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ARTICLE

Use of a Novel Cage System to Measure Postrecompression Survival of Northeast 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 the discard mortality of seven species of rockfish *Sebastes* with barotrauma. Altogether, 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 three blue rockfish *S. mystinus*, the condition of surviving fish after cage confinement from 41 to 71 h was excellent. At capture depths up to 54 m, survival was 100% for yelloweye rockfish *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 rockfish *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) and the surface–bottom temperature differential (°C). Blue rockfish survival was negatively associated with capture depth. 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. 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.

The Pacific rockfishes *Sebastes* spp. 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 *S. melanops*) and those that are severely overfished (e.g., yelloweye rockfish *S. ruberrimus* in the waters off California, Oregon, and Washington; PFMC 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 swim bladder gas (Hannah et al. 2008b; Pribyl et al. 2009). This may reduce the survival of released fish (Hannah and Matteson 2007; Jarvis and Lowe 2008). As a result, the effectiveness of mandatory discarding as a tool for rebuilding overfished rockfish species is uncertain.

Expanded swim bladder gas retained within the tissues creates buoyancy that can prevent released fish from returning to depth under their own power (Hannah et al. 2008b). To address this problem, anglers and scientists have developed an array of devices to assist discarded fish in returning to depth that 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 for hook-and-line gear in many fisheries, however, in part because the postrecompression survival of released fish is

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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).

Although the postrecompression survival of Southern California nearshore and shelf rockfish species has been studied (Jarvis and Lowe 2008), the survival of the rockfish species most commonly captured in the nearshore and shelf waters of northern California, Oregon, and Washington (the NCOW area) is mostly unknown. The postrecompression 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. 2008a), as has the behavioral impairment of these species when released at depth, which is a potential proxy for short-term postrecompression 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 (Brill et al. 2008; Hannah et al. 2008b; Pribyl et al. 2009, 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) postrecompression 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 the 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 postrecompression 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; parasitic amphipods (e.g., Lysianassidae commonly called sand fleas), which are abundant in some areas, may also adversely affect the survival of caged fish. In this article, we report on the development of a 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 had substantial negative effects on black rockfish within as little as 24 h. Fish retrieved from these systems had lesions from repeated contact with the sides of the cages, were notably emaciated, and/or were wholly or partially consumed by parasitic amphipods. The condition of these fish 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 sides was very frequent.

Our final individual rockfish caging system (Figures 1, 2) was purpose built to minimize the adverse effects of caging previously observed. The key features of the system included nonabrasive surfaces for all parts that might come into contact with the fish, sufficient weight to resist movement in currents, isolation of the cage from the movement caused by the mooring line, and exclusion of amphipods while maintaining adequate water exchange. We used an opaque, nonabrasive surface in the form of a plastic drum rather than 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 slime coat assists fish in handling 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 factor that is predictive of the ultimate survival of captured fish. We reduced the potential for movement of the cage along the substrate by positioning it beyond the primary anchor, isolating it from the mooring line forces, and attaching it directly to a heavy steel-plate bracket (Figure 1). To protect the constrained fish from attack by the parasitic lysianassid amphipod *Anonyx cf. lilljeborgi* 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 (57-L capacity; 65 × 33 × 41 cm; U.S. 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 a 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

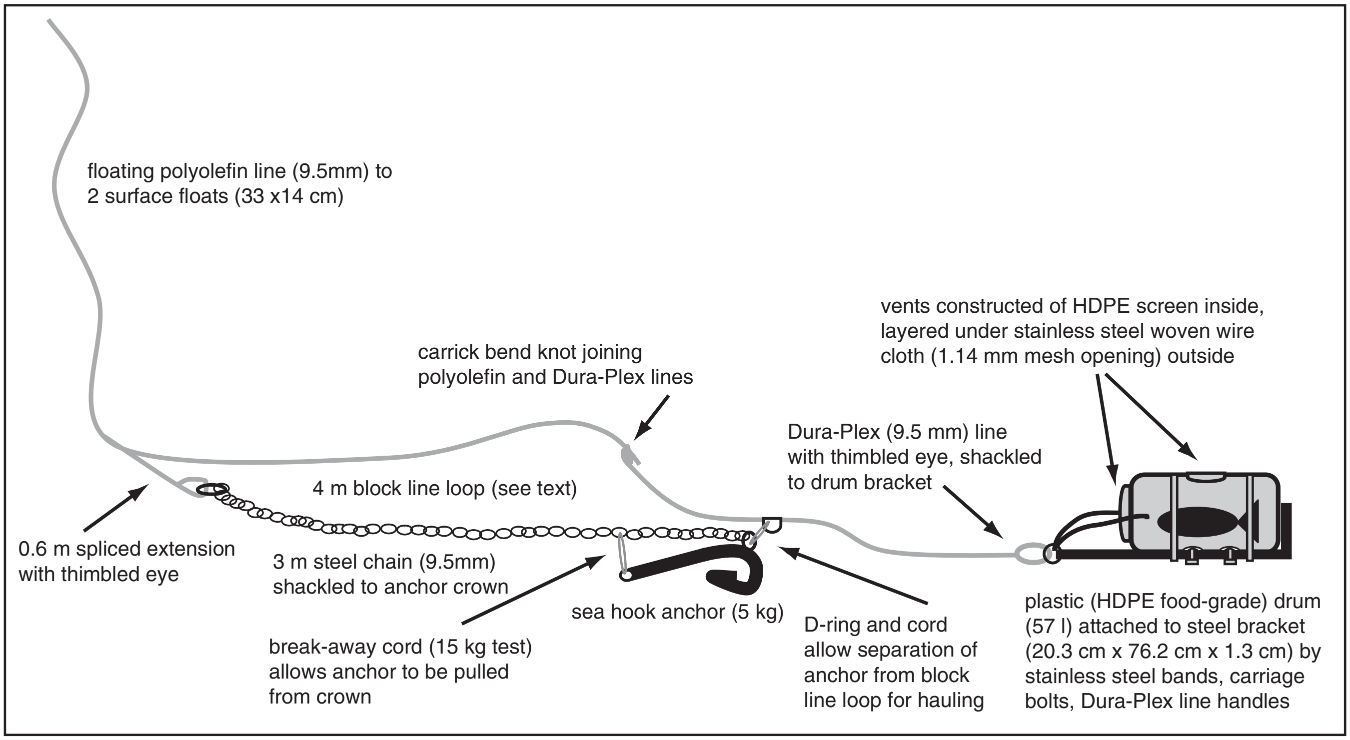

FIGURE 1. Schematic of the system developed to cage individual rockfish for evaluation of 48-h postrecompression survival.

secured in place with a large cable tie. The drums were tested for amphipod intrusion by deploying eight cages, each with a rockfish and an externally attached bait jar containing herring as bait, with drill holes large enough for parasitic amphipods to enter. The test revealed skeletonized herring and live amphipods in the bait jars, while the fish within the drums were unaffected and no amphipods were present inside.

FIGURE 2. Photograph of the food-grade polyethylene drum used to cage individual rockfish showing the screens and bracket.

Each drum was attached to a 15.3-kg steel L-shaped bracket (back: 20.3 × 76.2 × 1.3 cm; bottom: 20.3 × 15.2 × 1.3 cm) by two methods (Figures 1, 2). Two stainless steel bands (1.27 cm × 0.76 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 cage movement was occurring on the seafloor, a fact also revealed 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 gear, 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 was a sea hook anchor (5 kg; Sea-Dog, Everett, Washington) 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, California) spliced into the main floating polyolefin line connecting to two surface floats (33 × 14 cm). To more easily free a stuck anchor, breakaway 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).

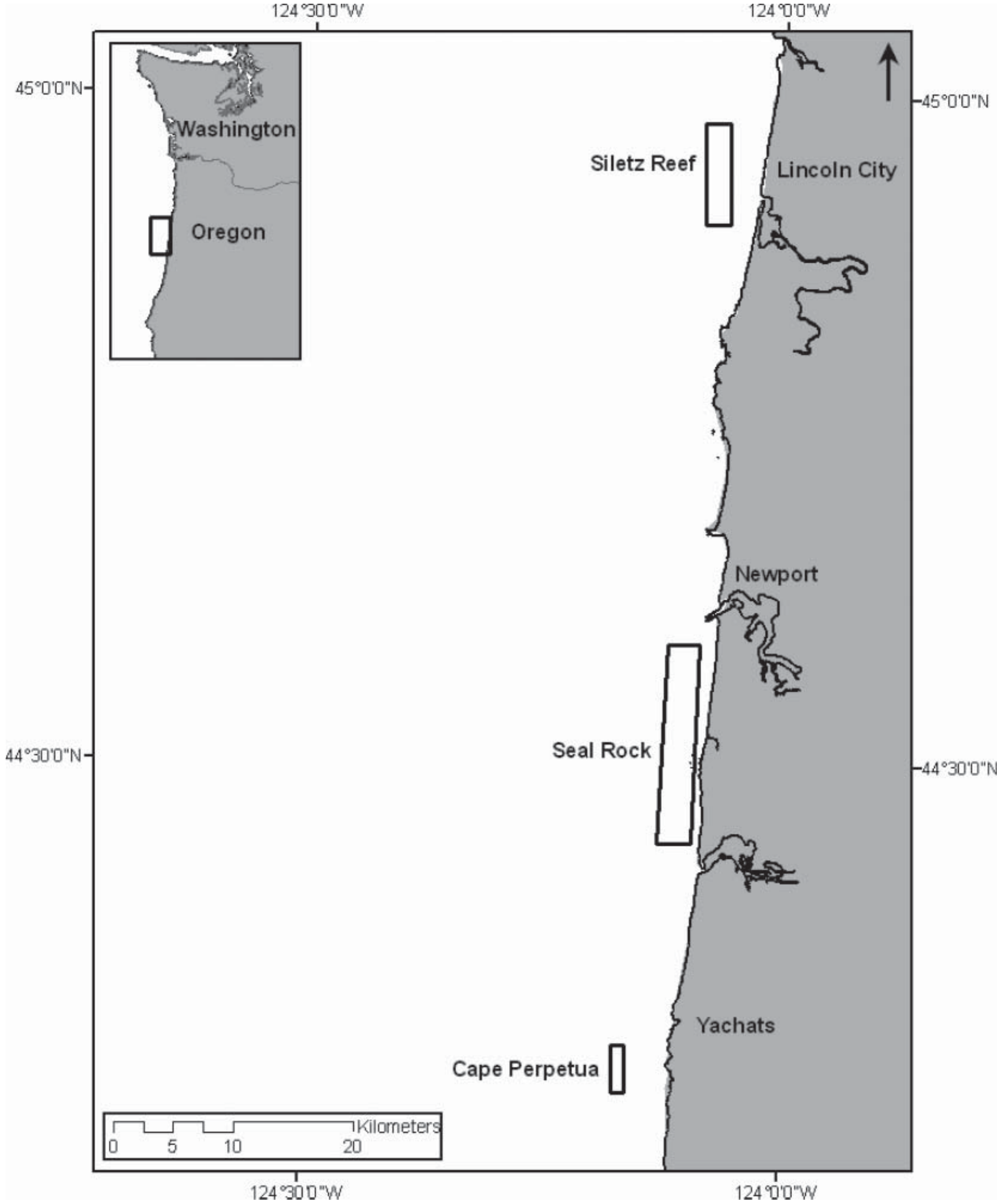

FIGURE 3. Map showing the locations of the three reef areas sampled to evaluate the 48-h postrecompression survival of rockfish.

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.

Postrecompression survival.—Sampling rockfish for the estimation of 48-h postrecompression 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). Rockfish were captured using standard recreational hook-and-line gear and reeled up manually. To distribute the sampling effort across depths, we attempted to capture and cage a variety of rockfish from each of six depth zones (8–9 m per zone) ranging from 9 to 64 m each day. We limited daily deployment to a maximum of 16 cages, each containing a single

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

Symptom	Indicator(s)
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

rockfish, with three to five cages each being 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 according to various measures to determine whether any factors were strongly associated with postrecompression mortality. Using a "jaw hold" to handle the fish, we scored them for seven signs of barotrauma (Table 1) following Pribyl et al. (2009) and Hannah et al. (2008a) and placed them in a wet tray to measure their fork length (cm) and take a photo. The fish were then placed in cages that were half-filled with seawater and evaluated behaviorally. We scored them with respect to 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 then 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 a flat bottom. The surface interval (min) for caged fish was calculated from the time the fish was brought on board to the deployment of the cage overboard and was minimized to the extent practicable. Data on the average surface interval for hook-and-line captured and discarded rockfish in the NCOW area are not available. We assumed that minimizing the surface interval for caged fish would best mimic the experience of a typical discarded rockfish that either successfully resubmerged 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 the depth and bottom temperature. The 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 they were removed from the cage, signs of barotrauma were again noted and an additional photo was taken. Each fish was then released into the ocean and its ability to descend noted. For each depth category, surface water temperature, salinity, and air temperature were again recorded.

Data analysis.—We estimated overall postrecompression survival by species as simple proportions but also provide LaPlace point estimates when survival exceeded 0.90 as suggested by Lewis and Sauro (2006) and Jarvis and Lowe (2008) to compensate for small sample sizes. 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 postrecompression survival. We also evaluated the effect of three other variables that can be related to survival: fish length, the 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 the captured rockfish, we included it as a variable that might influence survival, as it has been shown to be important in other studies of rockfish postrecompression survival (Jarvis and Lowe 2008). We used logistic regression (JMP software version 6.02) to evaluate the effect of all four variables on postrecompression survival. After a combined model was fitted, 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 the individual variables in the multiple logistic models, we profiled across the variable of interest while holding other variables constant at the mean values observed in our study.

We also separately evaluated measures of the physical condition of captured rockfish at the surface as predictors of postrecompression survival, including the presence of severe barotrauma and the ability of the fish to respond behaviorally. Behavioral impairment in NCOW rockfish released at depth (Hannah and Matteson 2007) and postrecompression survival in southern California rockfish (Jarvis and Lowe 2008) have both been shown to be associated with external signs of barotrauma. Reflex behaviors have been shown to be indicators of survival

TABLE 2. Numbers and length range (cm) of rockfish captured by hook-and-line in waters off Oregon and held in individual cages to estimate 48-h postrecompression survival and number of mortalities after 48 h (in parentheses), by species and depth of capture.

	Depth of capture (m)							Length
Species	9–18	19–27	28–36	37–45	46–54	55–64	Total	range (cm)
Black rockfish	34 (0)	38 (1)	34 (2)	21 (4)	14 (7)	3 (0)	144 (14)	24–49
Canary rockfish	0	1 (0)	14 (0)	10 (0)	14 (0)	2 (0)	41 (0)	22–39
Blue rockfish	1 (0)	14 (0)	9 (2)	7 (2)	5 (4)	0	36 (8)	23–39
Quillback rockfish	0	0	6 (0)	9 (0)	11 (0)	2 (0)	28 (0)	32–43
Yelloweye rockfish	0	2 (0)	3 (0)	8 (0)	12 (0)	0	25 (0)	31–52
Copper rockfish	0	0	2 (0)	7 (0)	1 (0)	0	10 (0)	33–48
China rockfish	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)	

following discarding in several fish species (Davis and Ottmar 2006; Davis 2007) as well as tanner crabs *Chionecetes bairdi* and snow crabs *C. opilio* (Stoner et al. 2008).

To determine the association between barotrauma and survival in each species that suffered some mortality, we used Fisher's exact test (Sokal and Rohlf 1981) to compare the frequency of severe barotrauma with the frequency of postrecompression survival. We defined severe barotrauma as the presence of any of the signs linked to extensive expansion and movement of swim bladder gas within the fish's body, including exophthalmia, ocular emphysema, and severe esophageal eversion (Hannah et al. 2008b; 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 with 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 its side," or "belly-up." The composite behavioral score was the sum of these values for each fish. Within species, we used logistic regression to determine whether the composite behavioral score was associated with postrecompression survival. To evaluate how surface behavior scores varied as an indicator of survival across species, we compared the mean behavior scores with 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 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 postrecompression survival (Table 2). Field data collection included 144 black rockfish, 36 blue rockfish *S. mystinus* (all references to blue rockfish refer to the solid subtype also called "blue sided"; Burford and Bernardi 2008; for physical descriptions, see http://www.reef.org/enews/articles/when-blue-not-blue), 42 canary rockfish *S. pinniger*, 3 China rockfish *S. nebulosus*, 10 copper rockfish *S. caurinus*, 28 quillback rockfish *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. The rockfish ranged from 22 to 52 cm in total length (Table 2). Time on deck was tightly controlled, averaging less than 3 min per fish, with a range of 1–9 min. Only 12 fish had a time on deck of 5 min or more, and all of those survived.

Up to a capture depth of 54 m, postrecompression survival was 100% for yelloweye rockfish ($n = 25$; 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 rockfish ($n = 41$) and quillback rockfish ($n = 28$) and 90%

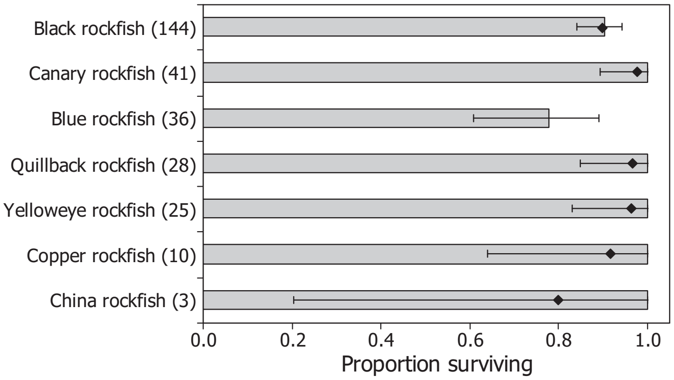

FIGURE 4. Forty-eight-h postrecompression survival of hook-and-line captured rockfish, by species, including LaPlace point estimates for species with greater than 90% survival (diamonds) and binomial confidence intervals calculated by the adjusted Wald method. Sample sizes are shown in parentheses.

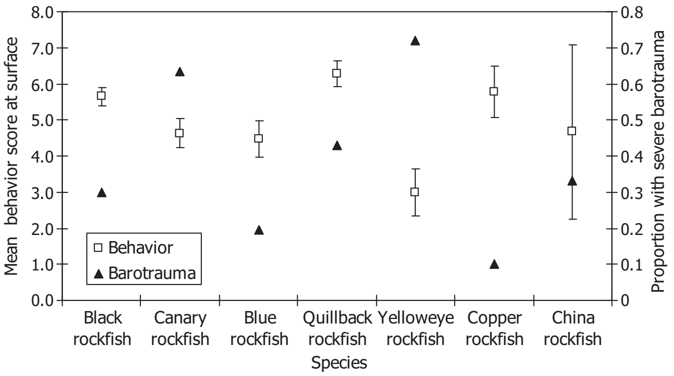

FIGURE 5. Mean composite surface behavior scores (higher scores indicate less behavioral impairment) and proportions of fish with severe barotrauma, by species; the error bars represent 95% confidence intervals.

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 rockfish occurred despite the frequency of barotrauma exceeding 60% (Figure 5). The high survival of quillback, copper, and China rockfish was consistent with relatively low frequencies of severe barotrauma (Figure 5). The lower 48-h postrecompression 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 postrecompression 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, 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 effects (worn fins, abrasions, or cloudy eyes). Only three (8%) of the 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 May 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 d, 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 and dents, contained very little sediment, and, with the one exception noted above, showed no evidence of amphipods or other crustaceans having entered them.

We also observed that although many fish had signs of severe barotrauma at initial capture, very few of them showed signs of barotrauma at cage retrieval. Of 93 surviving rockfish that showed severe barotrauma at capture, only 2 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 postrecompression survival in black rockfish was negatively associated with depth of capture ($P < 0.01$; Table 3) and the surface–bottom temperature differential ($P < 0.01$) but not with fish length or surface interval ($P > 0.05$). For blue rockfish, only depth of capture was significantly associated (negatively) with postrecompression 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–bottom temperature differential (Figure 6). Increasing depth of capture reduced postrecompression survival more rapidly and at shallower capture depths for blue rockfish than for black rockfish (Figures 6, 7).

Although both surface behavior scores and the presence of severe barotrauma were poor indicators of differences in postrecompression survival across species, they were somewhat useful indicators within species, especially for blue rockfish. The

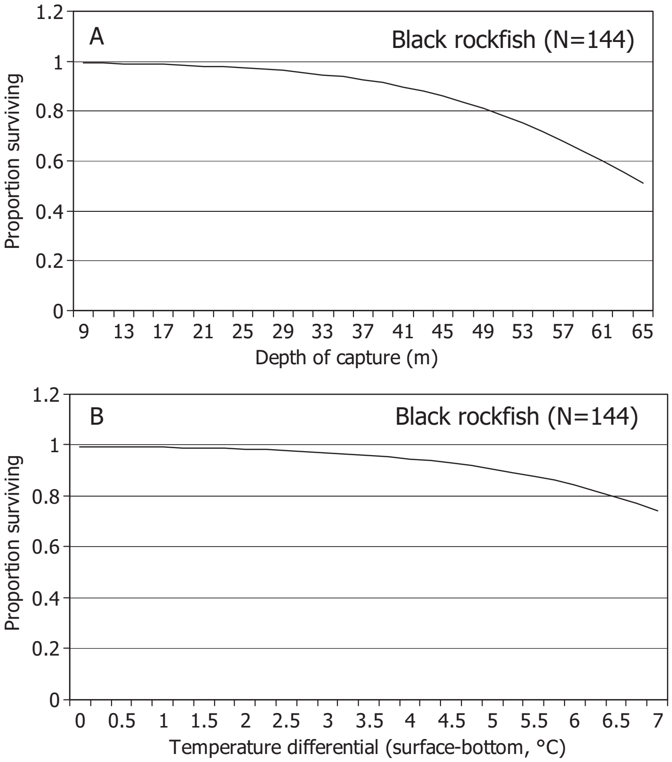

FIGURE 6. Fitted logistic curves relating the proportion of black rockfish surviving 48-h postrecompression to **(A)** the capture depth and **(B)** the surface–bottom temperature differential at the capture site. The curve for capture depth was fitted at a fixed temperature differential of 3.31°C, that for the temperature differential at a fixed capture depth of 28.27 m.

TABLE 3. Results of logistic regression analysis of the proportion of rockfish surviving after 48 h versus depth of capture (m), length (cm), surface interval (min), and surface–bottom temperature differential (°C) for black and blue rockfish.

Species	Independent variable	Coefficient	SE	*P*-value	Whole-model χ^2	R^2
Black rockfish	Constant	7.7877	1.6150	<0.0001	25.8528	0.2815
	Depth of capture	−0.0883	0.0320	0.0057		
	Temperature differential	−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		

presence of severe barotrauma was negatively associated with survival in both black ($P < 0.01$, $r^2 = 0.086$) and blue rockfish ($P < 0.0001$, $r^2 = 0.468$). Composite surface behavior scores were positively associated with postrecompression survival in black ($P < 0.01$, $r^2 = 0.088$) and blue rockfish ($P < 0.01$, $r^2 = 0.328$). Although many of the individual signs of barotrauma were negatively associated with postrecompression survival in black and blue rockfish ($P < 0.05$), only one stood out as a potential predictor of mortality. In blue rockfish, severe esophageal eversion was a strong indicator of postrecompression mortality. Of the 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 that the postrecompression 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 rockfish caged for at least 41 h, only 3 blue rockfish with cloudy corneas showed any evidence of adverse cage effects. This differs from the results of Jarvis and Lowe (2008), who studied postrecompression 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 the caged specimens after 2 d 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 that 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.

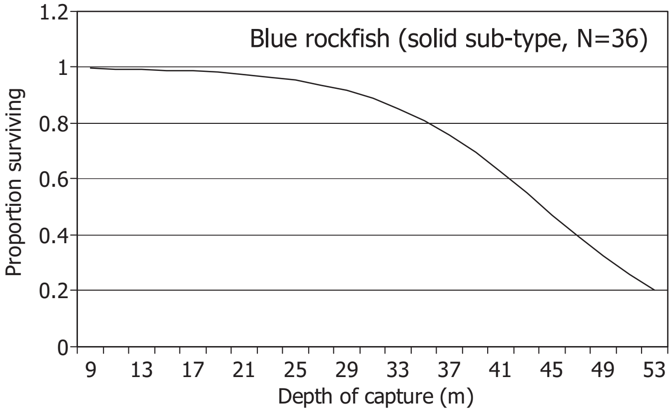

FIGURE 7. Fitted logistic curve relating the proportion of blue rockfish surviving 48-h postrecompression to the capture depth.

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 factor influencing postrecompression survival, as did Jarvis and Lowe (2008). Our data are consistent with the findings of Jarvis and Lowe (2008), however, because although the surface intervals in their study were longer (averaging 13.6–21.5 min across six species), they found higher survival of fish held at the surface for less than 10 min (78%) and even higher survival of fish 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 postrecompression survival that we obtained only apply to discards under a carefully considered set of conditions. Our survival estimates for these species are only representative for quickly released rockfish 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 in which resubmergence is delayed or unsuccessful. These estimates should probably also be viewed as an upper limit for postrecompression 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 the 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), indicating greater uncertainty in the mortality estimates we generated for those species and zones. Also, the longer-term survival of these seven species of rockfish following capture and successful recompression has not been studied. Studies of postrecompression survival for other line-caught fish with barotrauma have documented some mortality of individuals extending beyond 48 h, the nominal time of caging in our study (Gitschlag 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, 2011). Recent acoustic tagging studies that included some yelloweye and quillback rockfish have, however, documented the survival of some individuals with capture-related barotrauma for over a year (Hannah and Rankin 2011), and the longer-term survival of some Southern California rockfish with barotrauma has also been shown (Jarvis and Lowe 2008).

The postrecompression survival of both black and blue rockfish was inversely related to depth of capture (Table 3). This is consistent with the results from caging studies of the survival of line-caught red snapper with barotrauma (Gitschlag and Renaud 1994; Diamond and Campbell 2009) and with those from 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 Australasian snapper *Pagrus auratus* (Stewart 2008) also found depth of capture to be the primary determinant of postrecompression survival. Jarvis and Lowe (2008), however, did not find depth to be significantly related to 2-d postrecompression survival for Southern California rockfishes. However, they tested fish captured at 55–89 m, as compared with 20–55 m for most of our specimens, and also worked with different species (Table 2). It is 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 postrecompression 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 postrecompression survival provide several insights into the effects of barotrauma on rockfish. The association of severe barotrauma in black and blue rockfish with postrecompression mortality is not surprising. Barotrauma is known to generate a wide array of internal injuries in rockfish, some of which can be life threatening (Hannah et al. 2008b; Jarvis and Lowe 2008; Pribyl et al. 2009). However, some studies of other species of physoclists did not relate external signs of barotrauma to subsequent mortality (Gitschlag and Renaud 1994). The very strong association of severe esophageal eversion with postrecompression 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 postrecompression survival. The fact that in our study fish with barotrauma at initial capture generally showed no external signs of it 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. 2008b). It is also consistent with similar findings by Jarvis and Lowe (2008) for Southern California rockfish. The common external signs of barotrauma in rockfish, including exophthalmia and esophageal eversion, develop from gas that has escaped the overexpanded swim bladder 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 (Hannah et al. 2008b; Pribyl et al. 2009), they collect behind the point where the esophageal tissue is anchored in the pharynx and "roll" the esophageal tissue outward 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. 2008b; 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 swim bladder 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 rockfish with barotrauma at depth for 48 h is a useful technique for collecting live specimens without the use of surface pressure tanks or venting. It should be noted that the absence of barotrauma signs is likely to be a temporary effect. In pressure chamber experiments, Parker et al. (2006) found that after 21 d 77% of the black rockfish that had experienced a 304-kPa decrease in pressure during simulated capture experiments had swim bladders that were again holding gas. Some of our specimens that displayed no external signs of barotrauma at capture probably retained a healthy, functional swim bladder and then followed the normal physiological process of adding gas to their swim bladder 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 postrecompression survival in black and blue rockfish, consistent with studies relating reflex behavior and postcapture survival in other fishes (Davis and Ottmar 2006). However, considered across species, the mean composite scores for surface behavior did not correctly indicate which species had higher postrecompression survival potential. Postrecompression survival by species was more consistent with inferences based on postrecompression release (release at depth) behavior (Hannah and Matteson 2007). In that study, for a given depth of capture blue rockfish were the most behaviorally impaired when released at depth, followed by black rockfish and then yelloweye rockfish, a ranking similar to that of the survival estimates we generated. This suggests that, for species like yelloweye rockfish, the large amount of swim bladder gas retained 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 rockfish. For black and blue rockfish, the decline in postrecompression survival as a function of capture depth is only somewhat more gradual than the decline in resubmergence success after surface release (Figure 8; resubmergence data from Hannah et al. 2008a). 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, the 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 postrecompression survival, the very fish that need the most assistance to resubmerge 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 to small individuals that sometimes get discarded. Conversely, for canary rockfish (Figure 8) and probably yelloweye rockfish (for which detailed data on submergence success are lacking), 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 postrecompression survival, suggesting that requiring the use of recompression devices may reduce discard mortality much more for these species.

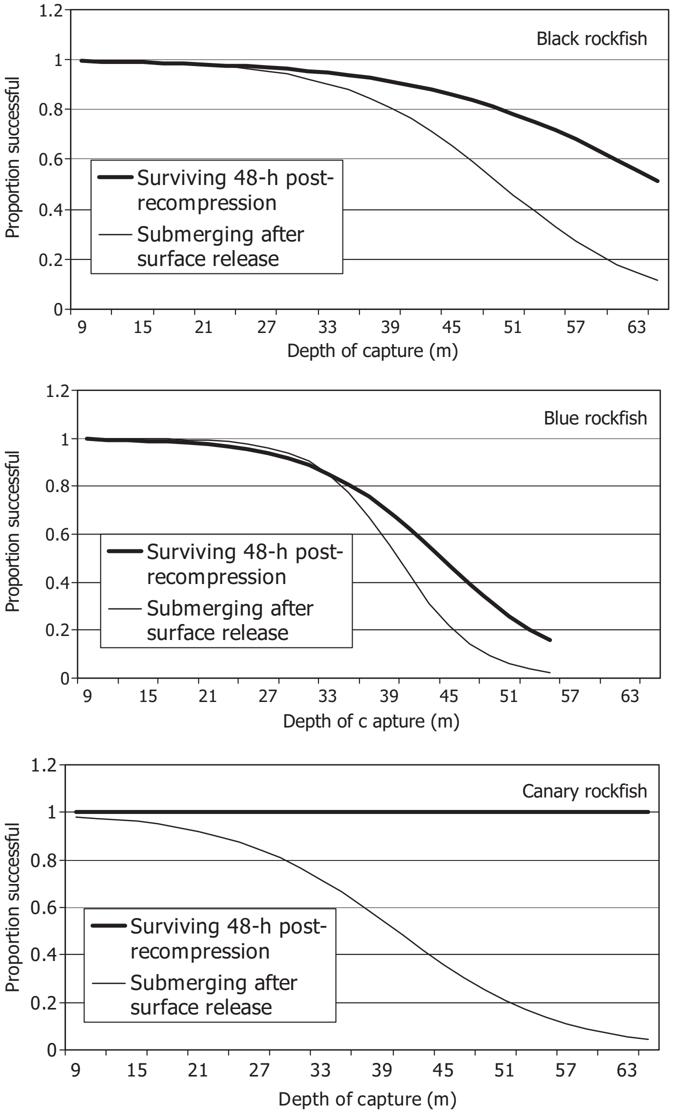

FIGURE 8. Comparisons of the fitted logistic curves for 48-h postrecompression survival and successful resubmergence after surface release (from Hannah et al. 2008a) as a function of capture depth for black, blue, and canary rockfish.

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 postrecompression 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. Thus, studies comparing the survival of vented versus unvented fish should consider as part of their design the degree to which the failure to submerge following surface release has been established for the fish population and depths of capture being studied.

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