Title: Use of a novel cage system to measure post-recompression survival of NE Pacific rockfish

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Abstract

We used a caging system designed to minimize the adverse effects of caging fish in marine waters to evaluate discard mortality of 7 rockfish (*Sebastes*) species with barotrauma. In total, 288 rockfish were captured, scored for barotrauma, evaluated behaviorally at the surface and caged individually on the seafloor for 48 h to determine survival. With the exception of 3 blue rockfish (*Sebastes mystinus*), condition of surviving fish after cage confinements from 41-71 h was excellent. At capture depths up to 54 m, survival was 100% for yelloweye (*S. ruberrimus*, n=25) and copper rockfish (*S. caurinus*, n=10) and 78% for blue rockfish (n=36). At capture depths up to 64 m, survival was 100% for canary (*S. pinniger*, n=41) and quillback rockfish (*S. maliger*, n=28) and 90% for black rockfish (*S. melanops*, n=144). Black rockfish survival was negatively associated with capture depth (m, $P<0.01$) and with surface-bottom temperature differential (°C, $P<0.01$). Blue rockfish survival was negatively associated with capture depth ($P<0.01$). Barotrauma signs and surface behavior scores were not good indicators of survival potential across species, but were useful within species. In black and blue rockfish, severe barotrauma was negatively associated with survival, while higher scores on reflex behaviors at the surface were positively associated with survival ($P<0.01$). The high survival rates and excellent condition of some species in this study suggest that requiring hook-and-line fishers to use recompression devices to help discarded rockfish return to depth may increase survival for some species.

Introduction

The Pacific rockfishes (*Sebastes*) are a diverse group of species that support major commercial and recreational fisheries on the U.S and Canadian west coasts (Love et al.

2002). The capture of some rockfish species presents managers with a classic “mixed stock” problem, as the catches are a mixture of species at healthy population levels (e.g. black rockfish, *Sebastes melanops*) and those that are severely overfished (e.g., yelloweye rockfish *S. ruberrimus* in waters off California, Oregon and Washington, Pacific Fishery Management Council 2006). In many of the hook-and-line fisheries, discard of the overfished species has been required by regulation in an effort to rebuild rockfish populations. However, because rockfishes are physoclists, most suffer some degree of barotrauma injury from the expansion of swimbladder gas (Pribyl et al. 2009, Hannah et al. 2008a). This may reduce the survival of released fish (Jarvis and Lowe 2008, Hannah and Matteson 2007). As a result, the effectiveness of mandatory discard as a tool for rebuilding overfished rockfish species is uncertain.

Expanded swimbladder gas retained within the tissues creates buoyancy that can prevent released fish from returning to depth unde rtheir own power (Hannah et al. 2008a). To address this problem, anglers and scientists have developed an array of devices to assist discarded fish in returning to depth (these are commonly called “recompression devices”, Theberge and Parker 2005). Rockfish with barotrauma are also sometimes “vented” by inserting a hypodermic needle through the lateral body musculature into the swim bladder (Theberge and Parker 2005). The use of recompression devices or venting has not been required by regulation for hook-and-line gear in many fisheries however, in part because post-recompression survival of released fish is not well understood. In the Gulf of Mexico however, venting of discarded red snapper (*Lutjanus campechanus*) to increase submergence success is now mandatory (GMFMC 2007).

The post-recompression survival of southern California nearshore and shelf rockfish species has been studied (Jarvis and Lowe 2008), however, for the rockfish species most commonly captured in nearshore and shelf waters of northern California, Oregon and Washington (NCOW area) it is mostly unknown. Post-recompression survival of black rockfish, a nearshore species, has been studied under laboratory conditions (Parker et al. 2006), but not in the wild. The ability of some common nearshore species to submerge following release has been evaluated for the NCOW area (Hannah et al. 2008b), as has the behavioral impairment of these species when released at depth, a potential proxy for short-term post-recompression survival (Hannah and Matteson 2007). The internal and external injuries associated with capture-related barotrauma in nearshore and shelf rockfish have also been described for some species in this area (Hannah et al. 2008a, Brill et al. 2008, Pribyl et al. 2009, Pribyl et al. 2011) and for many southern California species (Jarvis and Lowe 2008, Rogers et al. 2008). The primary objective of our study was to measure short-term (48 h) post-recompression survival for a variety of Pacific rockfish species commonly captured in the recreational hook-and-line fishery in the NCOW area, as a function of capture depth (m).

A common approach in many discard mortality studies is to use holding cages to monitor survival of “discarded” fish over time (e.g. Jarvis and Lowe 2008). Because caging a fish can never completely mimic release into the wild, a primary difficulty is adequately controlling for the effects of caging which, in some marine environments, can be adverse. In some instances, very large, deep cages can be used that come very close to simulating release into the wild (Brown et al. 2010). If the fish species of interest can be captured by trap and then held *in situ* without any handling, this can be an adequate control for the effect of caging. As a result, uncontrolled mortality studies are common and a qualitative assessment of observed "cage effects" is sometimes offered as the best available alternative (e.g. St. John and Syers 2005, Jarvis and Lowe 2008).

The lack of information on post-recompression survival for most rockfishes in the NCOW area stems, at least in part, from the difficulties inherent in controlling for the adverse effects of caging. In the NCOW area and many other areas along the Pacific coast of North America, strong currents and large waves create movement in a moored cage that stresses and injures fish, and parasitic amphipods (commonly called "sand fleas") which can be abundant in some areas may also adversely affect survival of caged fish. We report here also on the development of a purpose-built system for caging individual specimens of Pacific rockfish to minimize the adverse effects of caging in this environment.

Methods

Cage design

Our initial tests at reefs off Seal Rock, Oregon, using both on-bottom and suspended cages, showed that cages constructed from netting or aluminum bars and deployed with simple anchors and direct mooring lines to surface buoys produced substantial negative cage effects in black rockfish within as little as 24 hours. Fish retrieved from these systems had lesions from repeated contacts with the cage sides, were notably emaciated, and/or were wholly or partially consumed by parasitic amphipods. Fish condition suggested that some combination of surge, current and swell- and wind-induced movements of the cages was creating an environment that caused the fish to swim nearly continuously and in which physical contact with the cage sides was very frequent.

Our final individual rockfish caging system (Figures 1 and 2) was purpose-built to minimize the adverse effects of caging previously observed. The key features of the system included non-abrasive surfaces for all parts that might contact the fish, sufficient weight to resist movement of the cage in current, isolation of the cage from the movement caused by the mooring line to the surface, and exclusion of amphipods while maintaining adequate water exchange. We used an opaque, non-abrasive surface, in the form of a plastic drum, versus netting or wire, to house the fish. The smooth surface allowed a fish to make contact with the walls of the cage with less risk of removing its protective slime coat. The opaque surface provided a visual barrier, discouraging escape attempts and fish movements in response to stimuli from outside of the cage, further reducing opportunities for abrasion. Protecting the fishes' slime coat assists in their ability to handle the physical stress of confinement as they are better able to maintain their osmotic balance and a barrier against infection (Fletcher 1978). Davis and Ottmar (2006) found slime coat integrity to be one predictive factor of ultimate survival for captured fish. We reduced the potential for movement of the cage along the substrate by positioning it beyond the primary anchor, isolating it from mooring line forces and also by attaching it directly to a heavy steel-plate bracket (Figure 1). To protect the constrained fishes from attack by the parasitic lysianassid amphipod *Anonyx cf. lilljeborgi Boeck 1871b (id John Chapman, Oregon State University)* and other crustaceans (Stepien and Brusca 1985), we plastic-welded fine-mesh stainless steel screen on all vent openings and sealed any holes made in the drum for attachments (Figure 1).

The drum (Figure 2, 57 l capacity, 65 X 33 X 41 cm, United States Plastics Corporation, Lima, Ohio) was made of food-grade, high-density polyethylene (HDPE) and had a very smooth interior surface. It was cut and fitted with two ventilation openings, each layered with smooth mesh HDPE screen (12.5 mm square opening) on the inside and stainless steel (Type 316) woven wire cloth (1.14 mm mesh opening) on the outside. The interior screen served to protect the fish from abrasion by the cut drum edge and the stainless wire cloth. One vent (10 cm diameter) was located midway along the body of the drum and the other (15 cm diameter) was cut into the drum lid (Figure 2). The drum lid was secured in place with a large cable tie. Drums were tested for amphipod intrusion by deploying eight cages containing a rockfish, each with an externally-attached bait jar containing herring as bait, drilled with openings large enough for parasitic amphipods to enter. The test revealed skeletonized herring and live amphipods in the bait jar, while the fish residing within the drum were unaffected and no amphipods were present inside.

Each drum was attached to a 15.3 kg steel L-shaped bracket (20.3 x 76.2 x 1.3 cm back, 20.3 x 15.2 x 1.3 cm bottom) by two methods (Figures 1 and 2). Two stainless steel bands (1.27 cm x .76 mm, Band-It, Denver, Co) encircled the drum, weaving through slots in the bracket. Two stainless steel carriage bolts (13 mm, round head) also attached the interior wall of the drum to the bracket. On deck, the bracket helped keep the drum upright so that it could be partially filled with seawater prior to adding a fish. Fish condition in preliminary trials with a lighter-weight (5.2 kg) bracket indicated that, on the seafloor, cage movement was occurring, also shown by large dents and scuff marks on the plastic drum. Changing to the heavier bracket shown in Figures 1 and 2 provided an additional anchoring point, eliminating evidence of cage movement in field tests. In evaluating the cage with the heavier bracket underwater in large aquaria using SCUBA, we also noted that any movement of the cage caused it to be self-righting, i.e. the cage would rotate so that the heaviest (bracket) side was downwards.

The primary anchor for the cage consisted of a sea hook anchor (5 kg, Sea-Dog, Everett, WA) shackled by the crown to 3 m of steel chain (9.5 mm). The chain was shackled to a thimbled eye in a 0.6 m section of polyolefin line (9.5 mm, Blue Steel, Continental Western, San Leandro, CA), spliced into the main floating polyolefin line connecting to two surface floats (33 x 14 cm). To more easily free a stuck anchor, break-away cord (90.7 kg test) tied from the chain to the anchor shank allowed the mooring line to break free from the shank and transfer pulling force to the anchor crown (Figure 1).

The cage mooring incorporated a block line loop to allow separate handling of the cage and the anchor as the system was retrieved using a power block (Figure 1). The block line loop was 4 m long (slightly longer than the chain section) and connected the main mooring line to the abrasion-resistant Dura-Plex line (urethane-coated, 9.5 mm) used on the drum section (Figure 1). When brought on board via block, the anchor section was held off the block while the block line loop went through the block, creating the slack necessary to remove the anchor and chain for easier handling.

Post-recompression survival

Sampling rockfish for estimation of 48-h post-recompression survival was conducted on two recreational charter vessels between May 2009 and October 2010, at reefs off Seal

Rock, Cape Perpetua, and Lincoln City, Oregon (Figure 3). Rockfishes were captured using standard recreational hook-and-line gear and reeled up manually. To distribute sampling effort across depth, we attempted to capture and cage a variety of rockfishes from each of six depth zones (8-9 m depth per zone), ranging from 9-64 m each day. We limited daily deployment to a maximum of 16 cages, each containing a single rockfish, with three to five cages each deployed in four of the six depth zones. In the latter portion of our study, we limited the numbers of black rockfish that we caged to help increase the sample sizes for some of the less common species.

Following capture, each fish was evaluated using various measures to determine if any were strongly associated with post-recompression mortality. While using a “jaw hold” to handle fish, they were scored for seven signs of barotrauma (Table 1) following Pribyl et al. (2009) and Hannah et al. (2008), and placed in a wet tray to acquire fork length (cm) and a photo. Fish were then placed in the cages half-filled with seawater and evaluated behaviorally. We scored orientation (upright, on its side, or belly up), activity level (strong, weak, or none), and the presence or absence of movement in the operculum, body, tail and pectoral fins. The cage lid was sealed and secured with a cable-tie, and the cage and mooring were deployed as soon as the vessel had navigated to a nearby point of similar depth, over sand or flat bottom. Surface interval (min) for caged fish was calculated from the time the fish was brought on board to deployment of the cage overboard, and was minimized to the extent practicable. Data are not available on the average surface interval for hook-and-line captured and discarded rockfish in the NCOW area. We assumed that minimizing the surface interval for caged fish would best mimic the experience of a typical discarded rockfish that either successfully re-submerged itself, or was assisted back to depth with a recompression device (Theberge and Parker, 2005). A data logger (Vemco, Minilog-08-TDR, 0.1°C resolution, ±0.2°C accuracy, 0.4 m depth resolution) was attached to one cage per depth interval to record depth and bottom temperature. Surface water temperature, salinity and air temperature were also recorded daily for each depth category.

Our target for the duration of cage confinement was 48 h, however, efficient use of the chartered vessel sometimes necessitated shortening this interval by several hours for individual specimens. Bad weather also sometimes extended the caging period to approximately 72 h. Upon cage retrieval, fish were evaluated while still in water in the cage for condition (alive or dead), orientation, activity level, and movement. After removal from the cage, signs of barotrauma were again noted and an additional photo was taken. Each fish was then released into the ocean and their ability to descend noted. For each depth category, surface water temperature, salinity and air temperature were again recorded.

Data analysis

We estimated overall post-recompression survival by species as a simple proportion, but also provide LaPlace point estimates where survival exceeded 0.90 to compensate for small sample sizes, as suggested by Lewis and Sauro (2006) and Jarvis and Lowe (2008). We also calculated 95% binomial confidence intervals for survival based on the adjusted Wald method (Sauro and Lewis 2005).

Our primary interest was the effect of depth of capture on post-recompression survival. We also evaluated the effect of three other variables that can be related to survival: fish length, surface-bottom temperature differential, and time at the surface. The surface-bottom temperature differential has been shown to be predictive of mortality in hook-and-line captured red snapper (Diamond and Campbell 2009) a physoclistic species that similarly exhibits capture-related barotrauma. Although we minimized the surface time interval for captured rockfishes, we also included it as a potential variable influencing survival, as it has been shown to be important in other studies of rockfish post-recompression survival (Jarvis and Lowe 2008). We used logistic regression (JMP software ver. 6.02) to evaluate the effect of all four variables on post-recompression survival. After fitting a combined model, variables that were not significantly associated with survival ($P>0.05$) were removed in a stepwise manner to arrive at the final logistic model. To show fitted curves for individual variables in multiple logistic models, we profiled across the variable of interest while holding other variables constant at the mean value observed in our study.

We also separately evaluated measures of the physical condition of captured rockfish at the surface as predictors of post-recompression survival, including the presence of severe barotrauma and the ability of fish to respond behaviorally. Behavioral impairment in NCOW rockfishes released at depth (Hannah and Matteson 2007) and post-recompression survival of southern California rockfishes (Jarvis and Lowe 2008) have both been shown to be associated with external signs of barotrauma observed at the surface. Reflex behaviors have been shown to be indicators of survival following discard in several fish species (Davis 2007, Davis and Ottmar 2006) and Alaskan crabs (Stoner et al. 2008) .

To determine the association between barotrauma and survival within each species that suffered some mortalities, we used Fisher's exact test (Sokal and Rolf 1981) to compare the frequency of severe barotrauma with the frequency of post-recompression survival. We defined severe barotrauma as the presence of any of the signs linked to extensive expansion and movement of swimbladder gas within the fish's body, including exophthalmia, ocular emphysema, or severe esophageal eversion (Hannah et al. 2008a, Rogers et al. 2008). To evaluate how severe barotrauma varied as an indicator of survival across rockfish species, we compared the proportion of fish with severe barotrauma to the proportion of overall survival, by species.

A similar analysis was conducted for surface behavior scores. We first calculated a composite score for each fish, assigning a numeric score for the presence or level of response of each of the behaviors listed above. For behaviors that were either present or absent, such as opercular movement, a 0 (absent) or 1 (present) was assigned. For graded responses such as "activity" which could be noted as "strong" "weak" or "none", we simply assigned a graded numeric score of 2, 1 or 0, respectively. Orientation within the barrel was similarly coded as 2, 1, or 0 for "upright", "on it's side" or "belly up". The composite behavioral score was the sum of these values for each fish. Within a species, we used logistic regression to determine if the composite behavioral score was associated with post-recompression survival. To evaluate how surface behavior scores varied as an indicator of survival across species, we compared the mean behavior scores to the proportion surviving by species.

Results

Nineteen field deployments of 10-16 cages each were completed at rocky reefs off Seal Rock, Cape Perpetua, and Lincoln City, Oregon, between May 2009 and October 2010. In all, 288 individuals of seven species were captured from six depth intervals (up to 64 m) and evaluated for 48-h post-recompression survival (Table 2). Field data collection included 144 black, 36 blue *S. mystinus* (all references to blue rockfish refer to the solid sub-type also called “blue sided”, Burford and Bernardi 2008, for physical descriptions see http://www.reef.org/enews/articles/when-blue-not-blue), 42 canary *S. pinniger*, 3 china *S. nebulosus*, 10 copper *S. caurinus*, 28 quillback *S. maliger*, and 25 yelloweye rockfish. One canary rockfish that failed to survive was excluded from the analysis (not shown in Table 2) due to a failure in one of the cage seals that resulted in amphipods being present inside the cage at retrieval. Rockfishes ranged in total length from 22 to 52 cm (Table 2). Time on deck was tightly controlled, averaging less than three minutes per fish, with a range of one to nine minutes. Only 12 fish had a time on deck of five or more minutes, and all of those survived.

Up to a capture depth of 54 m, post-recompression survival was 100% for yelloweye (n=25, Figure 4) and copper rockfish (n=10, Figure 4) and 78% for blue rockfish (n=36). Up to a capture depth of 64 m, survival was 100% for canary (n=41) and quillback rockfishes (n=28) and 90% for black rockfish (n=144). Across species, the frequency of severe barotrauma was not a good indicator of survival potential. The high survival of canary and yelloweye rockfishes occurred despite the frequency of severe barotrauma exceeding 60% (Figure 5). The high survival of quillback, copper and china rockfish was consistent with relatively lower frequencies of severe barotrauma (Figure 5). The lower 48-h post-recompression survival of blue rockfish occurred despite relatively low levels of severe barotrauma (Figure 5). Mean surface behavior scores were also of little use in predicting 48-h post-recompression survival potential across species (Figure 5). Consistent with overall survival, blue rockfish had a lower mean surface behavior score than black rockfish (Figure 5). However, the lowest mean surface behavior scores were recorded for yelloweye rockfish, a species that had 100% survival at these capture depths (Figure 5).

Fish condition and cage performance

Our cage design (Figures 1 and 2) was very effective at minimizing the adverse effects of caging rockfish in the NCOW coastal marine environment. The vast majority of individuals were in excellent condition after cage confinement and showed no visible evidence of cage-effect (worn fins, abrasions, cloudy eyes). Only three (8%) surviving blue rockfish displayed one or two cloudy eyes upon cage retrieval. The duration of cage confinement averaged 47.9 h and, with the exception of one fish, ranged from 41.0 to 71.0 h. On 5-19-2009, one of the caging systems enclosing a black rockfish could not be freed from the seafloor and had to be left. When it was finally retrieved after a total of 17 days, the fish was found to be alive and in excellent condition. The condition of the cages at retrieval also indicated a lack of cage movement. The cages were uniformly in excellent condition with a lack of abrasions or dents, and contained very little sediment within and with the one exception noted above, showed no evidence of amphipods or other crustaceans having entered the cages.

We also observed that, although many fish had signs of severe barotrauma at initial capture, very few of these fish showed signs of barotrauma at cage retrieval. Of 93 surviving rockfishes that showed severe barotrauma at capture, only two of these showed any signs of barotrauma after cage confinement. In contrast, of 14 surviving fish that had shown no barotrauma signs at all at initial capture, 12 displayed at least one barotrauma indicator upon cage retrieval.

Factors associated with mortality by species

Logistic regression analysis showed that 48-h post-recompression survival in black rockfish was negatively associated with depth of capture ($P<0.01$, Table 3) and also with the difference between surface and bottom temperature ($P<0.01$), but was not associated with fish length or surface interval ($P>0.05$). For blue rockfish, only depth of capture was significantly associated (negatively) with post-recompression survival ($P<0.01$, Table 3). Fitted logistic curves showed that across the range of depths and temperatures observed in this study, depth of capture had a stronger negative effect on survival in black rockfish than did the surface to bottom temperature differential (Figure 6). Increasing depth of capture reduced post-recompression survival more rapidly and at shallower capture depths for blue than for black rockfish (Figures 6 and 7).

Although both surface behavior scores and the presence of severe barotrauma were poor indicators of differences in post-recompression survival across species, they were somewhat useful indicators within a species, especially for blue rockfish. The presence of severe barotrauma was negatively associated with survival in both black ($P<0.01$, $r^2=0.086$) and blue rockfishes ($P<0.0001$, $r^2=0.468$). Composite surface behavior scores were positively associated with post-recompression survival of black ($P<0.01$, $r^2=0.088$) and blue rockfishes ($P<0.01$, $r^2=0.328$). Many of the individual signs of barotrauma were negatively associated with post-recompression survival in black or blue rockfishes ($P<0.05$), however only one stood out as a potential predictor of mortality. In blue rockfish, severe esophageal eversion was a strong indicator of post-recompression mortality. Of six blue rockfish noted to have severe esophageal eversion at capture, none were alive 48 h after recompression.

Discussion

The results of our study show that, with careful attention to cage design, the adverse effects of 48-h cage confinement in the NCOW coastal marine environment can be virtually eliminated, and post-recompression survival of Pacific rockfishes can be estimated. This favorable view of cage performance is supported by the high survival of all species except blue rockfish despite the presence of severe barotrauma. It is also supported by the nearly complete lack of visible negative effects on fish condition at cage retrieval. Out of 287 rockfishes caged for at least 41 h, only three blue rockfish with cloudy corneas showed any evidence of adverse cage effects. This differs from the results of Jarvis and Lowe (2008) who studied post-recompression survival of rockfishes captured from depths of 55-89 m using a more conventional cage design (PVC-coated wire mesh) and noted cloudy corneas in 75% of caged specimens after two days of confinement. This difference may also have resulted from our use of individual cages rather than group cages, which would eliminate interactions between caged specimens that could have led to more movement of individual fish within the cage and more collisions with the cage sides. The other design elements of our caging system which made it successful included eliminating surge- and mooring-line-induced movement of the cage on the sea floor and the use of very smooth internal surfaces to limit opportunities for abrasion and removal of the protective slime coat of the fish (Fletcher 1978). Adequate screen area to allow water interchange, along with careful sealing of the cages to eliminate amphipods and other crustaceans (Stepien and Brusca 1985) were also important elements of the cage design.

The use of individual cages, although logistically more challenging than using “group” cages, also allowed us to minimize the surface interval of fish and match more closely the surface interval for most hook-and-line captured rockfish that are discarded by fishers. This approach eliminated the need for long surface intervals to accumulate a number of rockfish to place in a group cage and as a result we did not find surface interval to be a relevant factor influencing post-recompression survival, as did Jarvis and Lowe (2008). Our data are consistent with the findings of Jarvis and Lowe (2008) however, because surface intervals in their study were longer (averaged 13.6-21.5 min across six species) and they found higher survival of fishes held at the surface for less than 10 min (78%) and even higher survival of fishes with a surface interval of 2 min or less (83%), intervals that are more comparable to our results.

Although we were able to limit adverse cage effects, the estimates of 48-h post-recompression survival we generated only apply to discards under a carefully considered set of conditions. Our survival estimates for these species are only representative for quickly released rockfishes that either descend to depth successfully under their own power or that are assisted back to depth with recompression devices (Theberge and Parker 2005), and not to situations where re-submergence is delayed or unsuccessful. These estimates should probably also be viewed as an upper limit for post-recompression survival because other possible effects on survival were not considered. These include depths of capture exceeding 64 m (54 m for some species, Table 2), predation on released fish, possible adverse effects from dropping fish, venting or rough handling and any direct adverse effects from recompression devices. Our study also produced only small sample sizes for some species and depth zones (Table 2), indicative of a higher amount of uncertainty in the mortality estimates we generated. Also, longer-term survival of these seven species of rockfishes following capture and successful recompression has not been studied. Studies of post-recompression survival for other line-caught fishes with barotrauma have documented some mortality of individuals extending beyond 48 h, the nominal time of caging in our study (Gritschlag and Renaud 1994, Wilson and Burns 1996). Even after successful recompression, delayed mortality may be caused by the injuries sustained by the overpressure event. Cardiac injury, laceration or bruising of the liver, sepsis, intestinal injury, organ displacement and torsion, and tissue damage from the internal embolisms have all been documented in fish with barotrauma (Rummer and Bennett 2005, Jarvis and Lowe 2008, Pribyl et al. 2009, Pribyl et al. 2011). Recent acoustic tagging studies that included some yelloweye and quillback rockfishes have, however, documented survival of some individuals with capture-related barotrauma for over a year (Hannah and Rankin 2011) and longer-term survival of some southern California rockfish with barotrauma has also been shown (Jarvis and Lowe 2008).

Post-recompression survival of both black and blue rockfishes was inversely related to depth of capture (Table 3). This is consistent with results from caging studies of the survival of line-caught red snapper with barotrauma (Gritschlag and Renaud 1994, Diamond and Campbell 2009) and with results of survival studies for red grouper (*Epinephelus morio)* and scamp (*Mycteroperca phenax*) with barotrauma (Wilson and Burns 1996). Cage survival studies of recompressed Australian dhufish (*Glaucosoma hebraicum*, St. John and Syers 2005) and snapper (*Pagrus auratus*, Stewart 2008) also found depth of capture to be a primary determinant of post-recompression survival. Jarvis and Lowe (2008) however, did not find depth to be significantly related to 2-day post-recompression survival for southern California rockfishes. However, they tested fish captured at 55-89 m, as compared to 20-55 m for most of our specimens, and also worked with different species (Table 2). It's possible that depth of capture was significant in our study because we sampled more fish from shallower depths than Jarvis and Lowe (2008), incorporating greater contrast between specimens in the effect of depth on barotrauma. For black rockfish, 48-h post-recompression survival was also related to the temperature difference between surface and bottom waters at the capture site (Table 3). This is consistent with the findings of Jarvis and Lowe (2008) for southern California rockfish species and Diamond and Campbell (2009) for red snapper, as well as the general view of increased temperature as a stressor commonly involved in discard mortality (Davis 2002).

Our data on barotrauma and 48-h post-recompression survival provide several insights into the effects of barotrauma on rockfishes. The association of severe barotrauma in black and blue rockfishes with post-recompression mortality is not surprising. Barotrauma is known to generate a wide array of internal injuries in rockfish, some of which can be life-threatening (Pribyl et al. 2009, Jarvis and Lowe 2008, Hannah et al. 2008a). However some studies of other species of physoclists did not relate external signs of barotrauma to subsequent mortality (Gritschlag and Renaud 1994). The very strong association of severe esophageal eversion with post-recompression mortality in blue rockfish may indicate that this sign of barotrauma is connected with specific injuries that are not survivable. Interestingly, Diamond and Campbell (2009) found that esophageal eversion was positively associated with survival in red snapper, highlighting the species-specific nature of the interaction between specific signs of barotrauma and post-recompression survival. The fact that fish with barotrauma at initial capture in our study generally showed no external signs of barotrauma following 48-h cage confinement is consistent with expectations based on the recently described model of how the effects of barotrauma develop in some rockfish species (Hannah et al. 2008a). It is also consistent with similar findings by Jarvis and Lowe (2008) for southern California rockfishes. The common external signs of barotrauma in rockfishes, including exophthalmia and esophageal eversion, develop from gas that has escaped the overexpanded swimbladder due to the drop in pressure during ascent. This gas then generally travels forward in the body following a “path of least resistance” between or through tissue layers. When the expanding gases do not escape through ruptures in external membranes, such as the pharyngo-cleithral membrane (Pribyl et al. 2009, Hannah et al 2008a), they collect behind where the esophageal tissue is anchored in the pharynx and “roll” the esophageal tissue outwards through the mouth. The gas also bleeds into areas behind the eyes causing exophthalmia and ocular emphysemas, as well as moving throughout a variety of tissues (Hannah et al. 2008a, Rogers et al. 2008, Pribyl et al. 2011). When a rockfish is recompressed, the gas that has traveled throughout the body should go into solution or compress to very small bubble sizes and be removed fairly quickly via the circulation of blood through the gills. After 48 h in the cage at depth, if the swimbladder has not healed sufficiently to hold gas and reinflate, fish will not exhibit external signs of barotrauma when brought back to the surface. This suggests that caging rockfishes with barotrauma at depth for 48 h may be a useful technique for collecting live specimens without the use of surface pressure tanks or venting. It should be noted that this is likely to be a temporary effect. In pressure chamber experiments, Parker et al. (2006) found that after 21 days, 77% of black rockfish that had experienced a 3-ATA decrease in pressure during simulated capture experiments had swimbladders that were again holding gas. Some of our specimens that displayed no external signs of barotrauma at capture probably retained a healthy, functional swimbladder and then followed the normal physiological process of adding gas to their swimbladder as they were constrained at depth in our cages (Parker et al. 2006). This then resulted in the development of external barotrauma signs in these previously unaffected fish after the 48-h holding period.

In our study, higher composite surface behavior scores were also associated with higher post-recompression survival in black and blue rockfishes, consistent with studies relating reflex behavior and post-capture survival in other fishes (Davis and Ottmar 2006). However, considered across species, mean composite scores for surface behavior did not correctly indicate which species had higher post-recompression survival potential. Post-recompression survival in this study, by species, was more consistent with inferences made regarding survival potential based on post-recompression release (release at depth) behavior (Hannah and Matteson 2007). In that study, blue rockfish were the most behaviorally impaired when released at depth, for a given depth of capture, followed by black rockfish, followed by yelloweye rockfish, a similar ranking to the survival estimates we generated. This suggests that, for some species like yelloweye rockfish, the large amount of retained swimbladder gas interferes with movement at surface pressure and the presence of reflex behaviors is not easily detected. As retained gas is recompressed, more normal movement becomes possible and behavior becomes a better indicator of health.

Management and research implications

The survival data we developed also provide some insight into the potential benefits of requiring hook-and-line fishers to use recompression devices when discarding some rockfishes. For black and blue rockfishes, the decline in post-recompression survival as a function of capture depth is only somewhat more gradual than the decline in re-submergence success after surface release (Figure 8, resubmergence data from Hannah et al. 2008b). For these two species, the savings in mortality that would result from recompressing discarded fish would be modest, because across the depths at which they are normally caught, survival of fish that need assistance in returning to depth would be less than 100%. Because injuries from barotrauma in black and blue rockfish probably influence both self-submergence ability and post-recompression survival, the very fish that need the most assistance to re-submerge may be many of the same fish that would be less likely to survive after recompression. Because fishers can generally still retain these two species, benefits would also accrue only for small individuals that sometimes get discarded. Conversely, for canary rockfish (Figure 8), and probably for yelloweye rockfish (although detailed data on submergence success are lacking for yelloweye rockfish) both of which must currently be discarded in many Pacific fisheries, submergence success drops off much more quickly as a function of depth of capture than does post-recompression survival, suggesting that requiring the use of recompression devices may reduce discard mortality much more for these species.

The data shown in Figure 8 also illustrate an important consideration for studies evaluating the effectiveness of recompression devices, or techniques such as venting. In the absence of a marked departure between post-recompression survival and post-surface-release submergence success as functions of depth, there would be little *a priori* expectation of a positive survival effect from recompression devices or venting. As such, studies comparing survival of vented versus unvented fish should consider as part of the study design the degree to which failure to submerge following surface release has been established for the fish population and depths of capture being studied.

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Craig Taunton and Dick Murray provided the commercial passenger fishing vessel *Endeavor* and assisted with fish capture and cage retrieval. Mike Sorenson provided the commercial passenger fishing vessel *Miss Raven* and also assisted in fish capture and cage retrieval. John Chapman, Department of Fisheries and Wildlife, Oregon State University, provided identification of the amphipod species. Oregon Coast Aquarium provided access to a large exhibit aquarium for underwater testing of the fish cage.

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Table 1. Indicators used to define external signs of barotrauma in Pacific rockfish.

Symptom	Indicators
Tight abdomen	Abdomen swollen, tight to the touch
Bulging membrane	Outward bulge in the pharyngo-cleithral membrane
Membrane emphysema	Air spaces or bubbles visible within the pharyngo-cleithral membrane
Exophthalmia (popeye)	Eye protruding outward from orbit
Ocular emphysema (gas in the eye)	Gas present within the eye or connective tissue surrounding the eye
Esophageal eversion - moderate	Eversion of esophageal tissue at least 1 cm into the buccal cavity.
Esophageal eversion - severe	Eversion of esophageal tissue extending beyond the buccal cavity.

Table 2. Sample sizes, number of mortalities (in parentheses) and fork length range (cm) of rockfish captured by hook-and-line in waters off Oregon and held in individual cages to estimate 48-h post-recompression survival by species and depth of capture (m).

Common name	Scientific name	Depth of capture						Total	Fork length range (cm)
		9-18 m	19-27 m	28-36 m	37-45 m	46-54 m	55-64 m		
Black rockfish	*Sebastes melanops*	34 (0)	38 (1)	34 (2)	21 (4)	14 (7)	3 (0)	144 (14)	24-49
Canary rockfish	*Sebastes pinniger*	0	1 (0)	14 (0)	10 (0)	14 (0)	2 (0)	41 (0)	22-39
Blue rockfish*	*Sebastes mystinus*	1 (0)	14 (0)	9 (2)	7 (2)	5 (4)	0	36 (8)	23-39
Quillback rockfish	*Sebastes maliger*	0	0	6 (0)	9 (0)	11 (0)	2 (0)	28 (0)	32-43
Yelloweye rockfish	*Sebastes ruberrimus*	0	2 (0)	3 (0)	8 (0)	12 (0)	0	25 (0)	31-52
Copper rockfish	*Sebastes caurinus*	0	0	2 (0)	7 (0)	1 (0)	0	10 (0)	33-48
China rockfish	*Sebastes nebulosus*	1 (0)	0	1 (0)	1 (0)	0	0	3 (0)	34-37
Total		36 (0)	55 (1)	69 (4)	63 (6)	57 (11)	7 (0)	287 (22)	

* solid sub-type

Table 3. Results of logistic regression analysis of the proportion of rockfish surviving after 48 h versus depth (m) of capture, fork length (cm), surface interval (min) and surface to bottom temperature differential (°C), for black and blue (solid sub-type) rockfish.

Species	Independent variable	Coefficients	Standard error	P - value	Whole model Chi-square	R squared
Black rockfish	constant	7.7877	1.6150	<0.0001	25.8528	0.2815
	depth of capture	-0.0883	0.0320	0.0057		
	temperature difference	-0.6039	0.2226	0.0067		
Blue rockfish*	constant	6.9294	2.2449	0.0020	12.9350	0.3392
	depth of capture	-0.1566	0.0553	0.0046		

* solid sub-type

Figure captions

Figure 1. Schematic of the system developed for caging individual rockfish for evaluation of 48-h post-recompression survival.

Figure 2. Photograph of the food-grade polyethylene drum used for caging individual rockfish, showing screening and bracket design.

Figure 3. Map showing the location of the reef areas sampled to evaluate 48-h post-recompression survival of rockfish.

Figure 4. Post-recompression survival of hook-and-line captured rockfish held for 48 h, by species, including LaPlace point estimates for species with greater than 90% survival and binomial confidence intervals calculated by the “adjusted Wald method”. Sample sizes are shown in parentheses.

Figure 5. Mean composite surface behavior scores (higher scores indicate less behavioral impairment) with 95% confidence intervals and the proportion of rockfish with severe barotrauma (see text), by species.

Figure 6. Fitted logistic curves relating the proportion of black rockfish surviving 48-h post-recompression as a function of capture depth (m) and surface-bottom temperature differential (°C) at the capture site. Curve for capture depth is fitted at a fixed temperature differential of 3.31°C. Curve for temperature differential is fitted at a fixed capture depth of 28.27 m.

Figure 7. Fitted logistic curve showing the proportion of hook-and-line captured blue rockfish (solid sub-type) surviving 48-h post-recompression as a function of depth of capture (m).

Figure 8. Comparison of the fitted logistic curves for 48-h post-recompression survival and successful re-submergence after surface release (from Hannah et al. 2008b) as a function of depth of capture (m) for black, blue (solid sub-type) and canary rockfish.

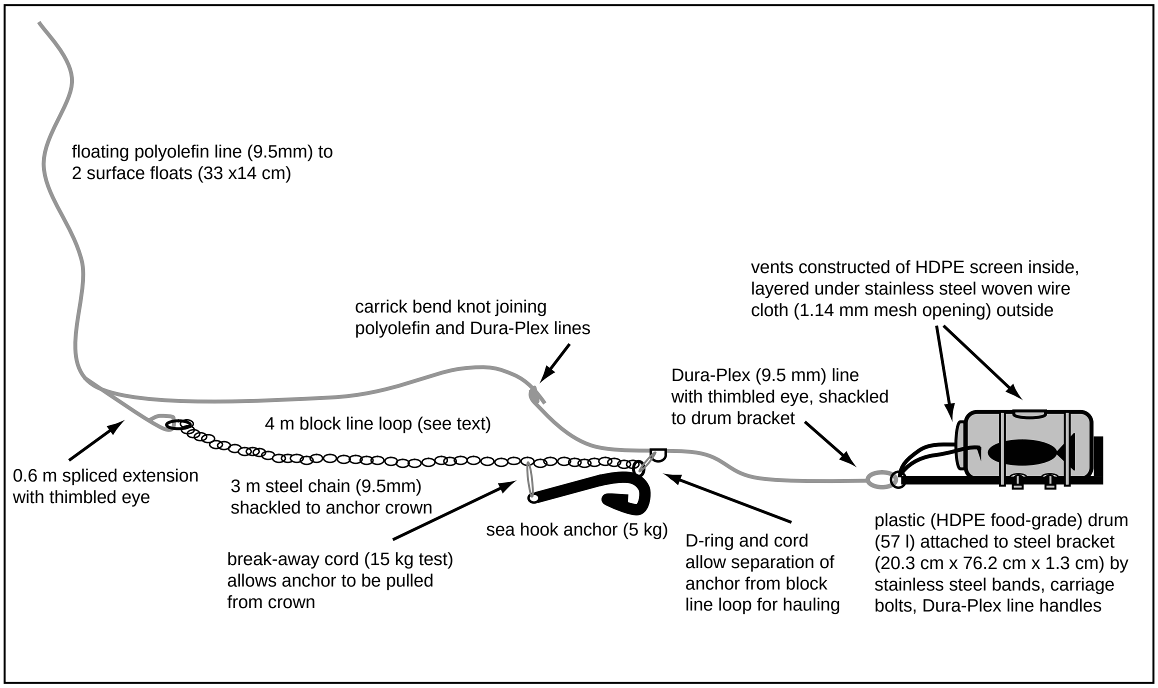

Figure 1

Figure 2

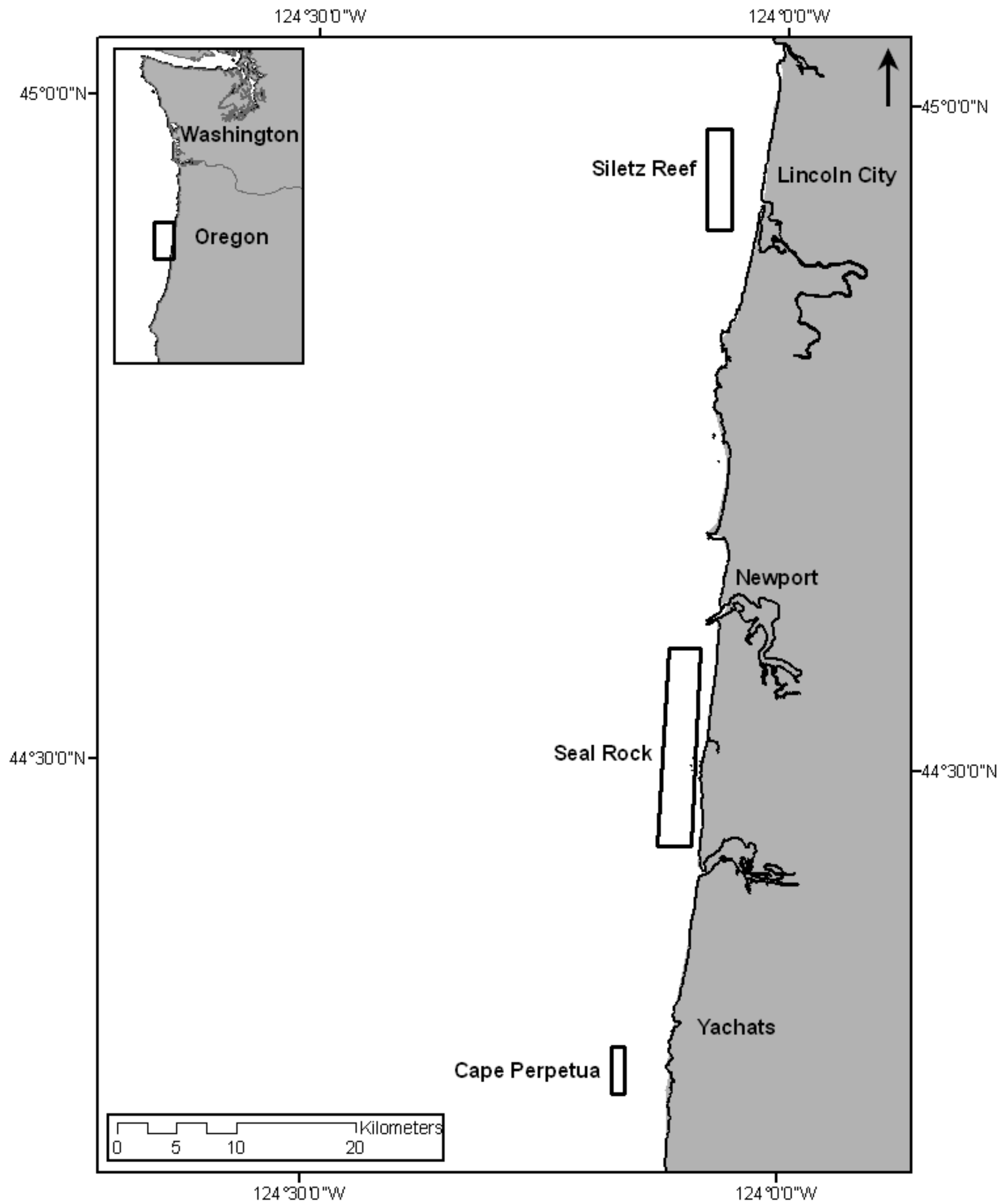

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Figure 3

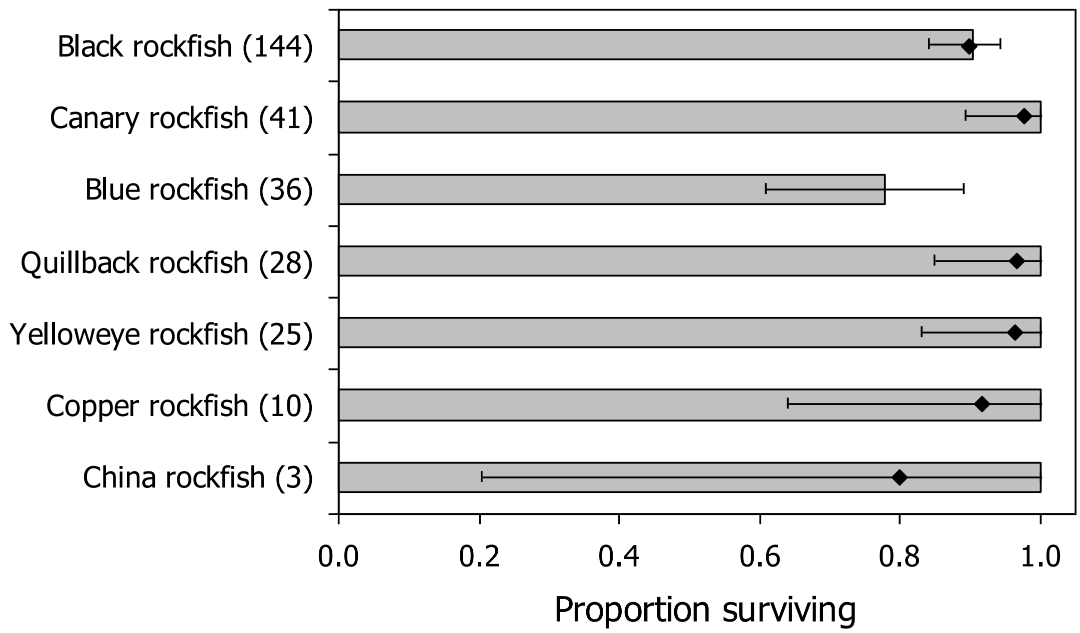


Figure 4

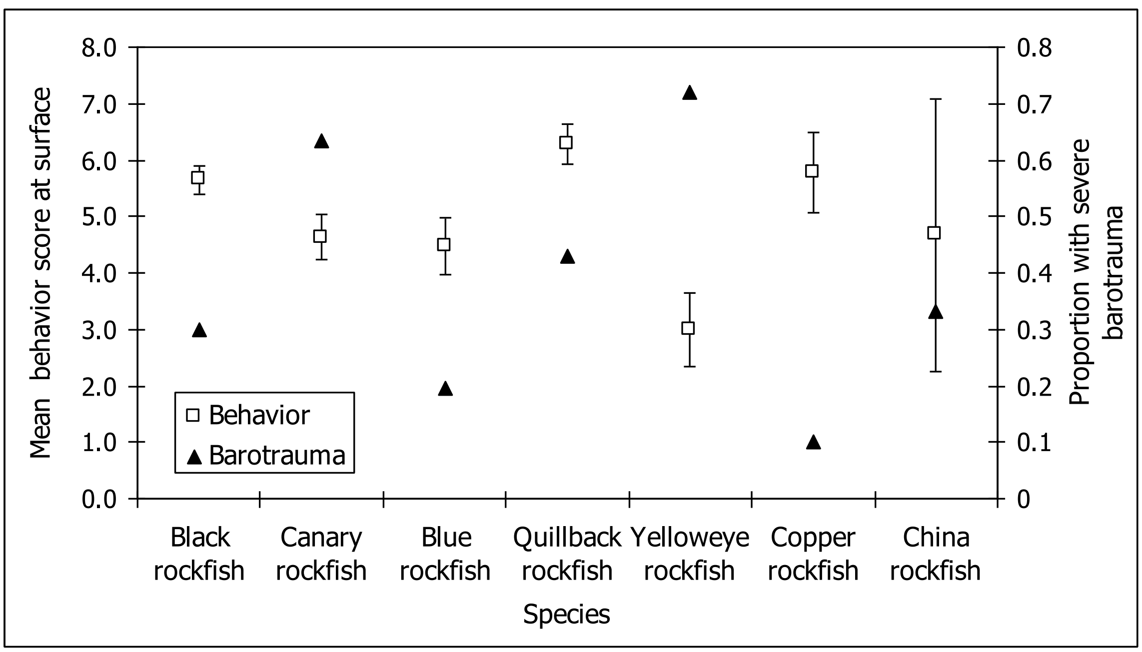


Figure 5

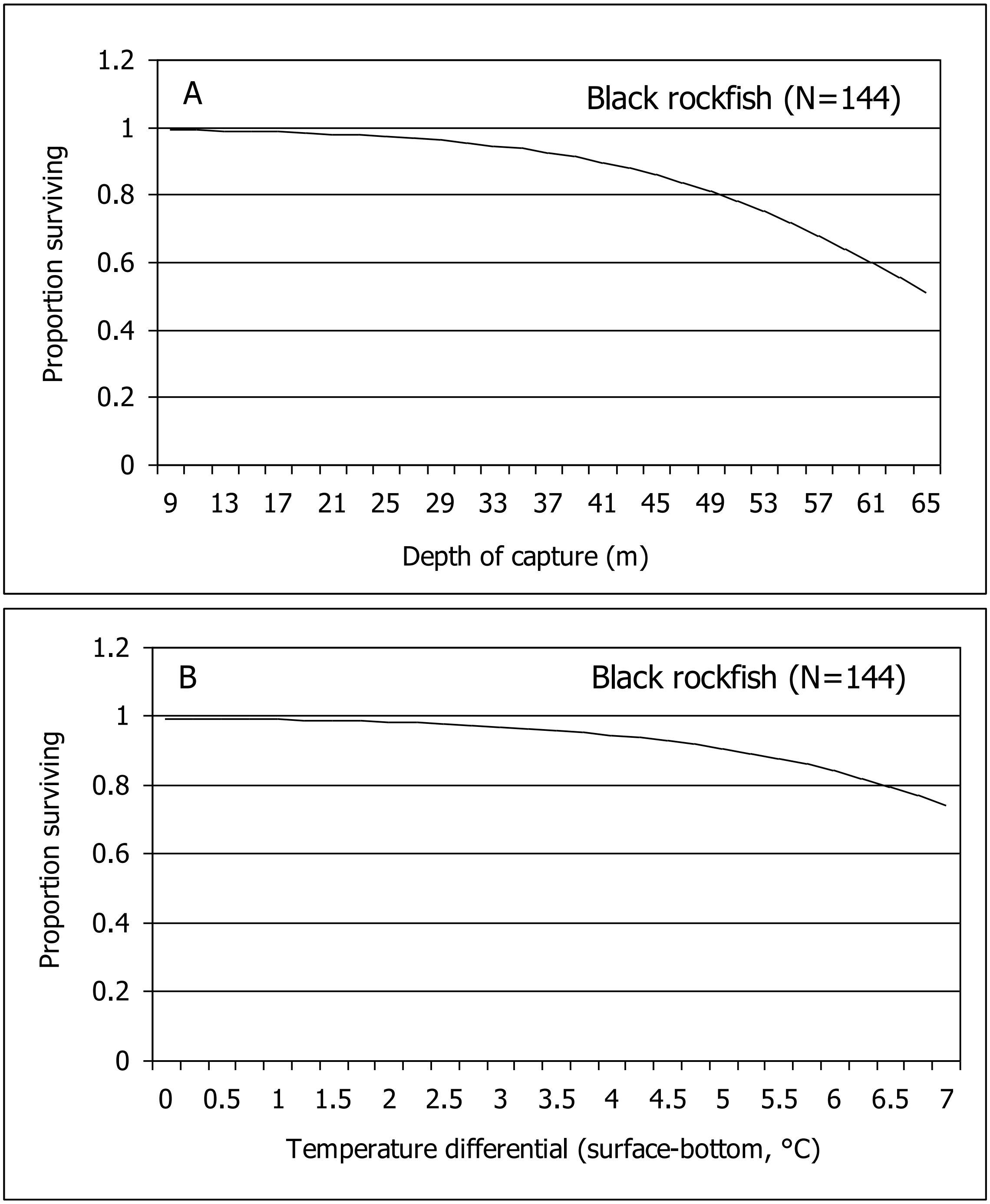

A
Black rockfish (N=144)
Proportion surviving
1.2
1
0.8
0.6
0.4
0.2
0
9 13 17 21 25 29 33 37 41 45 49 53 57 61 65
Depth of capture (m)
B
Black rockfish (N=144)
Proportion surviving
1.2
1
0.8
0.6
0.4
0.2
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7
Temperature differential (surface-bottom, °C)

Figure 6

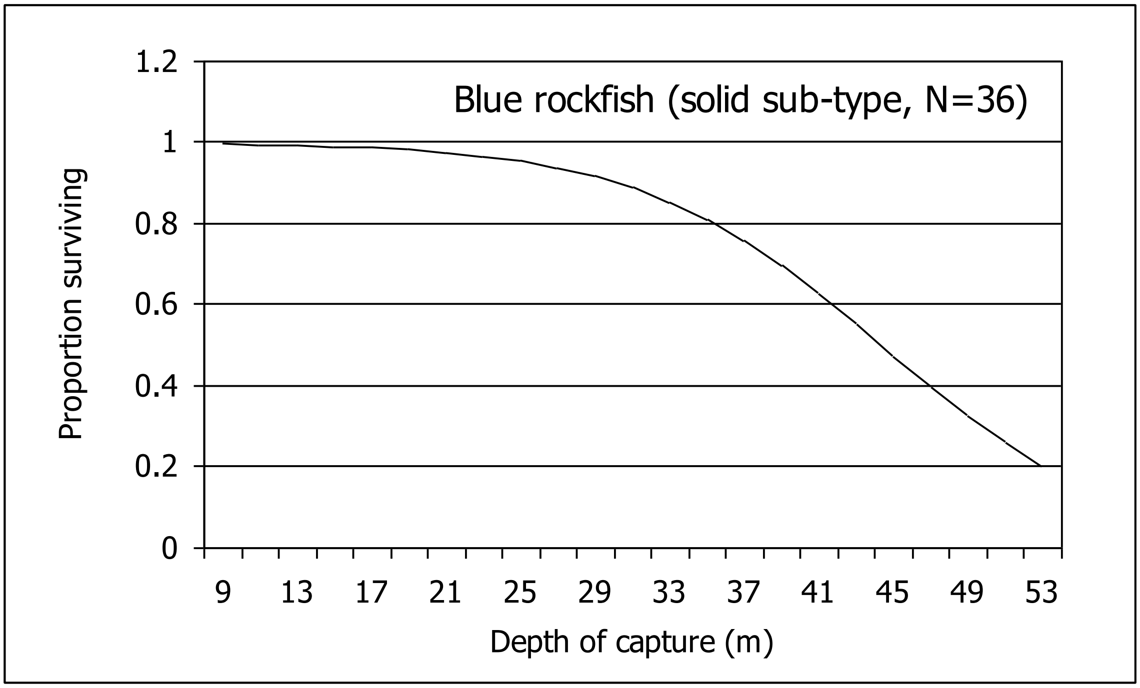
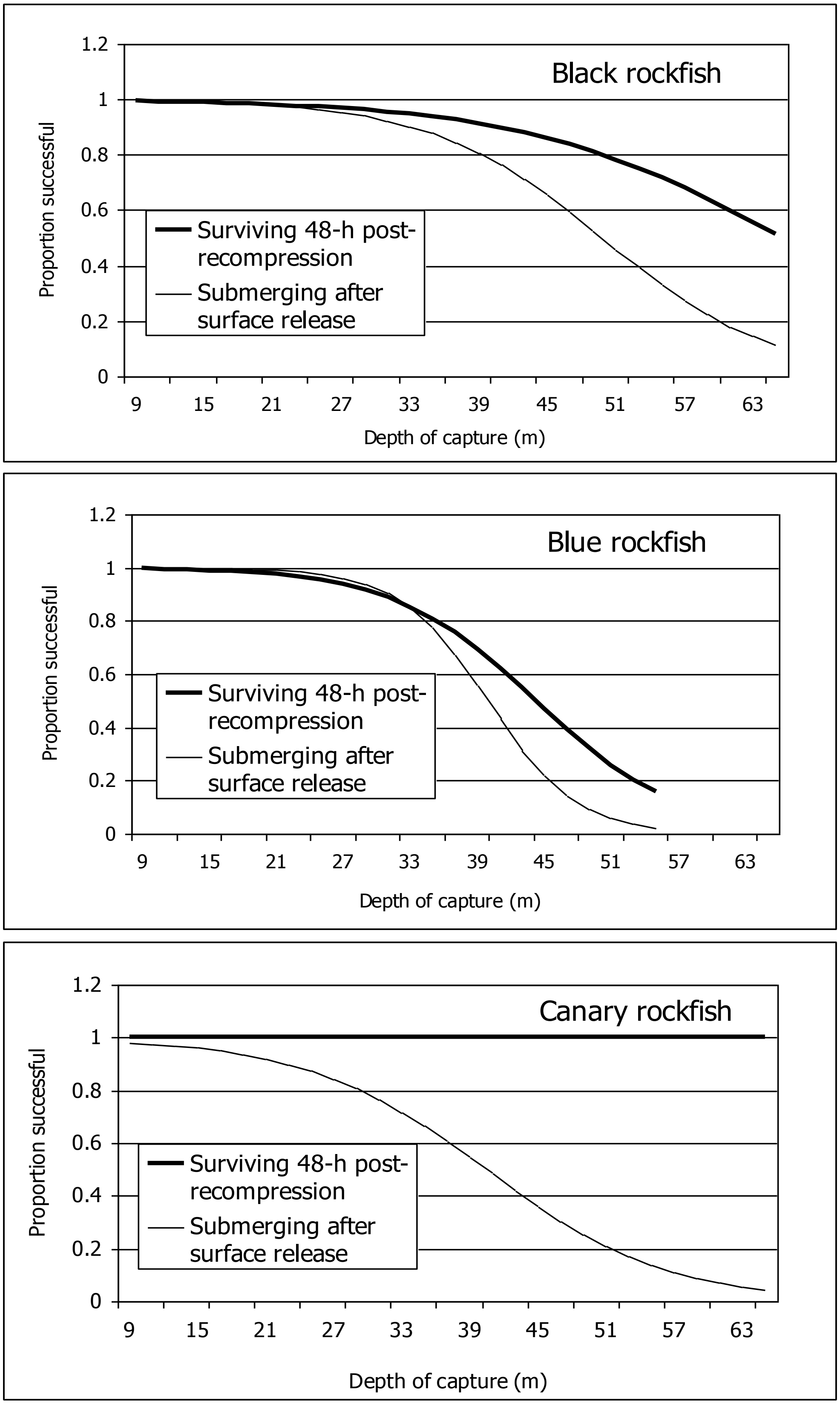

Blue rockfish (solid sub-type, N=36)
Proportion surviving
1.2
1
0.8
0.6
0.4
0.2
0
9
13
17
21
25
29
33
37
41
45
49
53
Depth of capture (m)

Figure 7


Black rockfish
Blue rockfish
Canary rockfish
Proportion successful
Depth of capture (m)
Surviving 48-h post-recompression
Submerging after surface release
1.2
1
0.8
0.6
0.4
0.2
0
9
15
21
27
33
39
45
51
57
63
Figure 8