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Robert W. Hannah [a], Steven J. Parker [b] & Keith M. Matteson [c]

[a] Oregon Department of Fish and Wildlife, Marine Resources Program, 2040 Southeast Marine Sciencey Drive, Newport, Oregon, 97365, USA

[b] National Institute of Water and Atmospheric Research, Private Bag 14901, Wellington, 6241, New Zealand

[c] Oregon Department of Fish and Wildlife, Marine Resources Program, 2040 Southeast Marine Science Drive, Newport, Oregon, 97365, USA

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[Management Brief]

Escaping the Surface: The Effect of Capture Depth on Submergence Success of Surface-Released Pacific Rockfish

ROBERT W. HANNAH*
Oregon Department of Fish and Wildlife, Marine Resources Program, 2040 Southeast Marine Science Drive, Newport, Oregon 97365, USA

STEVEN J. PARKER
National Institute of Water and Atmospheric Research, Private Bag 14901, Wellington 6241, New Zealand

KEITH M. MATTESON
Oregon Department of Fish and Wildlife, Marine Resources Program, 2040 Southeast Marine Science Drive, Newport, Oregon 97365, USA

Abstract.—We evaluated the effect of capture depth and fish size on the ability of several Pacific rockfishes *Sebastes* spp. to resubmerge after hook-and-line capture and surface release. We observed fish as they were released into a bottomless floating enclosure, and we recorded submergence success within a 5-min time limit. Submergence success was greater than 80% for all rockfish captured in depths less than 30 m. Yellowtail rockfish *S. flavidus* ($N = 51$) were 100% successful at submerging in less than 49 s at all depths sampled (10–51 m). At capture depths of 40–51 m, submergence success was 89% for quillback rockfish *S. maliger* ($N = 9$), 65% for black rockfish *S. melanops* ($N = 46$), and 30% for canary rockfish *S. pinniger* ($N = 40$). At depths of 30–51 m, submergence success was 32% for blue rockfish *S. mystinus* ($N = 31$). The external signs of barotrauma (e.g., exopthalmia, eversion of the esophagus) increased with depth of capture and were least prevalent in yellowtail rockfish and quillback rockfish. The presence of severe esophageal eversion (beyond the buccal cavity) was strongly negatively associated with submergence success for several species ($P < 0.01$). At 40–51-m capture depths, the frequency of severe esophageal eversion by species was correlated with the frequency of submergence failure ($P < 0.05$). Logistic regression showed a negative relationship between depth of capture and submergence success for black rockfish ($P < 0.001$), blue rockfish ($P < 0.001$), and canary rockfish ($P < 0.05$). Larger body length negatively influenced submergence success only in blue rockfish ($P < 0.05$).

As some stocks of Pacific rockfishes *Sebastes* spp. have become depleted, U.S. West Coast management agencies have relied on mandatory discard as one of the main management tools to control impacts from hook-and-line fisheries (PFMC 2004). For example, since 2004 marine recreational anglers have been required to discard all yelloweye rockfish *S. ruberrimus* that are captured. Current regulations also require the prompt discard of all canary rockfish *S. pinniger*.

Rockfish are physoclistic, and deep-dwelling species experience severe barotrauma from the expansion of swim bladder gases as the fish are brought to the surface (Parker et al. 2006; Hannah and Matteson 2007). Severe barotrauma, also referred to as "catastrophic decompression," can create a wide variety of internal injuries, including swim bladder rupture, organ displacement and compression, and embolism (Longbottom 2000; Rummer and Bennett 2005; Parker et al. 2006). Swim bladder gases retained within the fish's distended abdomen and everted esophagus also create excess buoyancy that can prevent discarded fish from returning to depth, reducing the probability of survival. In light of these problems, the effectiveness of discard as a management tool for deep-dwelling Pacific rockfishes must be evaluated.

The ability of Pacific rockfish to resubmerge after surface release has not been described. For many deep-dwelling rockfish species, postrelease mortality is assumed to be very high (Starr et al. 2002). The potential for significant survival after successful submergence, however, is supported by some evidence from field and laboratory studies (Gotshall 1964; Parker et al. 2006; Oregon Department of Fish and Wildlife [ODFW], unpublished data). In these studies, rockfish were assisted in overcoming surface buoyancy via the venting of swim bladder gases with a hypodermic needle (Gotshall 1964), direct recompression in pressure tanks (Parker et al. 2006), or release at depth from a remotely triggered release cage (ODFW, unpublished data). Although some marine anglers do use special devices to return Pacific rockfish to depth (Theberge and Parker 2005), most angler-released rockfish are simply discarded at the surface. Therefore,

* Corresponding author: bob.w.hannah@state.or.us

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

Symptom	Indicator
Tight abdomen	Abdomen is swollen and tight to the touch.
Bulging membrane	Outward bulge is visible in the branchiostegal membrane.
Membrane emphysema	Air spaces or bubbles are visible within the branchiostegal membrane.
Exophthalmia (popeye)	Eye protrudes outward from orbit.
Ocular emphysema	Gas is present within the eye or connective tissue surrounding the eye.
Esophageal eversion–moderate	Eversion of esophageal tissue extends at least 1 cm into the buccal cavity.
Esophageal eversion–severe	Eversion of esophageal tissue extends beyond the buccal cavity.

an evaluation of the ability of discarded Pacific rockfish to resubmerge is vital for determining the potential for discard survival. The objective of this study was to examine the resubmergence success of surface-released Pacific rockfish as a function of species, depth of capture, and fish size.

Methods

To study the ability of discarded Pacific rockfish to resubmerge, we constructed a floating, bottomless release pen that could be deployed next to a drifting charter fishing vessel. The purpose of the floating pen was to keep floating rockfish near a drifting boat so that their attempts to submerge could be observed. The circular pen was constructed from three flexible, modular, 2.2-m-long sections to form a 2.1-m-diameter enclosure. The top and bottom support frames were made from sections of 51–mm-diameter polyethylene pipe fastened together with male couplers and secured with clevis pins and stainless steel hose clamps. The sides of the pen were constructed from Vexar netting (13-mm square mesh) secured to the frame sections with cable ties. The sides of the pen extended 122 cm below the surface of the water. To provide flotation, two 2.2-m-long sections of foam pipe insulation were secured to the top frame member of each modular section using cable ties.

Rockfish were captured for this 2006 study by drifting over rocky reef areas using hook-and-line gear typical of the recreational fishery (a combination of flies and plastic worms on Mustad size-7 stainless steel J-hooks). A wide depth range of approximately 10–50 m was sampled. Each captured rockfish was quickly identified to species, measured (cm fork length [FL]), and evaluated for external signs of barotrauma using the criteria in Table 1. Any irregularities in the handling of a fish (e.g., dropping of a fish onto the deck) or outward signs of injury or bleeding were also recorded; however, because these injuries also occur during recreational fishing, the fish were not excluded from our analysis. Bottom depth at the capture site was noted for each fish. Some of the rockfish species we studied occupy both bottom and pelagic habitats (McElderry 1979; Pearcy 1992; Love et al. 2002), so bottom depth at the capture site was only an approximate indicator of capture depth.

To evaluate submergence success, each rockfish was immediately placed in the release pen and timed with a stopwatch to record how long it remained at the surface before successfully submerging. An individual sampler was assigned to monitor each fish. Up to four rockfish were placed in the pen, at which point it was considered full and fishing was stopped until one of the fish either submerged successfully or was removed from the pen. After a fish submerged successfully, the waters around the vessel and upwind of the vessel were observed to note any fish resurfacing. The few fish that resurfaced were noted but were not retrieved or placed back into the pen. Each fish was allowed to float in the pen for a maximum of 5 min, after which it was considered to have failed to submerge; these fish were removed from the pen and then released at depth using a remotely triggered release cage. The time limit of 5 min was chosen for several reasons. As a practical matter, longer observation times would have severely limited the number of fish that could be observed when submergence success was low. More importantly, in an actual fishery discard situation, rockfish stranded at the surface float away from the drifting boat and become vulnerable to attack and injury from avian predators. These floating fish also experience longer exposure to warm surface waters and continued physical stress and damage from ongoing barotrauma, thereby reducing the likelihood of recovery and submergence. Although a few fish that float at the surface for longer than 5 min probably do eventually submerge on their own, we assumed that this would be rare and would create very little bias in our data.

We used the chi-square test of independence (Sokal and Rohlf 1981) to test for associations between the frequency of submergence success and the outward signs of barotrauma within species. To determine whether severe barotrauma was correlated with submergence success across species, we calculated Spearman's rank correlation coefficient (r_s; Sokal and Rohlf 1981) between the frequencies of severe esophageal eversion and submergence failure. This test was applied to data from capture depths of 40–51 m to

TABLE 2.—Summary of Pacific rockfish *Sebastes* spp. captured off the coast of Newport, Oregon, in 2006 and percentage that successfully submerged within 5 min of release into a floating pen (see text), presented by capture depth interval. Fork length (FL) range (cm) sampled is shown in parentheses next to each species name.

Species (FL)	10–19 m *N*	10–19 m Submerged (%)	20–29 m *N*	20–29 m Submerged (%)	30–39 m *N*	30–39 m Submerged (%)	40–51 m *N*	40–51 m Submerged (%)	Total
Black rockfish *S. melanops* (26–54)	27	100.0	51	96.1	73	82.2	46	65.2	197
Blue rockfish *S. mystinus* (18–46)	17	100.0	56	100.0	25	28.0	6	50.0	104
Brown rockfish *S. auriculatus* (39–43)	1	100.0	0		1	100.0	1	0.0	3
Canary rockfish *S. pinniger* (19–50)	0		5	80.0	6	66.7	40	30.0	51
Copper rockfish *S. caurinus* (33–45)	0		1	100.0	1	100.0	2	100.0	4
Quillback rockfish *S. maliger* (28–41)	0		0		3	100.0	9	88.9	12
Vermilion rockfish *S. miniatus* (31–46)	0		1	100.0	1	100.0	1	100.0	3
Widow rockfish *S. entomelas* (22–30)	0		0		2	50.0	0		2
Yelloweye rockfish *S. ruberrimus* (36–39)	0		0		0		2	0.0	2
Yellowtail rockfish *S. flavidus* (19–39)	1	100.0	6	100.0	17	100.0	27	100.0	51
Total	46		120		129		134		429

allow comparison of the greatest number of different species. We evaluated the effect of capture depth and fish FL on submergence success by species using multiple logistic regression (StatView 5.0; main effects without interaction). For rockfish that submerged within the 5-min time limit, we used the nonparametric Mann–Whitney *U*-test (Sokal and Rohlf 1981) to determine whether severe esophageal eversion or being dropped on the deck influenced time to submergence.

Results

We observed the discard of 429 rockfish representing 10 different species (Table 2). Rockfish were captured at four sites off Newport, Oregon, ranging in bottom depth from 10 to 51 m. About 80% of the rockfish (341 of 429) submerged successfully after surface release. The majority (51 of 88) of the rockfish that failed to submerge were captured at depths greater than 39 m. Ninety-three percent (317 of 341) of the rockfish that successfully submerged did so in less than 60 s, suggesting that few fish would be likely to submerge after the 5-min observation time limit. Only two rockfish resurfaced outside the pen after initial submergence; both were blue rockfish.

Submergence success for capture depths less than 30 m was 80% or higher for all species sampled (Table 2). For most species, submergence success was inversely related to depth of capture (Table 2). Yellowtail rockfish were the notable exception and were the most successful at submerging: all submerged within 49 s at all depths sampled (Table 2). All copper rockfish and vermilion rockfish also submerged successfully within the 5-min time limit; however, few were sampled. Quillback rockfish and black rockfish were mostly successful at submerging; 89% of quillback rockfish and 65% of black rockfish submerged after capture at depths of 40–51 m. Blue rockfish were much less successful, and only 32% submerged after capture at depths exceeding 29 m. Although sampled in small numbers, all brown rockfish and yelloweye rockfish captured at depths greater than 39 m failed to submerge (Table 2).

Typically, rockfish that failed to submerge either did not attempt to do so or made a few brief, weak attempts that resulted in very little descent below the surface. Very few fish made repeated vigorous attempts to submerge but failed to overcome buoyancy, which suggests that buoyancy was not the sole cause of submergence failure. Only 8.8% of fish had hooking- or handling-related injuries. Being dropped on the deck was the most common injury observed (22 of 38 injuries). Across all species sampled, submergence success was 73% among dropped fish and 80% among fish that were not dropped; this difference was not statistically significant ($P > 0.05$). For rockfish that submerged, being dropped on the deck increased mean time to submergence from 14 to 43 s ($P < 0.01$).

The external signs of barotrauma generally increased in frequency with depth of capture (Table 3). Species with a low incidence of esophageal eversion, such as yellowtail rockfish and quillback rockfish, also had high rates of submergence success even at the greatest depths sampled (Tables 2, 3). At capture depths of 40–51 m, poor submergence success for a species was associated with a high frequency of severe esophageal eversion ($r_s = 0.821$, $P < 0.05$; Figure 1). For rockfish that were not dropped on the deck, severe esophageal eversion also increased the mean time to submergence from 10 to 40 s ($P < 0.001$). However, the relationship between the frequency of external barotrauma signs and submergence success was not consistent across species. For example, canary rockfish and black rockfish captured at depths greater than 39 m showed similar frequencies for most of the external signs of

TABLE 3.—Proportion of Pacific rockfish that displayed external barotrauma signs after capture off the coast of Newport, Oregon, in 2006. Signs are defined in Table 1. Only species with five or more observations (*n*) in a depth zone are shown.

Species (*n*)	Tight abdomen	Bulging membrane	Membrane emphysema	Exophthalmia	Ocular emphysema	Moderate esophageal eversion	Severe esophageal eversion
Capture depth: 10–19 m							
Black rockfish (27)	0.85	0.07	0.04	0.00	0.00	0.00	0.00
Blue rockfish (17)	0.88	0.18	0.00	0.00	0.00	0.00	0.00
Capture depth: 20–29 m							
Black rockfish (51)	0.98	0.75	0.57	0.06	0.00	0.55	0.16
Blue rockfish (56)	1.00	0.20	0.02	0.00	0.00	0.05	0.02
Canary rockfish (5)	1.00	1.00	0.80	0.40	0.00	0.40	0.20
Yellowtail rockfish (6)	1.00	0.50	0.33	0.00	0.00	0.00	0.00
Capture depth: 30–39 m							
Black rockfish (73)	0.93	0.84	0.77	0.05	0.00	0.78	0.32
Blue rockfish (25)	0.84	0.12	0.36	0.04	0.00	0.88	0.68
Canary rockfish (6)	1.00	1.00	1.00	0.17	0.00	0.83	0.50
Yellowtail rockfish (17)	0.35	0.71	0.88	0.00	0.00	0.00	0.00
Capture depth: 40–51 m							
Black rockfish (46)	0.89	0.96	0.74	0.28	0.07	0.94	0.57
Blue rockfish (6)	0.50	0.50	0.17	0.17	0.00	1.00	0.67
Canary rockfish (40)	0.93	0.95	0.95	0.50	0.18	0.95	0.70
Quillback rockfish (9)	0.89	1.00	0.89	0.67	0.22	0.11	0.11
Yellowtail rockfish (27)	0.26	0.41	0.93	0.00	0.00	0.00	0.00

barotrauma, but black rockfish were more than twice as likely to submerge after release (Tables 2, 3).

For some species, certain external signs of barotrauma were good indicators of submergence success. In black rockfish ($P < 0.001$), blue rockfish ($P < 0.001$), and canary rockfish ($P < 0.01$), failure to submerge was strongly positively associated with the presence of severe esophageal eversion. Moderate esophageal eversion was associated with failure to submerge in black rockfish and blue rockfish ($P < 0.001$) but not canary rockfish ($P > 0.05$). The presence of a bulge in the branchiostegal membrane was also associated with failure to submerge in black rockfish ($P < 0.05$). In canary rockfish, the presence of barotrauma-related eye problems, such as exophthalmia ($P < 0.01$) and ocular emphysema ($P < 0.05$), was associated with failure to submerge. For blue rockfish, exophthalmia was also associated with failure to submerge ($P < 0.05$).

Logistic regression analysis (Figure 2) showed that submergence success was negatively related to depth of capture for black rockfish ($P < 0.001$), blue rockfish ($P < 0.001$), and canary rockfish ($P < 0.05$). Increasing depth of capture reduced submergence success most rapidly in blue rockfish. Of these three species, black rockfish maintained the highest rates of successful submergence as depth of capture increased. Fish FL was unrelated to submergence success ($P > 0.05$) except in blue rockfish, which exhibited a decrease in success with increasing FL (for a depth of 26 m, 50% submergence FL was 46 cm; $P < 0.05$).

Discussion

Observations from this study and from work by Pearcy (1992) suggest that the ability of different rockfish species to submerge after fishery discard is related to three factors: (1) fish buoyancy, (2) species-specific differences in anatomy related to escape of swim bladder gas during ascent, and (3) injuries due to barotrauma and handling. Buoyancy is caused by the exponential expansion of swim bladder gases, which follows Boyle's Law (Alexander 1966). The diffusion

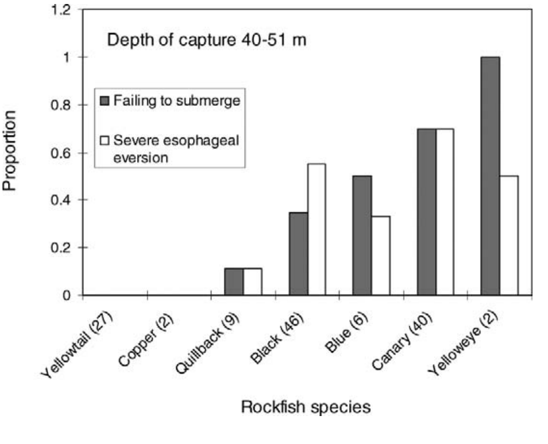

FIGURE 1.—Proportions of Pacific rockfish captured at a depth of 40–51 m off the coast of Newport, Oregon, in 2006 that failed to submerge after surface release and exhibited severe esophageal eversion (beyond the buccal cavity). Sample size is shown in parentheses.

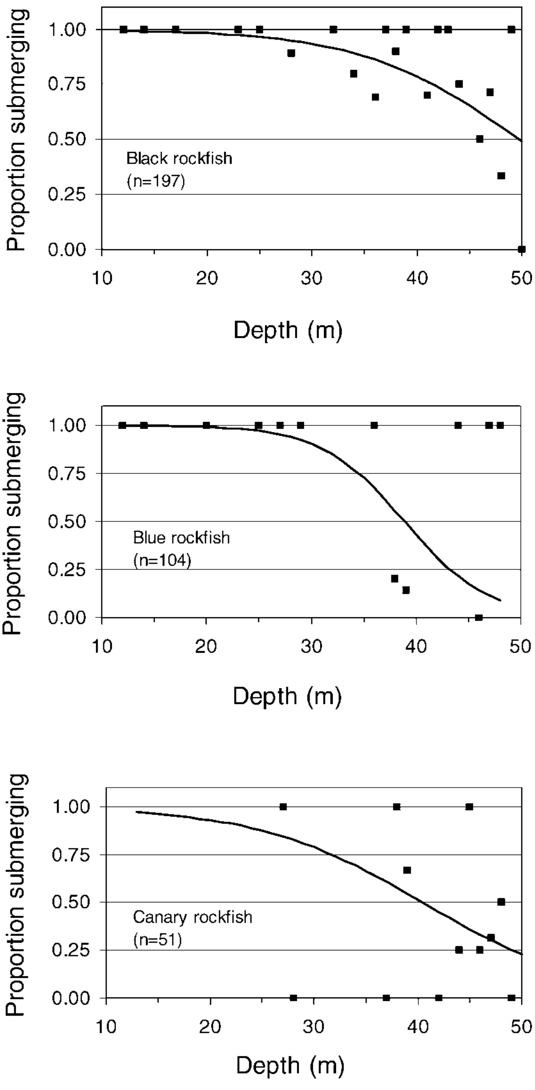

FIGURE 2.—Fitted logistic curves of the proportion of black rockfish, blue rockfish, or canary rockfish captured at various depths off the coast of Newport, Oregon, in 2006 that successfully resubmerged within 5 min of release, plotted in relation to bottom depth at the capture site. The curve for blue rockfish was fitted at a fixed fork length of 29.5 cm. Bin size is 1 m.

of gas from the swim bladder to the blood is passive and very slow in comparison with fishery ascent rates (Alexander 1966; Parker et al. 2006). Therefore, surface buoyancy of a rockfish is primarily a function of the depth at neutral buoyancy and fish size, lessened by the decrease in buoyancy from any swim bladder gas that has escaped from the body.

Escape of swim bladder gas during ascent appears to be an important factor related to submergence success after surface release for Pacific rockfish. In the greatest depth interval we sampled, the frequency of severe esophageal eversion, indicative of the retention of large amounts of swim bladder gas, was correlated with the frequency of submergence failure by species (Figure 1). The yellowtail rockfish we sampled had the highest submergence success and showed evidence of only minimal amounts of retained gas, indicated by a complete lack of esophageal eversion and very minimal external signs of barotrauma (Tables 2, 3). Yellowtail rockfish are semipelagic and are probably acclimated to shallower depths than other, more demersal Pacific rockfish species (Pearcy 1992). However, Pearcy (1992) observed bubbles of swim bladder gas escaping from under the opercula of yellowtail rockfish during ascent. In our study, we observed gas bubbles originating from under the opercula of many quillback rockfish and a few canary rockfish as they were brought to the surface. Our ability to detect escaping gas bubbles during ascent was dependent on sampling in very calm weather. Thus, while we did not observe bubbles emanating from yellowtail rockfish and some other species we sampled, this may have been due to the poor conditions for observation on most sampling dates. One plausible hypothesis for the high submergence success of yellowtail rockfish and quillback rockfish in this study is that substantial amounts of gas from their ruptured swim bladders escaped through ruptures in the branchiostegal membrane, thus reducing their surface buoyancy. The escape of swim bladder gas may also reduce some of the internal injuries that can arise when contained swim bladder gases expand (Rummer and Bennett 2005). Pacific rockfish species that retain less swim bladder gas and have high submergence success may therefore have higher short-term discard survival but possibly at the cost of other health problems resulting from ruptures in external membranes (e.g., increased risk of infection).

Injuries may also play a large role in the failure of rockfish to submerge; in this study, fish that did not submerge showed a lack of vigorous attempts rather than repeated attempts that failed to overcome buoyancy. This suggests that failure to submerge is caused by adverse physical effects of barotrauma and handling rather than excess buoyancy alone. This is supported by the lower submergence success and longer times to submergence of fish that were dropped on the deck. Further investigation of the internal injuries that different Pacific rockfish species experience from capture-related barotrauma would be helpful in explaining differences in behavior and apparent competency at release, including submergence success.

Submergence success may be a misleading indicator of even short-term survival for some species. Hannah and Matteson (2007) investigated the relationship between barotrauma and the behavioral impairment of rockfish released at depth. They found that rockfish from deeper capture depths were more frequently behaviorally impaired, which was defined as a reduced ability to exit a release cage within a defined time interval or to maintain vertical orientation while swimming. Behavioral impairment at release is significant because the loss of reflex behaviors, such as the ability to maintain a vertical orientation, is a good predictor of subsequent mortality in some fish species (Davis 2005; Davis and Ottmar 2006). Integration of submergence success data from this study with behavioral impairment observations by Hannah and Matteson (2007) shows that some species with high submergence success may also have a high frequency of behavioral impairment. Blue rockfish showed the largest disparity between the frequency of submergence success and behavioral impairment during release at depth (Figure 3). About 70% of the blue rockfish in our study submerged successfully after capture at a depth of 30–39 m. However, about 70% of blue rockfish in Hannah and Matteson's (2007) study showed behavioral impairment when released at depth. Conversely, Hannah and Matteson's (2007) data suggest that only about 25% of yelloweye rockfish showed behavioral impairment when captured at 40–50 m and released at depth. At similar capture depths in this study, however, both yelloweye rockfish failed to submerge (Table 2). For yelloweye rockfish, which are captured mostly at depths greater than 40 m (Love et al. 2002), overcoming surface buoyancy may be the most difficult step in surviving fishery discard, making submergence a better proxy for short-term discard survival. This argument is supported by the fact that five of six acoustically tagged yelloweye rockfish captured at 55 m and released at depth survived for more than 21 d (ODFW, unpublished data).

Low submergence success for some species indicates that short-term discard survival can be enhanced with devices that assist fish in submerging (Theberge and Parker 2005). The high submergence success rates of black rockfish, yellowtail rockfish, and quillback rockfish across all depths sampled (Table 2) suggest that discard does not result in high short-term mortality for these species. In contrast, blue rockfish, yelloweye rockfish, and canary rockfish probably do not survive fishery discard at high rates after release at the surface. Yelloweye and canary rockfish showed low submergence success even at capture depths near the shallow portion of their depth range, suggesting that (1) these species will benefit most from the use of submergence assistance devices (Theberge and Parker 2005) and (2) discard as currently practiced will result in high mortality rates for these species. Management actions to encourage recompression of discarded Pacific rockfish could reduce short-term mortality rates for vulnerable species; however, information on long-term survival is needed to evaluate the impact of such actions on stock rebuilding.

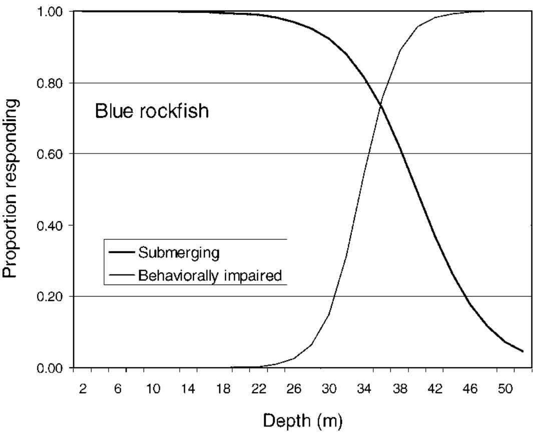

FIGURE 3.—Comparison of fitted logistic curves showing the proportion of blue rockfish captured off the coast of Newport, Oregon, in 2006 that submerged successfully within 5 min of release (this study) and that displayed behavioral impairment when released at depth (Hannah and Matteson 2007), plotted in relation to bottom depth at the capture site. Bin size is 1 m.

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