The divergent effect of capture depth and associated barotrauma on post-recompression survival of canary (*Sebastes pinniger*) and yelloweye rockfish (*S. ruberrimus*)

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Highlights

Postrecompression survival of two physoclists from deep capture depth was studied.

At capture, the external signs of severe barotrauma were similar for both species.

Survival (48 h) of the two rockfishes diverged sharply as capture depth increased.

Yelloweye rockfish survival remained high while canary rockfish dropped to 25%.

Abstract

We evaluated the external signs of barotrauma and 48-h post-recompression survival for 54 canary and 81 yelloweye rockfish captured at depths of 46-174 m, much deeper than a similar prior experiment, but within the depth range of recreational fishery catch and discard. Survival was measured using specialized sea cages for holding individual fish. The external physical signs associated with extreme expansion and retention of swimbladder gas (pronounced barotrauma), including esophageal eversion, exophthalmia and ocular emphysema, were common for both species at these capture depths and were more frequent than in prior studies conducted at shallower depths. Despite similar frequencies of most external barotrauma signs, 48-h post-recompression survival of the two species diverged markedly as capture depth increased. Survival of yelloweye rockfish was above 80% across all capture depths, while survival of canary rockfish was lower, declining sharply to just 25% at capture depths greater than 135 m. Fish of both species that were alive after 48 h of caging displayed very few of the external signs of pronounced barotrauma and had a high submergence success rate when released at the surface. Logistic regression analysis, using a combined data set from this and an earlier experiment conducted at shallower capture depths, was used to more broadly evaluate factors influencing post-recompression survival. For canary rockfish, depth of capture was negatively related to survival ($P<0.0001$), but the surface-bottom temperature differential was not ($P>0.05$). Exophthalmia and ocular emphysema were each negatively associated with survival for canary rockfish ($P<0.05$). For yelloweye rockfish, no significant associations were found between post-recompression survival and capture depth, the surface-bottom temperature differential or any of the signs of pronounced barotrauma ($P>0.05$).

1. Introduction

In multi-species hook-and-line fisheries, rules requiring non-retention of particular species are a common approach to limiting fishing mortality on weaker stocks. The effectiveness of non-retention depends on a variety of factors, but particularly upon the survival rate of released fish. Post-release survival can be difficult to estimate due to the many factors that can reduce it, including capture-related injuries, handling time, environmental conditions and predation after release (Davis 2002). Estimation of post-release survival is especially complex for species with closed swim bladders (physoclists), such as Pacific rockfish (*Sebastes* spp.), that experience a suite of injuries from barotrauma that are typically exacerbated by greater depth of capture (Hannah et al. 2008a, Jarvis and Lowe 2008, Pribyl et al. 2009). At surface pressure, some of these species have extreme buoyancy from retained swim-bladder gas that can also prevent them from submerging and returning to the seafloor under their own power (Hannah et al. 2008b, Hochhalter 2012), further complicating the estimation of post-release survival in a fishery.

The depressed status of several Pacific rockfishes in U.S. coastal waters has led to non-retention rules for these species in hook-and-line fisheries (PFMC and NMFS 2012), particularly fisheries encountering yelloweye (*Sebastes ruberrimus*) and canary rockfish (*S. pinniger*) and cowcod (*S. levis*). Yelloweye rockfish and cowcod typically inhabit high-relief rocky areas with boulders and crevices, while canary rockfish are found in these habitats as well as flat bedrock and mixed mud-boulder habitats (Love et al. 2002). Concerns about the effects of capture-induced barotrauma on these species have prompted a variety of studies investigating both the typical injuries from barotrauma, as well as the potential for post-release submergence and survival (Hannah and Matteson 2007, Hannah et al. 2008b, Hochhalter and Reed 2011, Pribyl et al. 2011, Hochhalter 2012). For yelloweye rockfish, both short-term (48 h) and longer-term (17 d) studies of post-release survival have shown high survival when these fish are returned to depth, referred to as "post-recompression survival" (Hochhalter and Reed 2011, Hannah et al. 2012). The single short-term post-recompression survival study on canary rockfish has also shown very high survival (Hannah et al. 2012). However, survival studies for these two overfished species were conducted almost exclusively at capture depths less than 64 m. Fishery capture and release of these fishes frequently occurs at much deeper capture depths, up to at least 175 m. We report here on a field study evaluating the short-term post-recompression survival of canary and yelloweye rockfish at much greater depths of capture, ranging from 46 m to 175 m.

2. Methods

2.1 Post-recompression survival

We evaluated post-recompression survival using a variation of the sea-caging method described in detail in Hannah et al. (2012). Sampling was conducted on a chartered commercial passenger fishing vessel equipped with a hydraulic block between September 2012 and October 2013, at 2 areas in the vicinity of Stonewall Bank, Oregon (Figure 1). Fish were captured using rod and reel and terminal tackle commonly used in the recreational rockfish fishery. Anglers fished just above the bottom, however, the capture of fish that were suspended above the bottom may have occurred, as is the case for the recreational fishery. Both species were captured in each sampling trip, however, the majority of the yelloweye rockfish were sampled in September-October 2012, while most of the canary rockfish were sampled in September-October 2013. Sampling effort was distributed across a depth range of 46-175 m. For depths of capture between 46 and 84 m (Figure 1, sampling area 1), a sampling goal of 15 canary and 15 yelloweye rockfish from each of four 9-10 m depth zones was chosen. To sample greater depths, we utilized a single depth zone of 135-175 m and a sampling goal of just 10 fish of each species (Figure 1, sampling area 2). The reduced sampling goals in the deeper sampling area were chosen to offset the longer travel time to this area and the increased handling time needed to retrieve both hooked fish and cages from this depth range. Our choice of depth ranges was also constrained by the availability of rocky reef habitat within the study area at various depths.

After capture, each fish was scored for a standardized set of external signs of barotrauma (Table 1) using a subset of the indicators from Hannah et al. (2008b) and Pribyl et al. (2009). The subset of barotrauma signs we chose are indicative of extreme expansion *and retention* of swimbladder gas, and will be referred to simply as signs of “pronounced barotrauma”. It should be noted however that because rockfish sometimes lose expanding gas through ruptures in the pharyngo-cleithral membrane, the range of the external signs is not always a reliable indicator of the severity of internal trauma (Hannah et al 2008a, Pribyl et al. 2009). After scoring for barotrauma, each fish was then placed in a wet tray for measurement of fork length (cm). The fish was then photographed and placed in a sea cage that was partially filled with seawater and the cage lid was sealed and secured with a large cable-tie. The cage was then deployed as soon as the vessel could navigate to a nearby point of similar depth, over suitable bottom for successful cage retrieval. As in Hannah et al. (2012), the surface interval of fish was minimized and calculated from the time the fish was brought on board to deployment of the cage overboard. 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 and salinity were also recorded at cage deployment and retrieval for each depth category in which sampling was conducted.

The sea cages we used for holding rockfish have been described in detail in Hannah et al. (2012) and were designed specifically to minimize adverse cage-effects on fish. The cages incorporated non-abrasive surfaces for all parts that might contact the fish and sufficiently heavy steel bases to be self-righting and to resist current-induced movement. They were also isolated from the forces generated by the mooring line to the surface by a double anchoring system and incorporated screening designed to exclude carnivorous amphipods while maintaining adequate water exchange. We made only two alterations to the cage design described by Hannah et al. (2012) to adapt it to the much deeper depths sampled in this study. We changed the gasket material used to seal the cage lid to a non-compressible material to prevent seal failure at these greater depths and we increased the length of the mooring lines used.

Our study utilized a nominal caging duration of 48 h, but allowed durations ranging from 44-96 h in consideration of inclement weather or sea conditions and vessel availability. Following retrieval of each cage, fish were evaluated for survival while still in seawater in the cage. They were then removed from the cage, the physical signs of barotrauma were again noted, another photo was taken and the fish was released at the surface. The ability of each fish to submerge following release was recorded, and any surviving fish that could not submerge were assisted back to depth with a sub-surface release device (Theberge and Parker 2005).

2.2 Data analysis

We estimated post-recompression survival by species and depth zone using LaPlace point estimates to compensate for small sample sizes, as suggested by Lewis and Sauro (2006) and Jarvis and Lowe (2008). We calculated 95% binomial confidence intervals for survival using the adjusted Wald method (Sauro and Lewis 2005).

To provide a more complete picture of the effect of capture depth on barotrauma and post-recompression survival for these two species, we combined the data from this study with data from shallower depths of capture collected with very similar methods as reported by Hannah et al. (2012). We used logistic regression (JMP software ver. 6.02) to evaluate the effect of depth of capture and the surface-bottom temperature differential on post-recompression survival for both data sets. The surface-bottom temperature differential has been related to mortality in hook-and-line captured red snapper (*Lutjanus campechanus*, Diamond and Campbell 2009), and may be important for black rockfish (*Sebastes melanops*, Hannah et al. 2012). We also included it in this study because at the deeper depths we sampled, the temperature differential was likely to be greater than in previous studies conducted at shallower depths (Hannah et al. 2012). For both data sets, we graphically evaluated the relationship between specific signs of pronounced barotrauma and depth of capture. We also evaluated the association between these barotrauma signs and post-recompression survival for the combined data sets using Fisher's exact test (Sokal and Rolf 1981).

3. Results

We completed 11 deployments of 7-16 sea cages each between September, 2012 and October, 2013. In all, 135 canary and yelloweye rockfish from 5 depth intervals up to 174 m were evaluated for signs of pronounced barotrauma (Table 1) and caged to evaluate post-recompression survival (Table 2). This total included 81 yelloweye and 54 canary rockfish. The length range of canary and yelloweye rockfish sampled was 26-52 cm and 30-59 cm, respectively (Table 2). Time-at-the-surface averaged (± 1 standard error) 2.8 (± 0.2) min for all 135 fish, with only 2 specimens having a surface interval longer than 5 min, both of which survived. Post-recompression survival of yelloweye rockfish was very high across all depths of capture, with 77 of 81 fish surviving (95.1%, Table 2). Survival of canary rockfish was much lower, with 42 of the 54 canary rockfish sampled surviving (77.8%, Table 2).

The LaPlace point estimates of survival show a marked divergence between canary and yelloweye rockfish in 48-h survival as a function of depth of capture (Figure 2). At capture depths greater than 135 m, the survival of canary rockfish declined to only about 25%, while the survival of yelloweye rockfish remained well above 80% (Figure 2). Inspection of the fish captured at depths greater than 135 m showed that for canary rockfish, a large amount of blood pooling under the pharyngo-cleithral membrane was frequently observed. For both species, dissections of the specimens that died frequently showed evidence of pronounced bleeding within the abdominal cavity and/or within the pericardial cavity. Two non-surviving yelloweye rockfish also showed visible evidence of embolisms or ruptures in the heart muscle.

At all capture depths sampled, esophageal eversion was very frequently observed in both canary and yelloweye rockfish at initial capture, being noted in 70% or more of the specimens (Figure 3, panel A and B). Across all capture depths, exophthalmia was noted in 50% or more of the canary rockfish and 40% or more of the yelloweye rockfish (Figure 3, panel A and B). Ocular emphysema was less frequently encountered in both species (Figure 3, panel A and B). However it increased in frequency as capture depth increased, reaching levels of 70% in canary rockfish and 40% in yelloweye rockfish at capture depths greater than 135 m (Figure 3, panel A and B). A comparison of barotrauma signs from this study with those noted by Hannah et al. (2012, Figure 3, panel C and D) shows that for both species, exophthalmia and ocular emphysema were generally more frequent at the greater depths sampled in this study (Figure 3, panel A and B). Also notable in this comparison is the variability that can be observed in barotrauma signs as a function of depth of capture (Figure 3). For example, at capture depths of 46-54 m, exophthalmia in both species was much more frequent in this study than observed in 2009-10 sampling (Hannah et al. 2012).

Most fish that were alive after 48 h of caging were judged to be in good condition. Signs of pronounced barotrauma were mostly absent, especially in yelloweye rockfish and almost all of the fish were able to submerge without assistance when released at the sea surface. Of 42 canary and 77 yelloweye rockfish released, 41 and 76, respectively, were capable of submerging.

Logistic regression of 48-h post-recompression survival on depth of capture and the surface-bottom temperature differential, for the data collected in this study, showed no relationship between survival in yelloweye rockfish and either variable ($P>0.05$). For canary rockfish sampled in this study, post-recompression survival was significantly negatively related to capture depth ($P<0.05$), but not to the surface-bottom temperature differential ($P>0.05$).

Logistic regression analysis of the combined data from this study and data from Hannah et al. (2012) showed that post-recompression survival was not significantly related to the surface-bottom temperature differential in either canary or yelloweye rockfish ($P>0.05$), even though the differential was much higher, as expected, at the deeper depths of capture (Figure 4). In the combined data set, 48-h post-recompression survival was negatively related to capture depth for canary rockfish, ($P<0.0001$), but not for yelloweye rockfish ($P>0.05$, Table 3). A comparison of the two fitted curves for the combined data sets (Figure 5) and the frequency of barotrauma signs (Figure 3) shows that increasing capture depth created pronounced barotrauma in both species, however, the negative effect on survival was much stronger for canary rockfish. This was supported by the results of the Fisher's exact tests. The presence of exophthalmia and ocular emphysema was each negatively associated with survival in canary rockfish ($P<0.05$), while none of the physical signs of barotrauma were negatively associated with survival in yelloweye rockfish ($P>0.05$).

4. Discussion

The divergence of 48-h post-recompression survival of canary and yelloweye rockfish as depth of capture increased beyond 135 m shows how difficult it can be to evaluate the survival potential of rockfish with barotrauma based on their appearance at the surface. Most specimens of both species captured at these depths showed some signs of pronounced barotrauma, yet nearly all of the yelloweye rockfish survived following recompression while many of the canary rockfish perished as capture depth increased beyond about 75 m. Studies of post-recompression release behavior also support the notion that surface observations are not indicative of survival, at least for rockfish that tend to retain most of their expanded swimbladder gas (Hannah and Matteson 2007, Hannah et al. 2008a). The retained gas can make it very difficult or impossible for rockfish to submerge (Hannah et al. 2008b, Hochhalter 2012) and also interferes with the evaluation of reflex behaviors, which have been shown to be useful predictors of survival in other captured and discarded fishes (Davis 2007, Davis and Ottmar 2006).

Our data for canary rockfish suggest that there may be a critical capture depth for some rockfish species at which post-recompression survival decreases rapidly. Between the capture depth intervals of 75-84 m and 135-174 m, post-recompression survival of canary rockfish plummeted from about 80% to just 25% (Figure 2). Our observations of pooled blood under the pharyngo-clethral membrane of captured canary rockfish and in the abdomen of canary rockfish that failed to survive suggests that critical internal physical injuries can be caused by barotrauma at these capture depths. Across these same 2 depth intervals, the typical external signs of pronounced barotrauma in canary rockfish increased just moderately in frequency (Figure 3, panel A and B). The high 48-h post-recompression survival of yelloweye rockfish captured at depths greater than 135 m, also experiencing the effects of pronounced barotrauma, was unexpected and is surprising. It's possible that a similar critical capture depth exists for yelloweye rockfish, but simply at a greater depth of capture than sampled in this study.

It should be noted that our study results represent just an initial estimate of how capture depth and related barotrauma influence post-recompression survival of these two species. With the modest sample sizes in our study, it was not possible to evaluate the many factors that often affect survival, such as fish size or age, time spent above the bottom for schooling species, season or variable environmental conditions, handling, surface interval, predation and longterm health effects from barotrauma (Davis 2002). Some of these factors simply require additional studies, but others are very difficult to study in the field. For example, the ontogenetic migration of Pacific rockfish (Love et al. 2002) makes it difficult to separate the effects of fish size and capture-depth on barotrauma and post-recompression survival, as they are inherently somewhat confounded from a sampling standpoint.

The absence of most of the physical signs of pronounced barotrauma noted in the rockfish that survived 48 h of sea caging is consistent with prior sea-caging studies with a wide variety of rockfish species (Jarvis and Lowe 2008, Hannah et al. 2012). It is also consistent with the physical model of how barotrauma signs are thought to develop in rockfish (Hannah et al 2008a). Esophageal eversion, exophthalmia and ocular emphysema result from the expansion and "patterned" anterior travel of gas that escapes from the compromised swimbladder of a rockfish during ascent and decompression. The gas that has escaped into a variety of tissues then contracts during recompression and can be removed quickly via absorption into the blood and normal respiration. Since the swimbladders of rockfish typically cannot heal and re-inflate appreciably within 48 h (Parker et al. 2006), the second decompression event does not produce the typical physical signs associated with swimbladder gas expansion and travel.

The estimates developed in this study can be very useful for informing the management of hook-and-line fisheries that encounter these two overfished species, especially in combination with data on submergence success as a function of capture depth, like that provided by Hochhalter (2012) for yelloweye rockfish. For example, a primary recommendation from prior studies of post-recompression survival and submergence success for these two species was that hook-and-line fishers should use a variety of "descending" devices to help released fish overcome surface buoyancy (Theberge and Parker 2005, Hochhalter and Reed 2011, Hannah et al. 2012, Hochhalter 2012). The data from this study suggest that descending devices may have a positive effect on survival of yelloweye rockfish across a wide depth range (Figure 6, lower panel). However, for canary rockfish captured at depths greater than 135 m, survival may be so low that it might be better to either allow retention of these fish or to simply not allow a fishery to operate at these deeper depths (Figure 6, upper panel).

Although short-term post-recompression survival is now better understood for a variety of Pacific rockfish species (Jarvis and Lowe 2008, Hochhalter and Reed 2011, Hannah et al. 2012), longer term studies of the health of rockfish that have experienced pronounced barotrauma are still badly needed, as well as studies evaluating the cumulative effects of multiple capture events on these long-lived fishes. Critical as well, is understanding the behavioral and sensory compromise that may be evident in fish immediately post-recompression, in the absence of a protective cage. Fish suffering from extensive gas embolisms at the surface may be physically and physiologically compromised for some unknown period of time. It's reasonable to expect that after recompression some time would be needed for recovery, leaving fish vulnerable to predation or unable to quickly seek refuge in a school or within specific habitat. Until such studies can be completed, the effectiveness of population rebuilding strategies for Pacific rockfish that rely heavily on non-retention in hook-and-line fisheries remains uncertain.

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Figure captions

Figure 1. Location of the study areas at Stonewall Bank, Oregon.

Figure 2. LaPlace point estimates of the proportion of canary and yelloweye rockfish surviving after 48 h of sea caging, by depth of capture (m), with 95% confidence intervals.

Figure 3. Percentage of canary and yelloweye rockfish displaying 3 different signs of pronounced barotrauma at initial capture, as a function of depth of capture (m), September 2012 through October 2013 (panel A and B) and from the 2009-10 study by Hannah et al. (2012, panel C and D). Sample size in parentheses.

Figure 4. Mean difference in temperature (ºC, ± 1 standard error) between the sea surface and seafloor, by capture-depth interval (m) from all canary and yelloweye rockfish cage deployments from this study (2012-13) and from Hannah et al. (2012, 2009-2010).

Figure 5. Fitted logistic curve of the proportion of yelloweye and canary rockfish surviving 48 h after hook-and-line capture and recompression, as a function of capture depth (m).

Figure 6. Fitted logistic curves comparing the proportion of canary and yelloweye rockfish submerging following surface release and surviving 48 h after hook-and-line capture and recompression, as a function of capture depth (m). Modeled submergence

data for canary and yelloweye rockfish are from Hannah et al. (2008b) and Hochhalter (2012), respectively.

Table 1. Indicators used to identify the physical signs of pronounced barotrauma in canary and yelloweye rockfish.

Symptom	Indicators
Esophageal eversion	Eversion of esophageal tissue at least 1 cm into the buccal cavity.
Exophthalmia (popeye)	Eye protruding outward from orbit
Ocular emphysema (gas in the eye)	Gas present within the eye or connective tissue surrounding the eye

Table 2. Summary of canary and yelloweye rockfish captured by hook-and-line in waters off Newport, Oregon and held in individual cages to estimate 48 h post-recompression survival, by species and capture depth interval (m). Mean fork length (standard error) by species and depth interval is also shown. The number of mortalities is shown in parentheses.

			Depth of capture					
Common name	Scientific name	Statistic	46-54 m	55-64 m	65-74 m	75-84 m	135-174 m	Total
Canary rockfish	*Sebastes pinniger*	Number	5(0)	13(0)	11(1)	15(3)	10(8)	54(12)
		Mean length	35.0±1.8	32.4±0.9	35.6±0.7	36.2 ±0.9	48.3 ±1.0	
Yelloweye rockfish	*Sebastes ruberrimus*	Number	11(0)	20(1)	20(1)	20(1)	10(1)	81(4)
		Mean length	38.5±1.2	39.9±2.1	43.8±1.4	44.8±1.7	55.4±1.7	
Total			16(0)	33(1)	31(2)	35(4)	20(9)	135(16)

Table 3. Results of logistic regression analysis of the proportion of rockfish surviving after 48 h versus depth (m) of capture for canary and yelloweye rockfish. Curves were fitted using the canary and yelloweye rockfish data from this study in combination with the data from shallower depths of capture reported in Hannah et al. (2012).

Species	Independent variable	Coefficients	Standard error	P - value	Whole model Chi-square	R squared
Canary rockfish	constant	6.3499	1.1442	<0.0001	34.9821	0.4854
	depth of capture	-0.0531	0.0116	<0.0001		
Yelloweye rockfish	constant	4.4034	1.1583	0.0001	1.3616	0.0400
	depth of capture	0.0150	0.0118	0.2043		

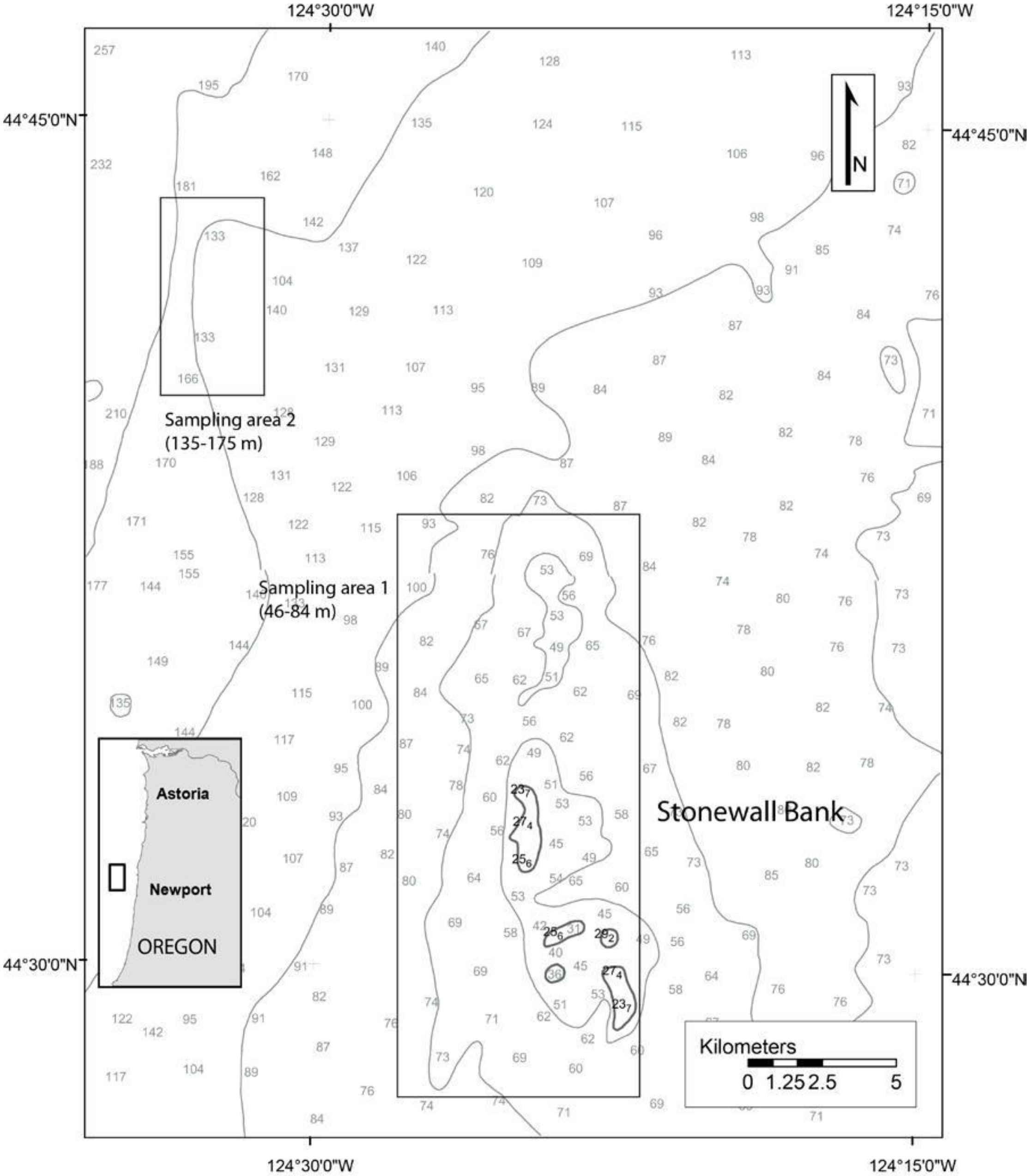
124°30'0"W
124°15'0"W
44°45'0"N
44°30'0"N
N
Sampling area 2
(135-175 m)
Sampling area 1
(46-84 m)
Stonewall Bank
Astoria
Newport
OREGON
Kilometers
0 1.25 2.5 5

Figure 1

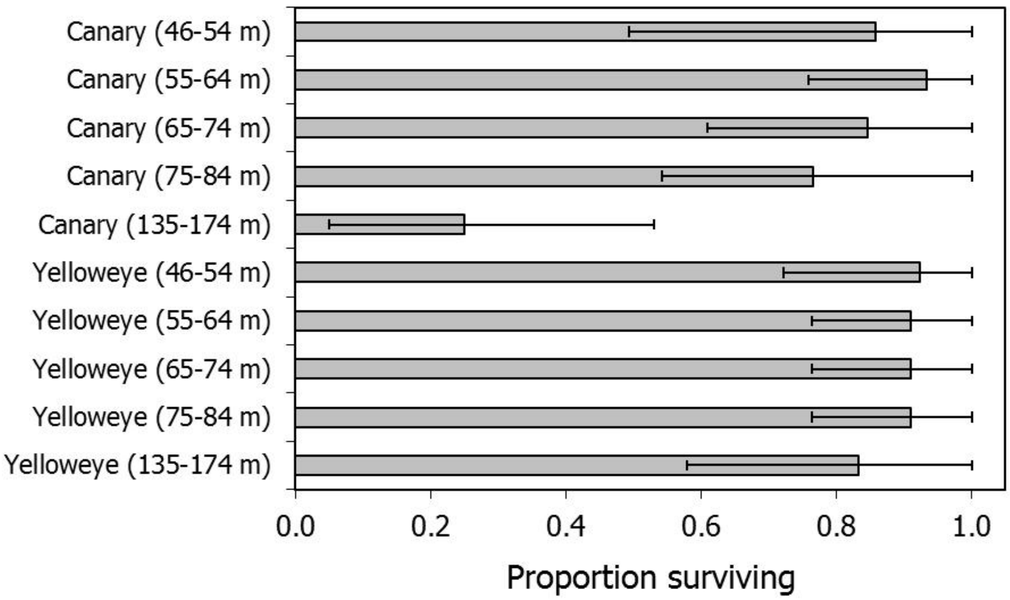
Canary (46-54 m)
Canary (55-64 m)
Canary (65-74 m)
Canary (75-84 m)
Canary (135-174 m)
Yelloweye (46-54 m)
Yelloweye (55-64 m)
Yelloweye (65-74 m)
Yelloweye (75-84 m)
Yelloweye (135-174 m)
0.0
0.2
0.4
0.6
0.8
1.0
Proportion surviving

Figure 2

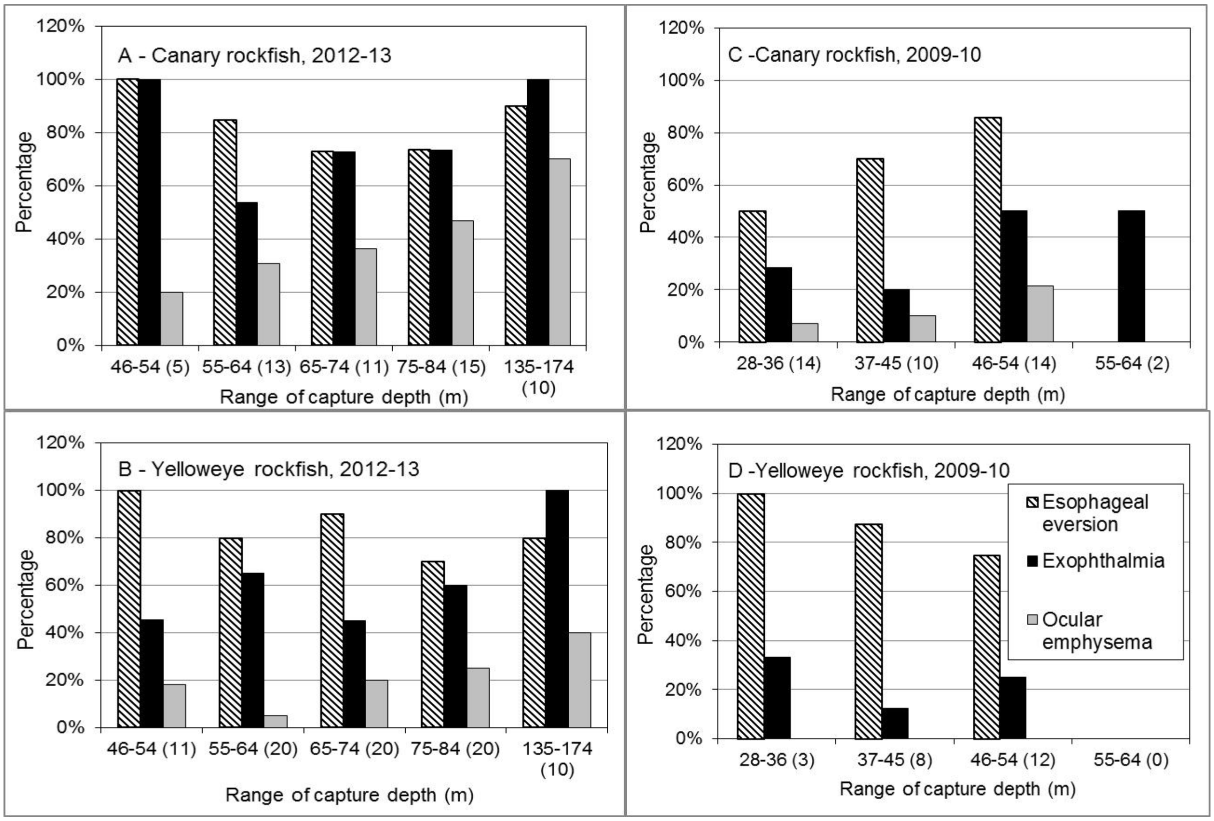
A - Canary rockfish, 2012-13
120%
100%
80%
60%
40%
20%
0%
Percentage
46-54 (5)
55-64 (13)
65-74 (11)
75-84 (15)
135-174 (10)
Range of capture depth (m)
C -Canary rockfish, 2009-10
120%
100%
80%
60%
40%
20%
0%
Percentage
28-36 (14)
37-45 (10)
46-54 (14)
55-64 (2)
Range of capture depth (m)
B - Yelloweye rockfish, 2012-13
120%
100%
80%
60%
40%
20%
0%
Percentage
46-54 (11)
55-64 (20)
65-74 (20)
75-84 (20)
135-174 (10)
Range of capture depth (m)
D -Yelloweye rockfish, 2009-10
120%
100%
80%
60%
40%
20%
0%
Percentage
▨ Esophageal eversion
■ Exophthalmia
□ Ocular emphysema
28-36 (3)
37-45 (8)
46-54 (12)
55-64 (0)
Range of capture depth (m)

Figure 3

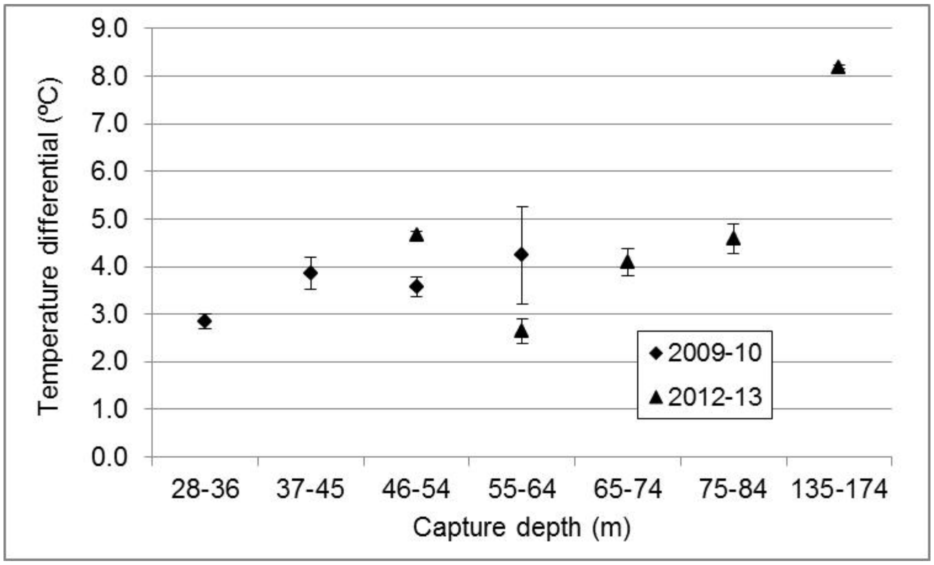
Temperature differential (ºC)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
28-36
37-45
46-54
55-64
65-74
75-84
135-174
Capture depth (m)
◆ 2009-10
▲ 2012-13

Figure 4.

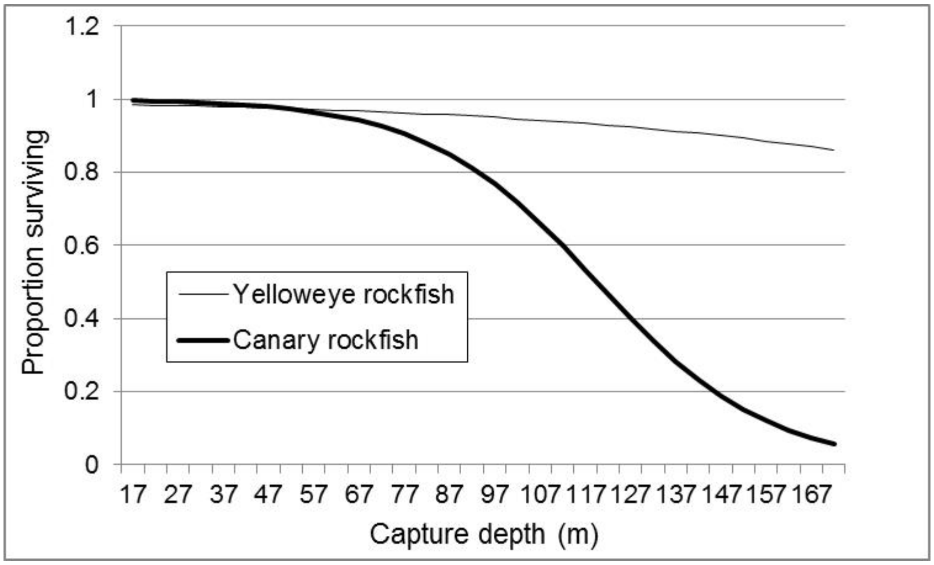
1.2
1
0.8
0.6
0.4
0.2
0
Proportion surviving
Yelloweye rockfish
Canary rockfish
17
27
37
47
57
67
77
87
97
107
117
127
137
147
157
167
Capture depth (m)

Figure 5

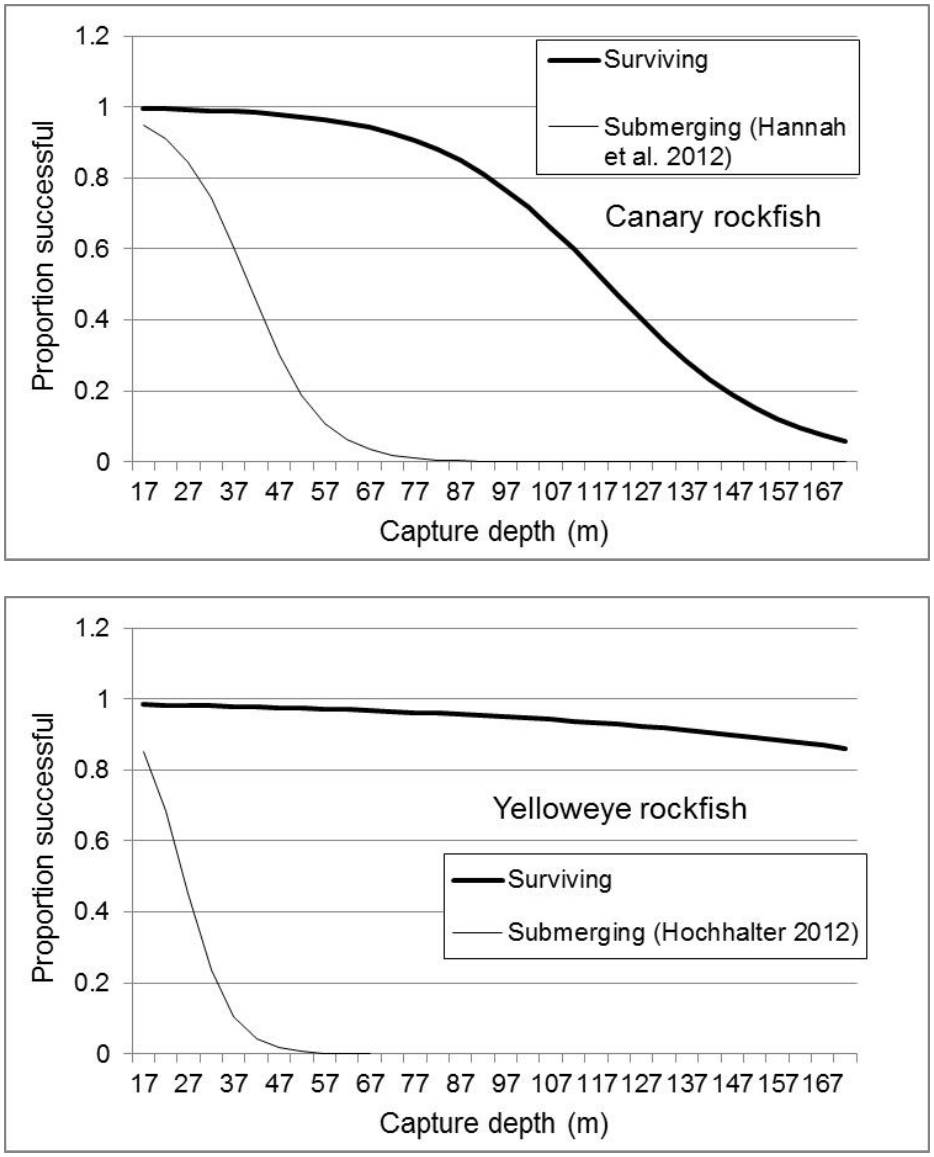
1.2
1
0.8
0.6
0.4
0.2
0
Proportion successful
17 27 37 47 57 67 77 87 97 107 117 127 137 147 157 167
Capture depth (m)
Surviving
Submerging (Hannah et al. 2012)
Canary rockfish
1.2
1
0.8
0.6
0.4
0.2
0
Proportion successful
17 27 37 47 57 67 77 87 97 107 117 127 137 147 157 167
Capture depth (m)
Yelloweye rockfish
Surviving
Submerging (Hochhalter 2012)

Figure 6