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ARTICLE

The Effectiveness of Deepwater Release at Improving the Survival of Discarded Yelloweye Rockfish

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Abstract
The effectiveness of deepwater release at improving the 17-d survival of discarded yelloweye rockfish *Sebastes ruberrimus* was determined by comparing an estimate of survival for individuals released at depth with an estimate of submergence probability for individuals released at the water's surface. A mark–recapture study was used to generate a maximum likelihood estimate of the 17-d survival probability of yelloweye rockfish (n = 182) caught by hook and line (depth = 18–72 m) and subsequently released at depth. The average Cormack–Jolly–Seber survival probability for yelloweye rockfish released at depth was remarkably high (0.988; 95% confidence interval = 0.478–0.999) and positively correlated with individual total length. Survival probability was not significantly influenced by the range of capture depths explored in this study or by exposure to barotrauma and other capture stressors. The submergence success of yelloweye rockfish released at the water's surface was 0.221 (95% confidence interval = 0.149–0.315), suggesting that the maximum survival potential of individuals released at the surface is low. The results of this study indicate that the average survival of discarded yelloweye rockfish can be substantially improved by deepwater release.

Worldwide, approximately one-quarter of all fish caught are discarded (Alverson et al. 1994; Harrington et al. 2005), with nearly 60% of the fish caught in recreational fisheries being released (Cooke and Cowx 2004; Bartholomew and Bohnsack 2005). Recreational fisheries are typically open access with no restriction on the number of participants. As such, regulatory measures to reduce directed harvest commonly include seasons and size, bag, and annual limits. Fish are discarded because anglers often catch more fish than they can legally retain, catch fish that are smaller or larger than they are allowed to retain, or catch fish that are not of the targeted or desired species. The potential impact of discarding on fisheries sustainability is well recognized (Alverson et al. 1994; McPhee et al. 2002; Coggins et al. 2007), although direct quantification of the impact of recreational discarding is sorely lacking (Harrington et al. 2005). The magnitude and severity of discarding has prompted a movement among fisheries scientists to develop improved methods to quantify, predict, and increase the survival of discarded fish (Davis 2002; Davis and Ottmar 2006; Pollock and Pine 2007).

The inability of deep-dwelling physoclistic species to regulate swim bladder pressure during forced decompression associated with capture frequently results in a series of external and internal injuries (Rummer and Bennett 2005; Pribyl et al. 2009), behavioral impairment (Hannah and Matteson 2007), and positive buoyancy (Hannah et al. 2008a). These signs, collectively referred to as barotrauma, can decrease the survivability of discarded fish (Diamond and Campbell 2009) and thus the effectiveness of regulatory restrictions on directed harvest (Coggins et al. 2007).

Serial depletion of several Pacific rockfish *Sebastes* spp. stocks in the coastal waters of the USA has led to implementation of no-retention regulations for overfished species such as yelloweye rockfish *S. ruberrimus* (PFMC and NMFS 2009). In addition to no-retention regulations, in 2010 the population

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segments of yelloweye and canary rockfish *S. pinniger* in Puget Sound–Georgia Basin (Washington State and British Columbia) were listed as threatened under the U.S. Endangered Species Act (NMFS 2010) and that of bocaccio *S. paucispinis* as endangered.

Rockfish are often found in mixed species assemblages (Love et al. 2002) and are both targeted by recreational anglers and incidentally caught in recreational fisheries targeting other species (e.g., Pacific halibut *Hippoglossus stenolepis* and lingcod *Ophiodon elongatus*). When rockfish are released at the water's surface, the positive buoyancy associated with barotrauma often prevents their successful submergence back to depth (Hannah et al. 2008). Release methods that maximize the survival of discarded fish are needed to ensure the long-term sustainability of the recreational fisheries in the Northeast Pacific. Additionally, effective release methods may help rebuild depleted stocks and minimize the incidental take of threatened and endangered species of rockfish in recreational fisheries.

Several methods that attempt to ameliorate the effects of barotrauma on discarded fish are available to anglers (e.g., venting and deepwater release mechanisms; see Theberge and Parker 2005), although the effectiveness of these methods at improving discard survival is equivocal (Wilde 2009; Brown et al. 2010; Sumpton et al. 2010). For example, in a meta-analysis encompassing numerous species of fish and a broad geographical area, Wilde (2009) concluded that venting failed to improve the discard survival of fish exposed to barotrauma. Conversely, the short-term survival of several species of rockfish returned to depth quickly after capture was estimated to be as high as 83% in a controlled field experiment (Jarvis and Lowe 2008) and 96.7% in a laboratory study (Parker et al. 2006). While the results from these experiments are encouraging, we hypothesized that these estimates represent the upper bound of survival because they do not account for delayed mortality (Davis 2002). Survival estimates derived from controlled field and laboratory experiments fail to account for the behavioral impairment of discarded fish, which may reduce the ability of individuals to escape predators (Ryer et al. 2004) and compete for resources such as food and favorable habitat. Given the limitations of existing estimates of survival for rockfish released at depth, we desired estimates of survival that (1) allowed released fish to be at liberty in a wild setting, (2) encompassed a time frame long enough to incorporate delayed mortality (i.e., mortality that occurs beyond 2 d), and (3) included the effects of behavioral impairment and predation. Therefore, the overall goal of this study was to quantitatively evaluate the effectiveness of deepwater release at improving the survival (>2 weeks) of discarded yelloweye rockfish in the wild. To meet this goal, we estimated the 17-d survival of yelloweye rockfish released at depth and the submergence probability of yelloweye rockfish released at the water's surface.

METHODS

Survival of yelloweye rockfish released at depth.—A mark–recapture study was used to collect individual encounter histories of yelloweye rockfish released at depth. A total of six sampling sessions were conducted beginning in mid-May 2009. Each session consisted of 7 consecutive days of sampling followed by a 10-d hiatus. Survival was estimated for the 17-d time intervals separating the midpoints of the consecutive sample sessions. Two to three anglers used hook-and-line methods to capture yelloweye rockfish on an isolated 1.7-km^2 reef in eastern Prince William Sound, Alaska. We attempted to represent the full range of fishing conditions in the recreational fisheries of the Gulf of Alaska by sampling across the entire summer fishing season using a wide variety of terminal tackle. Terminal tackle included numerous J-hook sizes and bait and artificial lure configurations. To meet the assumption of equal probability of capture across sampling events, we attempted to sample the reef in its entirety each day by conducting systematic drifts across the reef. Each drift was tracked with an onboard georeferenced navigation system to ensure adequate distribution of sampling. Because rockfish often exhibit clustered distributions (Love et al. 2002), drifts that produced a catch of one or more rockfish were repeated until no rockfish were captured. Replication of successful drifts maximized daily sample sizes.

The times of hook-up, reaching the surface, beginning of descent, and release were recorded for each captured rockfish. These times allowed the calculation of total fight time, total time at the surface, and total time to release. Once at the surface, each fish was measured for total length (TL; mm), assessed for external signs of barotrauma, and examined for hook location. Captured fish were given a passive integrated transponder (PIT) tag as a primary mark and an individually numbered T-bar tag as a secondary mark. Passive integrated transponder tags were inserted according to the methods of Parker and Rankin (2003), and T-bar tags were inserted in the dorsal musculature adjacent to the midlength of the dorsal fin. Four external barotrauma signs were recorded for each individual; everted esophageal tissue (EV), exophthalmia (EX), corneal emphysema (CE), and distended abdomen (DA). A categorical classification was used for each symptom whereby it was assigned the value 0 if absent and 1 if present. The presence or absence of external barotrauma signs was assigned using the criterion outlined by Hannah et al. (2008a).

We used a 680-g lead-head jig with the barb filed off as a deepwater release mechanism (DRM). The line from a rod and reel was attached to the bend in the hook shank and the hook of the DRM was placed through the soft tissue of the lower jaw lateral to the tongue and medial to the mandible. With the bail of the reel open, the DRM and fish were dropped into the water, allowing the DRM and the attached fish to descend to depth. Once the DRM and attached fish reached the ocean bottom the bail was closed and a swift upward tug removed the DRM from the fish.

Individual encounter histories of tagged yelloweye rockfish and Cormack–Jolly–Seber models were used to generate maximum likelihood estimates of survival in program MARK (White and Burnham 1999). Briefly, Cormack–Jolly–Seber models estimate apparent survival and capture probability. The apparent survival of an individual is defined as the probability of surviving and not permanently emigrating from the study site (hereafter referred to as survival or Φ). Capture probability is typically a parameter of little practical interest, but it is necessary to estimate survival within the Cormack–Jolly–Seber framework (Williams et al. 2002). The variability within the estimates of a parameter can potentially be explained (i.e., modeled) by individual covariates (Williams et al. 2002). Candidate Cormack–Jolly–Seber models were assembled to examine the effects of capture depth, individual length, and exposure to barotrauma on the survival and capture probabilities of yelloweye rockfish released at depth. Depth at initial capture was included as a covariate in several candidate models because the frequency of barotrauma signs typically increases with increased capture depth (Rummer and Bennett 2005; Hannah et al. 2008a; Jarvis and Lowe 2008). We included total length as a covariate in several candidate models to test for size-selective survival and capture probabilities. To investigate the effect of barotrauma and other capture stressors on survival and capture probabilities, the encounter history of each individual was used as a covariate. This allowed models to differentiate the survival and capture probability of individuals captured on a particular sampling occasion from those of individuals not captured on that occasion. Additionally, we allowed survival and capture probability to vary with time in some models to account for potential temporal effects. We corrected for overdispersion in our model selection procedure by applying a variance inflation factor (median $\hat{c}$) calculated from the fully parameterized model (see Burnham and Anderson 2002). Quasi-likelihood modifications of Akaike information criterion corrected for small sample size ($QAIC_c$) were used to evaluate the fit of candidate models (Burnham and Anderson 2001).

We used a stepwise approach to modeling whereby we first identified the most parsimonious models for capture probability by comparing models that allowed the capture probability structure to vary but had a constant survival structure (i.e., Φ[.]). In the second step, we used the most parsimonious capture probability model identified in the first step and allowed survival structure to vary (Budy et al. 2007). Finally, we ran the top survival models identified in the second step ($\Delta QAIC_c$ values < 4.0) with each capture probability model that had a $\Delta QAIC_c$ value less than 4.0 identified from step 1. A structured approach to modeling, such as the one used here, allows for a relatively objective exploration of candidate models while minimizing the potential for overfitting the data (see Burnham and Anderson 2002).

The effects of individual covariates on survival and capture probabilities were examined by comparing differences in the $QAIC_c$ values of models with and without a given covariate. Additionally, covariate effects were evaluated by assessing the values and precision of the associated beta estimates. Covariates were considered important (i.e., improved model fit) when models without the covariate had $\Delta QAIC_c$ values greater than 2.0 and the 95% confidence interval (CI) of the beta estimate did not encompass zero. To account for uncertainty in model selection, we used model-weighted averaging to derive final parameter estimates of survival and capture probabilities (Burnham and Anderson 2001).

To further explore the effects of capture depth and individual length on the discard survival of yelloweye rockfish, we compared the distribution of initial capture depths and individual lengths for individuals that were only captured once (i.e., fate unknown) with those of individuals that were later recaptured (i.e., fate known). These groups are hereafter referred to as single captures and recaptures, respectively. Differences in the distribution of capture depth and length-frequencies between single captures and recaptures were tested with two-sample Kolmogorov–Smirnov tests (Conover 1980). Differences in the frequency of the four external signs of barotrauma at the time of initial capture between single captures and recaptures were tested with Fisher's exact tests. All tests were performed with R statistical software version 2.0.1 (R Development Core Team 2004).

Submergence success of yelloweye rockfish released at the surface.—Our second objective was to estimate the submergence success of yelloweye rockfish released at the water's surface. This estimate represents a conceptual upper bound on the survival of yelloweye rockfish released at the surface. The ability of rockfish to submerge to depth is considered to be the most critical step to surviving discarding and has been cited as an appropriate surrogate for survival after release at the surface (Hannah et al. 2008a).

To estimate submergence success, we sampled reefs near the mark–recapture reef with hook-and-line gear. Submergence success trials were conducted across six sampling events in 2010. The timing of these events was the same as that for the 2009 mark–recapture study, and we targeted similar depths. Captured yelloweye rockfish were measured for TL and assessed for the four external signs of barotrauma. Fish were then released at the surface and observed for up to 30 min. A 30-min observation time was considered to be more than adequate because previous studies have shown that 93% of the rockfish that successfully submerge do so within the first 60 s after release (Hannah et al. 2008a). Submergence success trials were conducted during slack tides under calm weather and sea surface conditions to minimize the distance that released rockfish drifted from the boat. Binoculars were used to assist with observation when necessary.

Differences in the depth and length-frequency distributions between individuals captured in the mark–release study and individuals captured in the submergence success study were tested with two sample Kolmogorov–Smirnov tests.

RESULTS

Survival of Yelloweye Rockfish Released at Depth

A total of 182 individual yelloweye rockfish were captured and tagged on the six sampling occasions. Of the 45 recaptures (Table 1), 29 were recaptured one time and 8 were recaptured two times. Thirty-eight of the 45 (84%) recaptures occurred

TABLE 1. Total number of yelloweye rockfish captured initially, total number of recaptures, and proportion of recaptures on six sampling occasions in a mark–recapture study conducted May–August 2009 in Prince William Sound.

Sampling occasion	Number captured	Number recaptured	Proportion recaptured
1	25	0	0.00
2	34	0	0.00
3	55	4	0.07
4	34	8	0.24
5	47	18	0.38
6	32	15	0.47

on at least two sampling occasions after the previous capture. Retention of both the PIT and T-bar tags was high; only one PIT tag was shed and no T-bar tags. Total fight time, time at the surface, and release time averaged less than 2 min each. Only 8% of the captured yelloweye rockfish were at the surface for more than 2 min (maximum of 5 min). Based on the results of Jarvis and Lowe (2008), we assumed that the variability in survival resulting from differences in time at the surface was negligible. Depths of capture ranged from 21 to 72 m (Figure 1), and individual lengths ranged from 250 to 675 mm (Figure 2).

One or more external signs of barotrauma were present in 168 of the 182 (91%) individuals captured in the mark–release study. Of the four signs investigated, DA was the most frequently observed symptom, followed by EV, EX, and CE. The frequencies of EV, EX, and CE were higher for single captures than for recaptures, although with the exception of EX, none of the differences were significant (Figure 3). The difference in the occurrence of EX between recaptures (2%) and single captures (13%) was marginally significant ($P = 0.049$). The distributions of the depths of initial capture for single captures and recaptures were not significantly different ($D = 0.246$, $P = 0.057$), although we did not recapture fish in the shallowest or the deepest depth intervals sampled (Figure 1). The length-frequencies of single captures and recaptures were significantly different ($D = 0.284$, $P = 0.017$), with fewer fish being recaptured from the smallest length-classes sampled (Figure 2).

The stepwise approach to modeling identified four capture probability models in the first step and four survival models in the second step (Table 2). A total of 16 candidate models were considered after the final step in the stepwise approach; 8 of these models were supported by the data ($\Delta QAIC_c < 4.0$; Table 2). Overdispersion of our data was minor ($\hat{c} = 1.359$, SE = 0.078).

Of the four covariates that were included in the survival structure of the most parsimonious models, only length had a meaningful influence on the probability of survival of yelloweye rockfish released at depth. For example, the model that provided the best fit and did not include length as a covariate had a $\Delta QAIC_c$ value of 2.6 (Table 2). Likewise, of the three models in our candidate list that had $\Delta QAIC_c$ values less than 2.0, all included

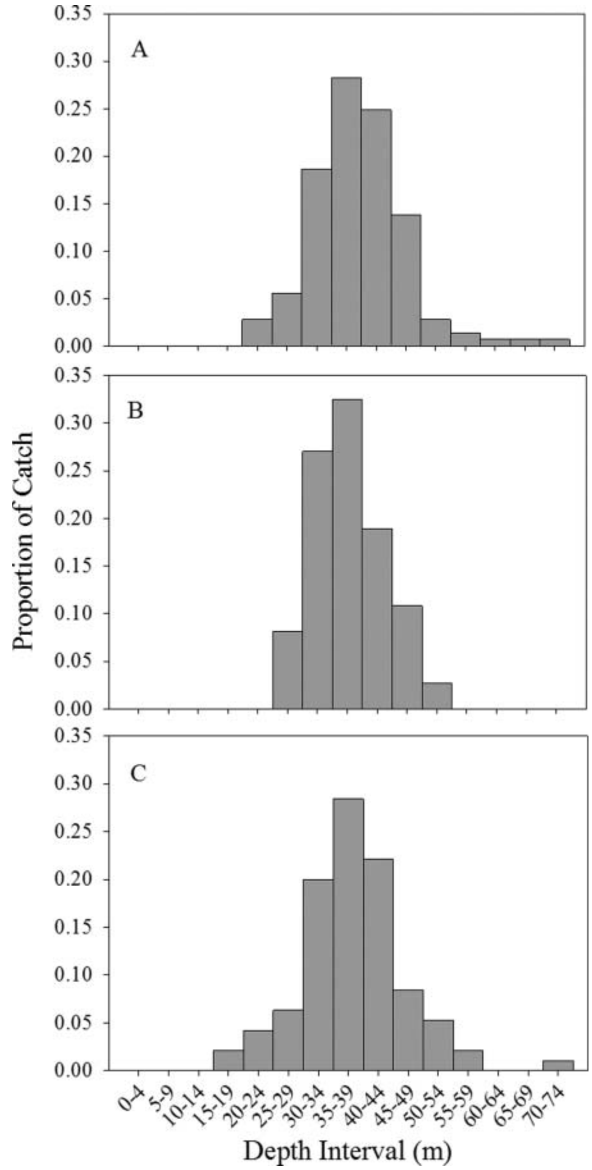

FIGURE 1. Frequencies of capture depths for yelloweye rockfish **(A)** captured once (fate unknown) and **(B)** recaptured (fate known) in a mark–recapture study conducted May–August 2009 in Prince William Sound as well as for **(C)** individuals captured for submergence success trials conducted May–August 2010.

length as a covariate in the survival structure and had 95% CIs around the beta estimates that did not encompass zero. These models indicated a positive relationship between length and survival probability, with the probability of survival increasing an average of 0.043 for each 10-mm increase in length until reaching an inflection point at approximately 400 mm (Figure 4). The probability of survival for individuals greater than 450 mm TL was 0.999. The three remaining covariates (encounter history, capture depth, and time variation) did not improve model fit, and the 95% CIs around the beta estimates for these covariates were centered on zero. These findings indicate that exposure

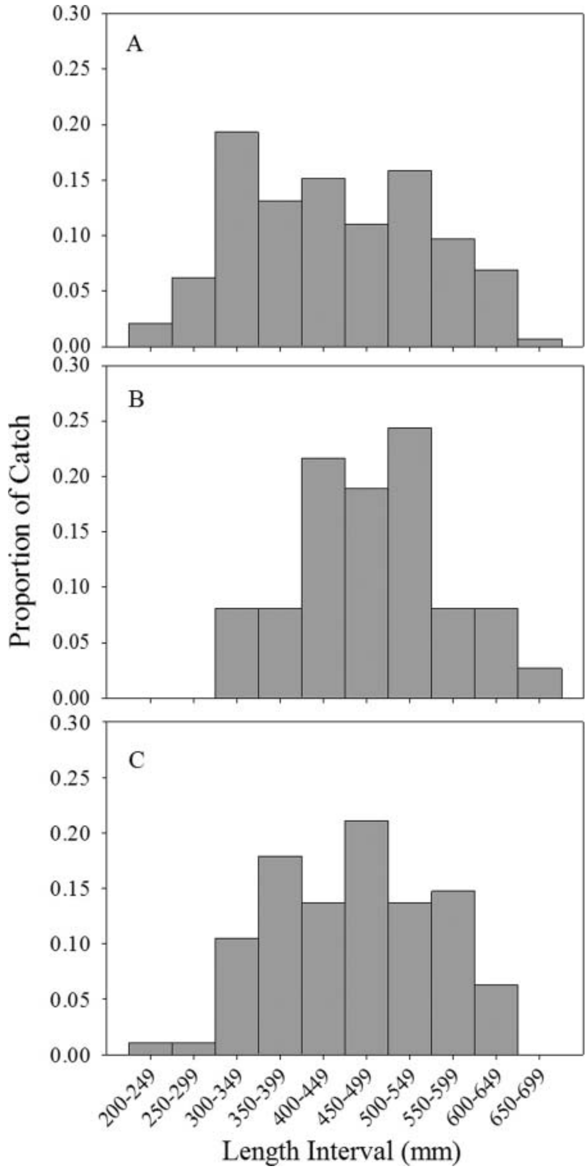

FIGURE 2. Length frequencies of yelloweye rockfish **(A)** captured once (fate unknown) and **(B)** recaptured (fate known) in a mark–recapture study conducted May–August 2009 in Prince William Sound as well as **(C)** individuals captured for submergence success trials May–August 2010.

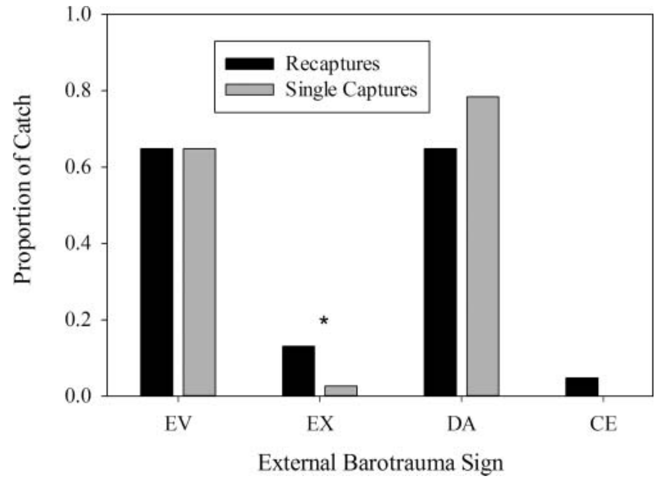

FIGURE 3. Presence of external signs of barotrauma in yelloweye rockfish at time of initial capture for individuals captured once and those that were recaptured. Abbreviations are as follows: EV = everted esophageal tissue, EX = exophthalmia, DA = distended abdomen, and CE = corneal emphysema. The asterisk denotes a significant difference between the two capture groups ($P < 0.05$).

to barotrauma and the capture-and-release process did not significantly affect the survival probability of yelloweye rockfish released at depth in our study. Furthermore, these results indicate that survival probability was similar across all six sample occasions and the range of depths sampled.

The extent to which individual covariates helped to explain capture probabilities was also assessed by comparing differences in $QAIC_c$ values as well as the values and precision of the associated beta estimates. Including the encounter history and capture depth covariates in the capture probability structure contributed substantially to model fit. The encounter history covariate had the effect of reducing capture probability from 0.154 on a particular sampling occasion to 0.037 on the subsequent occasion. We identified a negative relationship between capture probability and depth, whereby capture probability decreased 28% for each 10-m increase in depth. Inclusion of individual length and time variation as covariates in the capture probability structure did not improve model fit, and the 95% CIs around the beta estimates were centered on zero.

Five of the 16 models in our candidate list failed to provide realistic estimates of survival ($\Phi = 1.0$, SE = 0) and were excluded from the model-averaged parameter estimation (Table 2). Point estimates of survival were surprisingly high for

TABLE 2. Candidate Cormack–Jolly–Seber models of apparent survival (Φ) and capture probability (p) derived from the encounter histories of yelloweye rockfish released at depth in Prince William Sound. Model structure included time-varying parameters (T) or constant parameters (.) as well as covariates that accounted for exposure to barotrauma and other capture stressors (EH), individual length (L), and depth of capture (D). The models were evaluated in terms of the quasi-likelihood Akaike information criterion corrected for small sample size ($QAIC_c$; variance inflation factor = 1.36, effective sample size = 195).

Model	K	$QAIC_c$	$\Delta QAIC_c$	$QAIC_c$ weights	Model likelihood
Φ(T_EH_L), p(._EH_D)[a]	10	212.791	0.000	0.253	1.000
Φ(._L), p(._EH_D)	5	213.546	0.754	0.174	0.686
Φ(._L_D), p(._EH_L_D)[a]	7	214.161	1.369	0.128	0.504
Φ(T_EH_L), p(._EH)[a]	9	214.997	2.206	0.084	0.332
Φ(._L_D), p(._EH_D)	6	215.028	2.237	0.083	0.327
Φ(._D), p(._EH_L_D)	6	215.397	2.605	0.069	0.272
Φ(._L), p(._EH)	4	216.226	3.435	0.045	0.180
Φ(._D), p(._EH_D)	5	216.448	3.657	0.041	0.161

[a]Model failed to estimate Φ (e.g., $\Phi = 1.0$, SE = 0).

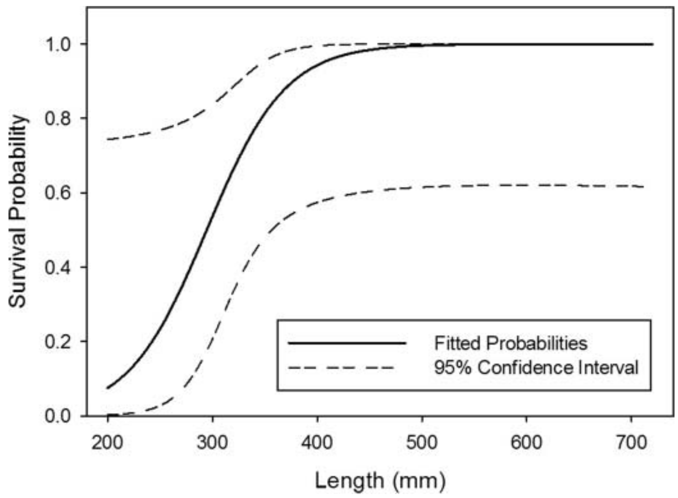

FIGURE 4. The 17-d survival probability of yelloweye rockfish released at depth as a function of individual total length, as estimated by Cormack–Jolly–Seber models in a mark–recapture study conducted May–August 2009 in Prince William Sound.

the remaining 11 candidate models (range = 0.980–0.997). The model-averaged point estimate of survival probability was 0.988 (95% CI = 0.478–0.999), with 13.5% of the estimate's variability being attributed to model variation.

Submergence Success of Yelloweye Rockfish Released at the Surface

A total of 95 yelloweye rockfish were captured and released at the surface to estimate the probability of submergence. Of the 95 individuals observed, 21 successfully submerged, for a submergence probability of 0.221 (95% CI = 0.149–0.315). The average time to submerge was 4.5 min from the time of release (range = 0–24 min). The depth and length-frequency distributions did not differ between fish caught in the submergence success trials and fish caught in the mark–release experiment ($D = 0.114$, P-value = 0.388, and $D = 0.150$, P-value = 0.153, respectively). Thus, the estimate of submergence probability can be used as a maximum survival estimate for yelloweye rockfish released at the surface and is expected to provide a reasonable comparison with the estimate of survival for fish released at depth. The results presented indicate that the average survival of discarded yelloweye rockfish can be increased by 4.5 times if the fish are released at depth quickly after capture (<2 min surface holding time) rather than at the water's surface.

DISCUSSION

Survival of Yelloweye Rockfish Released at Depth

To our knowledge, this study represents the first direct quantification of the survival of a Pacific rockfish species released at depth in a wild setting. The individuals in this study were at liberty for an extended period of time and exposed to predation, allowing the estimate of survival to account for delayed mortality and the effects of predation—factors that can limit the applicability of estimates derived from controlled field studies and laboratory experiments (Pollock and Pine 2007; Campbell et al. 2010). Using mark–recapture techniques to estimate the survival of discarded fish in large, open systems can be very difficult, especially for species exhibiting extensive movements or low capture probabilities. The apparently high site fidelity of yelloweye rockfish, coupled with the relatively high capture probabilities found in this study, undoubtedly contributed to our success.

The contribution of delayed mortality to total discard mortality varies by species and by the duration of exposure to capture stressors. For example, the majority of delayed discard mortality occurred within 2 d after initial exposure to various capture stressors in red snapper *Lutjanus campechanus* (Gitschlag and Renaud 1994; Diamond and Campbell 2009), 8 d in lingcod (Parker et al. 2003), and 30 d in Pacific halibut (Davis and Olla 2001). Black rockfish *S. melanops* exposed to simulated capture and recompression in the laboratory suffered relatively low mortality rates (3 of 90 fish died), with delayed mortality occurring up to 9 d after recompression. With this in mind, we propose that the mortality of yelloweye rockfish after the 17-d interval used in this study would be infrequent. Supporting this suggestion further is the fact that during sampling in 2009 and 2010 we recaptured 28 of 43 yelloweye rockfish (65%) originally tagged during a 2008 pilot study conducted on the study reef. These fish survived and were at liberty for a known period of 10–25 months since initial exposure to barotrauma and other capture stressors. Survival could not be modeled from the encounter histories of these individuals, but the facts that capture probability was estimated at 0.15 and some level of emigration may have occurred between years suggest that annual survival is higher than the 65% recapture rate.

The estimate of 17-d survival found in our study is similar to the short-term estimates generated from controlled field experimentation and the longer-term estimates generated from laboratory experiments. For example, the 2-d survival of Pacific rockfish returned to depth of capture and held in cages was as high as 83% if surface holding time was minimized (i.e., <2 min; Jarvis and Lowe 2008). Similarly, laboratory experiments on black rockfish rendered a 25-d survival estimate of 96.7% (Parker et al. 2006). Thus, cage and laboratory studies to estimate the short-term survival of recompressed Pacific rockfish, coupled with estimation of submergence success, could be a viable way to quantify the effectiveness of deepwater release at improving the discard survival of other species of Pacific rockfish.

The positive relationship between length and survival identified in this study may be driven by the greater predation risk of smaller individuals. Pacific rockfish released at depth often exhibit signs of behavioral impairment, such as difficulty in achieving and maintaining vertical orientation (Hannah and Matteson 2007). While Hannah and Matteson (2007) found that yelloweye rockfish were among the species with the highest behavioral score (i.e., least impaired), logistic regression models suggested that 15–40% of the yelloweye rockfish captured at depths from 10 to 75 m would display some level of behavioral impairment. Behavioral impairment of discarded fish can limit the ability of individuals to escape predation (Ryer et al. 2004). The occasional capture of large Pacific halibut (>150 cm TL) and lingcod (>100 cm TL) while we were sampling the study reef indicated the presence and potential influence of predators in our study. Pacific rockfish as large as 400 mm TL are a prey item of lingcod in nearshore waters (Beaudreau and Essington 2007). Smaller, behaviorally impaired individuals are expected to be more susceptible to predation because most predators are limited by the gape size of their mouths. In addition, larger individual predators such as lingcod do not necessarily select for larger prey (Nilsson and Bronmark 2000; Beaudreau and Essington 2007), suggesting that predation pressure is higher for smaller individuals.

The lower survival of smaller individuals may also be explained by their suffering thermal stress more quickly than larger ones (Davis 2002). The effect of thermal gradients on discard survival has been identified for several species of fish, including Pacific rockfish (Jarvis and Lowe 2008; Diamond and Campbell 2009). Jarvis and Lowe (2008) found that for every 1°C increase in seafloor-to-surface temperature the odds of mortality of five species of recompressed Pacific rockfish increased 1.96 times. The average seafloor-to-surface thermal gradient on the study reef was 6.0°C. Albeit the average surface holding time was less than 2 min in our study, this time frame may have been long enough to induce thermal stress in smaller individuals but not in larger ones. The effect of thermal stress on the survival of yelloweye rockfish will probably be more pronounced in the southern portion of their range (e.g., California and Oregon), where seafloor-to-surface temperature gradients are larger.

Cormack–Jolly–Seber estimates of survival are a combination of the probability of surviving and not permanently emigrating from the study area (Williams et al. 2002). With this in mind, we cannot dismiss the potential contribution of differential emigration rates among juvenile and mature yelloweye rockfish to the identified length–survival relationship. Despite our inability to discriminate among the potential factors contributing to the lower survival of smaller individuals, the relationship between length and survival that we found suggests that the length composition of discarded yelloweye rockfish in a fishery will be an important consideration in determining the efficacy of deepwater release at improving discard survival.

Despite the presence of one or more signs of barotrauma in the majority of captured yelloweye rockfish, we found a high estimate of survival for individuals released at depth. Likewise, our modeling results suggest that the physical damage associated with these signs and the stresses associated with the capture and release process did not influence the 17-d survivability of yelloweye rockfish released at depth. This finding corroborates results from cage studies that found that the 2-d survival of Pacific rockfish exposed to barotrauma and subsequently held at the depth of capture was not significantly correlated with external signs of barotrauma (Jarvis and Lowe 2008). The frequency of barotrauma signs typically increases with capture depth (Hannah et al. 2008a). Failure to detect an effect of capture depth on the survival probability of yelloweye rockfish released at depth supports our conclusion that exposure to and the severity of barotrauma does not influence the survivability of yelloweye rockfish across the range of depths sampled in this study.

Submergence Success of Yelloweye Rockfish Released at the Surface

Our estimate of the submergence probability for yelloweye rockfish is among the lowest reported for a Pacific rockfish species captured at the range of depths covered in this study. The submergence probability of Pacific rockfish is highly species specific (Hannah et al. 2008a) and has been linked to physiological variability within the *Sebastes* complex (Parker et al. 2006; Hannah et al. 2008b). Physiological differences between species influence which tissues are affected by the gases that escape from ruptured or perforated swim bladders and are considered a driving factor in the ability of discarded rockfish to submerge (Hannah et al. 2008a). Specifically, species that exhibit a low occurrence of everted esophageal tissue have high submergence probabilities. This is due in part to excess gases escaping through ruptures in the pharyngo-cleithral membrane (Hannah et al. 2008b; Pribyl et al. 2009). The low probability of submergence for the yelloweye rockfish in our study, coupled with the relatively high occurrence of everted esophageal tissue, suggests that excess gases failed to exit the body cavity in quantities sufficient to alleviate positive buoyancy.

Management Implications

Alternative release methods that attempt to improve the survival of discarded fish have been widely applied in recreational fisheries (e.g., regulatory requirements for the venting of released red snapper in the Gulf of Mexico and encouragement of deepwater release for discarded Pacific rockfish in California and Oregon). However, quantification of the effectiveness of such alternatives is sorely lacking, and unequivocal evidence that such methods improve discard survival remains to be produced (Wilde 2009; Brown et al. 2010). We believe that our approach provides clear evidence that the average 17-d survival of discarded yelloweye rockfish can be increased more than 4 times through the use of deepwater release. We believe that implementing deepwater release is the best management action to minimize discard mortality of yelloweye rockfish if elimination of yelloweye rockfish bycatch in recreational fisheries is not possible. However, caution should be exercised when considering length limits for yelloweye rockfish because the benefit of deepwater release is probably size dependent.

The range of capture depths and the size distribution of yelloweye rockfish in this study are similar to those of the recreational fishery in the Gulf of Alaska (Alaska Department of Fish and Game, unpublished data). Thus, we expect our survival estimates to be representative of those that would be realized in the recreational fisheries of that region. The estimate of survival reported here could be applied to other yelloweye rockfish fisheries if it is adjusted for differences in seafloor-to-surface thermal gradients and the length composition of the fishery (Davis 2002). With this in mind, laboratory studies to estimate the effects and potential interactions of thermal gradients and surface holding time on the length-specific survival probabilities of yelloweye rockfish are needed.

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