of movement related to spawning or ontogeny, which are currently unknown.

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Table 1. -- Number of blackspotted and rougheye rockfish that either survived long-term after capture or resulted in mortality 1) while in pressurized tanks, 2) within 3 to 10 days of capture, or 3) after 10 months. The count is followed by the percent of the total fish put into pressurized tanks in that year (i.e., all percentages sum to 100 in each row).

		Mortality		
Year	Long-term survival	In pressurized tank	3-10 days	10 months
All years	38 (63%)	17 (27%)	5 (8%)	1 (2%)
2011	12 (54%)	7 (32%)	2 (9%)	1 (5%)
2012	12 (60%)	5 (25%)	3 (15%)	0
2013	16 (78%)	4 (22%)	0	0

Table 2. -- Eye condition of blackspotted and rougheye rockfish immediately after capture and then after repressurization and subsequent slow depressurization in pressure tanks (eye condition after tank). Eye condition immediately after capture included either exophthalmia and ocular emphysema (EX/EM), exophthalmia only (EX), or clear eyes. The decompression schedule in pressure tanks was 2 days in 2011 and 2012 and was 4 days in 2013. Eyes that cleared in the laboratory did so after 5 to 6 months.

		Condition immediately after capture		
Year	Eye condition after tank	EX/EM (34)	EX (2)	Clear (4)
2011-2012	Clear when released from tank	10	2	3
2011-2012	Cleared in laboratory	4		
2011-2012	Gas in cornea persisted	7		
2011-2012	Eye loss	1		
2013	Clear when released from tank	12		1

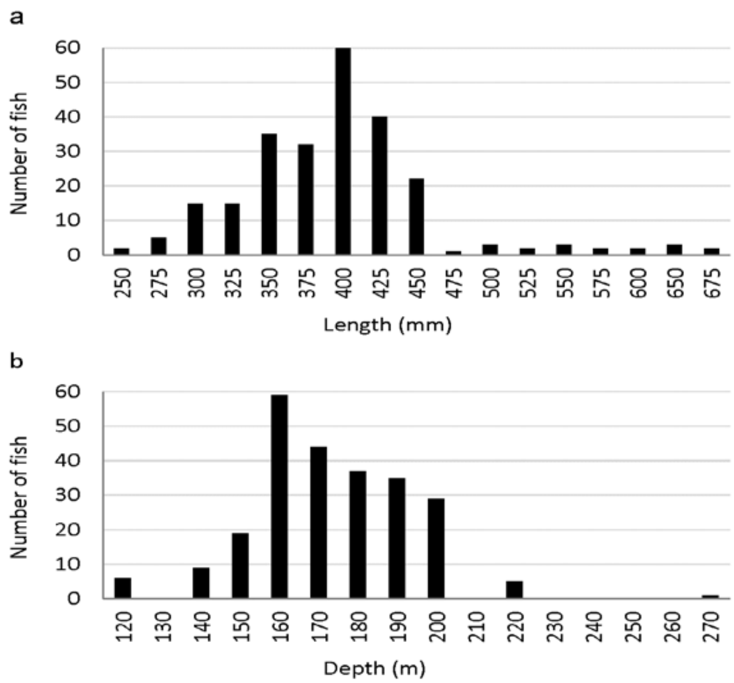

Fig. 1. -- Number of blackspotted and rougheye rockfish caught by fish length (a) and by capture depth (b) sampled in Southeast Alaska from 2011to 2013.

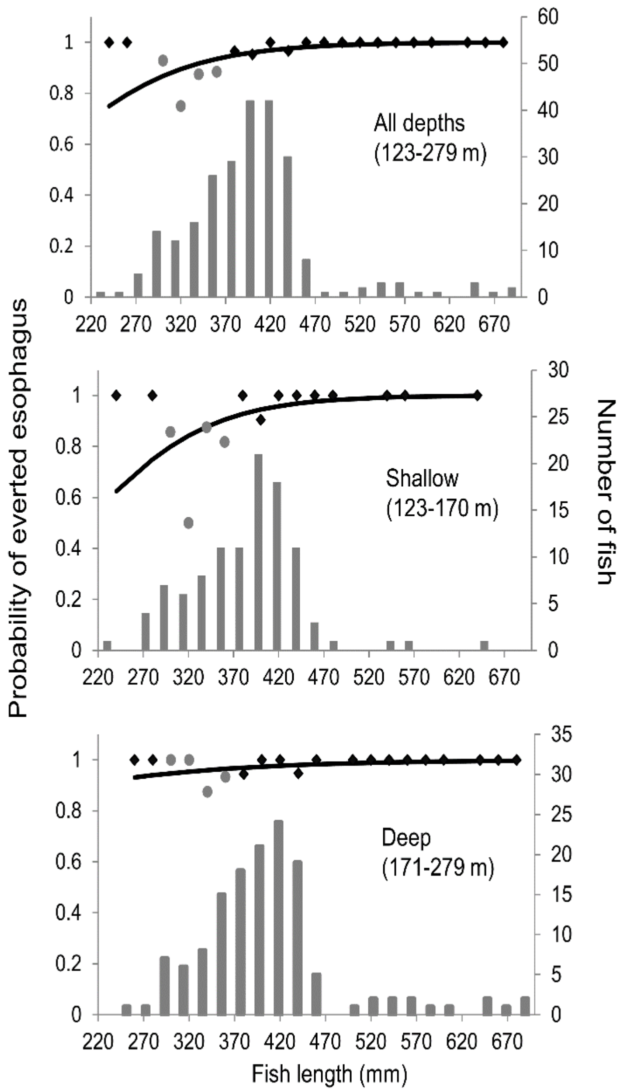

Fig. 2. -- Observed proportion of blackspotted and rougheye rockfish with an everted esophagus (gray and black circles; primary x-axis) by fish length and the predicted probability of having an everted esophagus from a logistic regression (solid line). Observed proportions of fish with lengths from 300-379 mm (moderate-sized fish) are gray and proportions for other sizes are black (small fish length range is 240 to 299 mm; large fish length range is 380 to 680 mm). The number of fish sampled in each 20 mm length bin is included in all figures (gray bars, secondary x-axis). Results in “shallow” (those shallower than 170 m) and “deep” depths are presented separately to illustrate the depth range at which the effect of length had the most impact (“shallow”)

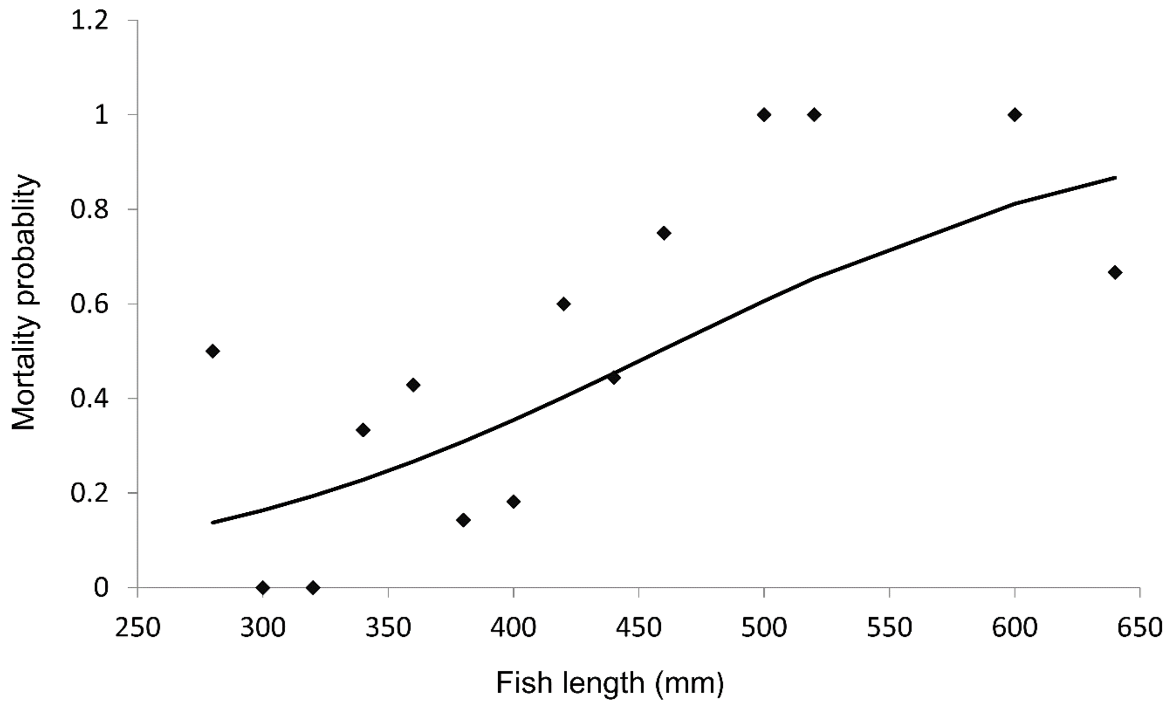

Fig. 3. -- Observed proportion of blackspotted and rougheye rockfish (diamonds) that did not survive after being repressurized, shown by fish length, and the predicted probability of mortality from a logistic regression (solid line)

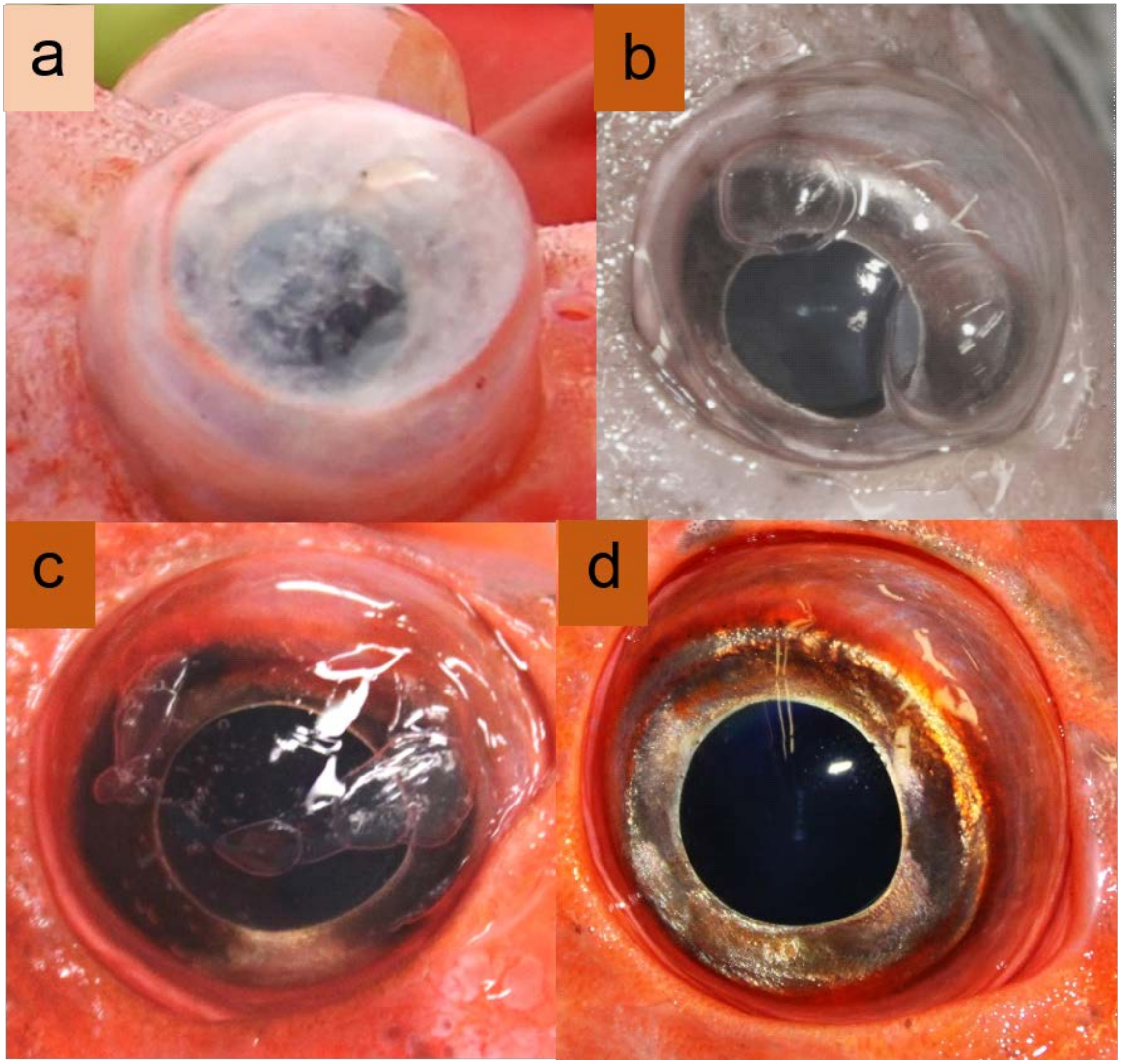

Fig. 4. -- Photographs of blackspotted and rougheye rockfish eyes a) immediately post-capture, exhibiting exophthalmia and corneal emphysema, and (b–d) those that experienced both exophthalmia and corneal emphysema after capture and were recompressed and then held long-term in captivity. In panel b gas has coalesced in the corneal tissue into two bubbles and in panel c it has coalesced into multiple bubbles. In panel d the eye has no gas in the corneal tissue.

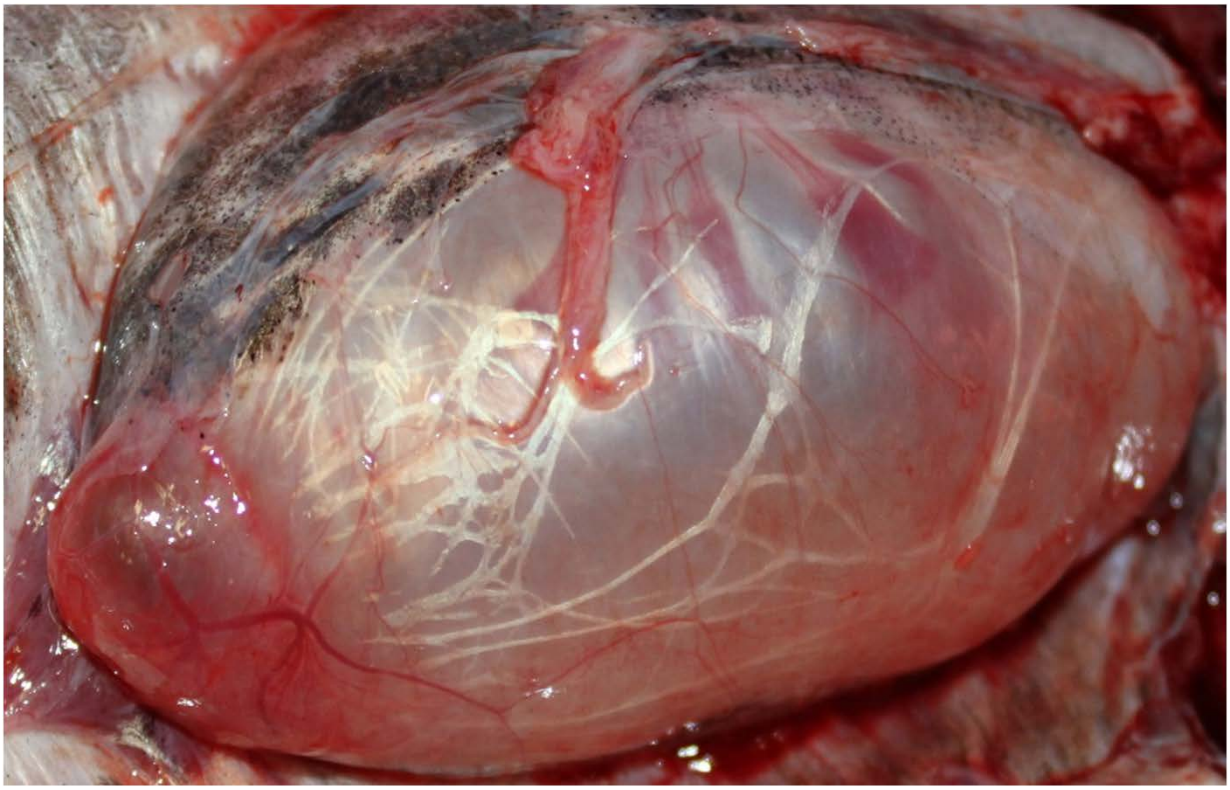

Fig. 5. -- Photograph of a blackspotted or rougheye rockfish swim bladder with a healed rupture. The thin, herniated section of the swim bladder on the left side is likely a portion of the tunica interna that is bulging due to an unhealed tear in the tunica externus.

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