Juvenile and small adult cowcod (*Sebastes levis*) show high post-release survival following angling-induced barotrauma

Nicholas C. Wegner[1,2*], Lyall Bellquist[1,2,3], Roberto Silva[2], John R. Hyde[1]

[1] Fisheries Resources Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, CA 92037

[2] Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093

[3] California Oceans Program, The Nature Conservancy, San Diego, CA 92101

*corresponding author: nick.wegner@noaa.gov

Abstract:

The cowcod, *Sebastes levis*, is a large slow-growing rockfish species found along the West Coast of the United States and Baja California, Mexico that has been historically heavily exploited off of southern California. As the cowcod population recovers from past overfishing, previously closed fishing areas and depths are reopening, leading to increased fisher interactions with the species, particularly juveniles and small adults, which are typically found at shallower depths closer to shore. In this study, we quantify post-release survival rates of juvenile and small adult cowcod (< 50 cm) following angling-induced barotrauma in comparison to previous work focused on larger adult cowcod. All fish were captured using recreational hook-and-line gear and descended back to depth using commercially available fish descending devices. Kaplan-Meier survivorship modeling showed an overall survival rate of 92.9% (95% CI: 80.3 – 100%) for the 14 cowcod examined (22.9 – 49.5 cm fork length). This survival rate was nearly twice that determined previously for larger cowcod. The higher survival rate of smaller individuals may reflect their thinner tissues, allowing for expanding gas from the swim bladder to escape the body and preventing some of the severe internal organ damage typically associated with barotrauma in larger cowcod. Combination of our results with previous research thus suggests that small cowcod caught by recreational anglers can be released with high survival rates, while larger cowcod are less likely to survive capture and barotrauma.

Key Words: Catch and release, post-release mortality, recreational fishing, rockfish, size-dependent mortality, survival

1. Introduction

Fishes with a physoclistous, or closed, gas (swim) bladder often experience barotrauma when captured from depth. As such fishes are brought to the surface, the gas in their swim bladder expands, often rupturing the organ and releasing gas into the visceral cavity and surrounding tissues (Parker et al., 2006; Pribyl et al., 2011; Brownscombe et al., 2017). Common external signs of severe barotrauma include a stiff and bloated body and extension of the pharyngo-cleithral membrane under the gill operculum from the expansion of gas within the visceral cavity, an everted esophagus with stomach protrusion from the mouth, exophthalmia (bulging of the eyes), and ocular and subcutaneous emphysema (free gas bubbles within the eye under the cornea or under the skin) (Fig. 1) (Rummer and Bennett, 2005; Hannah et al., 2008b; Jarvis and Lowe, 2008; Pribyl et al., 2009; Pribyl et al., 2011). Internally, the expanded gas can exert extreme pressure on visceral organs, which can be crushed and displaced leading to various degrees of tissue damage and internal hemorrhaging (Rummer and Bennett, 2005; Jarvis and Lowe, 2008; Rogers et al., 2008; Pribyl et al., 2009; Pribyl et al., 2011; Pribyl et al., 2012).

In addition to such injury, gas expansion in the viscera often results in excessive buoyancy for fishes released after capture, hindering their ability to resubmerge and return to depth (Gitschlag and Renaud, 1994; Hannah et al., 2008a; Hochhalter, 2012). Fishes left floating at the surface can quickly succumb to their barotrauma injuries, temperature shock of the warmer surface water, and predation from birds and marine mammals (Jarvis and Lowe, 2008; Campbell et al., 2010; Kerwath et al., 2013; Ferter et al., 2015). To address these challenges, the recreational fishing community has developed a number of commercially available descending devices that use weights to assist fishes in overcoming buoyancy and returning to depth (Theberge and Parker, 2005; Runde and Buckel, 2018; Bellquist et al., 2019). Once at depth, internal gas from the swim bladder is recompressed, largely alleviating barotrauma symptoms (Parker et al., 2006; Pribyl et al., 2012; Drumhiller et al., 2014; Rankin et al., 2017). Consequently, these devices have proven largely effective in releasing fishes and reducing immediate surface mortality (Eberts and Somers, 2017; Bellquist et al., 2019; Wegner et al., 2021; Madden et al., 2024).

Increasing evidence has shown the potential for descended and recompressed fishes to completely recover from barotrauma, although survival rates and recovery times appear largely species specific (Nichol and Chilton, 2006; Curtis et al., 2015; Rankin et al., 2017; Runde and Buckel, 2018; Wegner et al., 2021). For example, recent work examining survival of two important rockfish species from southern California following capture and barotrauma showed significantly different post-release survival rates: cowcod (*Sebastes levis*), a large benthic-oriented rockfish, showed survival rates of approximately 50%, while bocaccio (*S. paucispinis*), a more pelagic-oriented species inhabiting similar depths, showed higher survival at approximately 90% (Wegner et al., 2021). These different survival rates are likely related to the ecology and physiology of the species (e.g., gas bladder morphology, ability for vertical movements and buoyancy adjustments, and sensitivities to environmental stressors that are

exacerbated following barotrauma stress and injury) (Jarvis and Lowe, 2008; Wegner et al., 2021). To further complicate matters, at least some species appear to show within species differences in survival associated with size or age class (Hochhalter and Reed, 2011; Wegner et al., 2021). In cowcod, fish size was the most important predictor of survival, with larger cowcod showing much lower survival rates than smaller individuals (Wegner et al., 2021). In contrast, the opposite pattern has been observed in yelloweye rockfish (*S. ruberrimus*), with smaller individuals showing lower survival rates post capture and barotrauma (Hochhalter and Reed, 2011). Such inter and intraspecific differences suggest caution against broad generalizations in fish recovery from barotrauma, even within species, which consequently complicates management decisions. For historically-overfished species which heavily influence such management decisions, it is important to consider how life stage affects post-release survival.

This study expands upon recent work by Wegner et al. (2021) that found a strong correlation between fish size and mortality in adult cowcod, by examining survival rates in juvenile and small adult individuals that are more likely to be encountered in recreational and commercial fisheries. Following a rapid population decline in the 1970s - 1980s, cowcod were deemed overfished in 2000, prompting fisheries managers to adopt a number of progressive measures to reverse the decline (Butler et al., 2003; Dick and He, 2019). This included a 2001 species moratorium and the establishment of large offshore Cowcod Conservation Areas (no bottom fishing) as well as bottom-fishing depth restrictions (no hook and line bottom fishing deeper than specified depths) to avoid cowcod bycatch while anglers target other rockfish species. These restrictions, in conjunction with a number of successful recruitment years, allowed cowcod to rebound, with the stock being declared rebuilt in 2019 (Dick and He, 2019). Associated with the cowcod resurgence, depth restrictions and area closures put in place primarily to protect the species have been systematically reduced and removed. This has resulted in increased fisheries interactions with cowcod. However, due to their historically overfished status, slow growth rates, and late maturation (Love et al., 1990; Butler et al., 2003), cowcod are still protected and cannot be retained in US waters, and must therefore be released. As juvenile cowcod are usually found at shallower depths and closer to shore than adults, they are more likely to be captured in recreational and commercial fisheries targeting other rockfish species. This study thus examines the survival rate of juvenile and early adult stage cowcod to further our understanding of the impact of capture and barotrauma on this important species.

2. Methods

Juvenile and small adult cowcod (<50 cm fork length (FL)) were targeted offshore of San Diego County, CA using standard recreational fishing techniques for rockfish (rod and reel, typically with spectra braided fishing line containing a monofilament leader with two baited J hooks and a weight). Cowcod were captured during the spring and early summer (March-June) 2016 and 2017 at depths of 67-118 m (mean 102 ± 14.6 SD m). Captured cowcod (n = 14, mean 33.5 ±

8.2 SD cm FL, range: 22.9 – 49.5 cm FL) were externally tagged with either a Thelma Biotel AADTT-HP-9 (Trondheim, Norway) or VEMCO 13AP (Innovasea, Boston, USA) acoustic transmitter selected to match the size of the fish (with one exception, the largest fish were outfitted with the larger VEMCO 13AP) (Fig. 1). Cowcod were then released following common recreational fishing fleet release practices using a standard Seaqualizer descending device set to the deepest release setting of 150 ft (=45.7 m, which, depending on the individual, was 39-68% of its capture depth) in order to help them overcome buoyancy caused by barotrauma. All individuals were successfully released and did not return to the surface. All fish capture, tagging, and release procedures were conducted in accordance with the NOAA Southwest Fisheries Science Center and University of California, San Diego Institutional Animal Care and Use Committee protocols SW1901 and S00080.

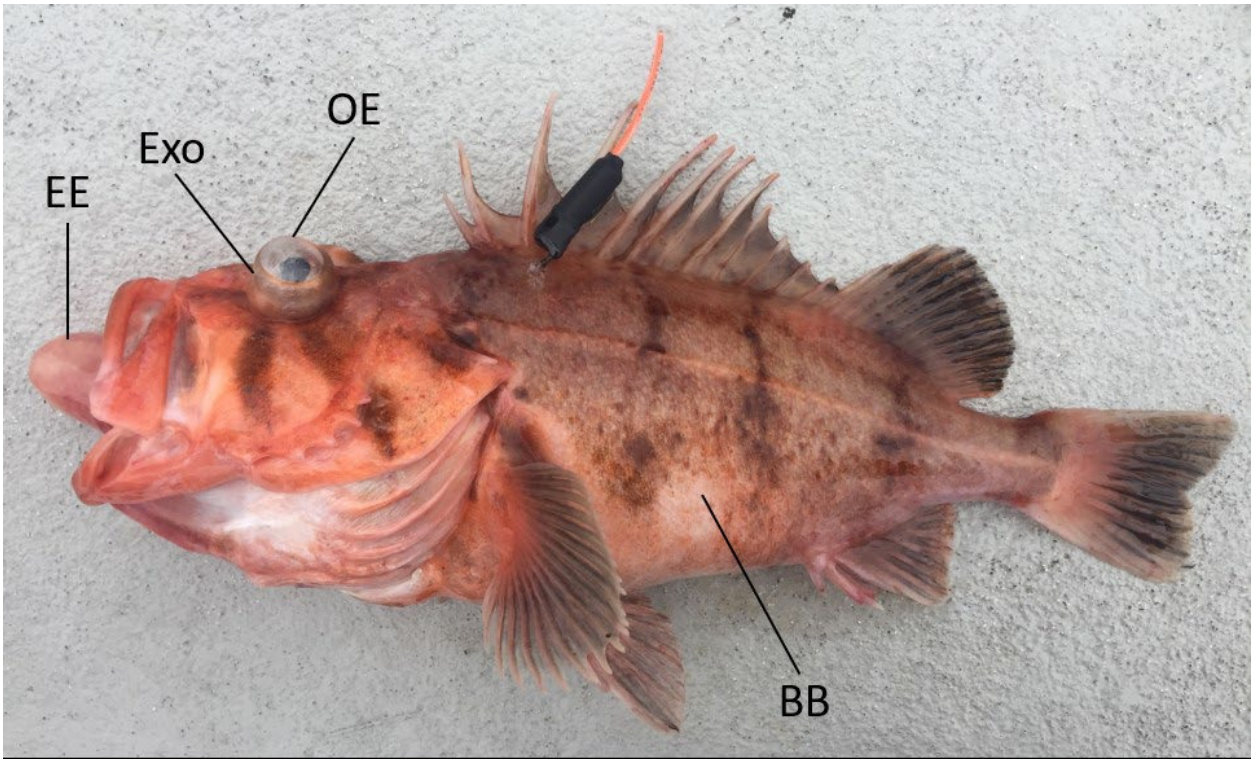

Figure 1: Image of a 35.6 cm FL juvenile cowcod (*Sebastes levis*) showing typical external signs of barotrauma associated with capture from depth (stiff and bloated body (BB), everted esophagus (EE) with distended stomach, exophthalmia (Exo), and ocular emphysema (OE)) and the dorsal attachment of an acoustic transmitter (Thelma Biotel AADTT-HP-9) used to monitor fish survival post release.

Acoustic transmitters were programmed to transmit alternating pressure and acceleration data (and temperature data in the case of the Thelma AADTT-HP-9) every 4 min (randomized between 170 to 310 s to minimize repeated acoustic collisions among nearby tags). Acoustic transmissions were monitored and recorded using VEMCO receivers (VR2, VR2W) suspended approximately 6 m above the seafloor at sites of fish capture and release (Fig. 2).

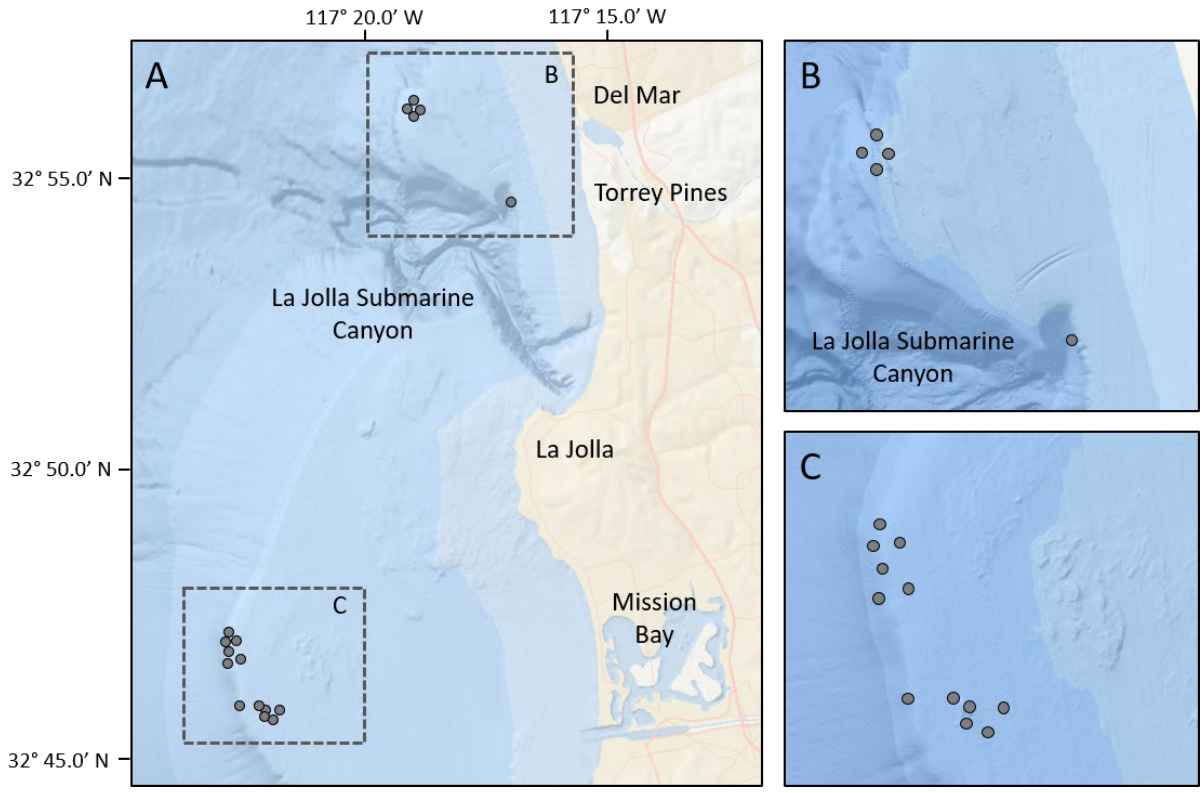

Figure 2: Coastline and local bathymetry of northern San Diego County, USA (A) showing the location of acoustic receivers (gray dots) near cowcod capture locations off Del Mar and Torrey Pines near the La Jolla submarine canyon (B) and offshore of Mission Bay (C) near the continental shelf dropoff.

Pressure (fish depth) and acceleration data downloaded from the receivers were analyzed according to Wegner et al. (2021), in which continuous changes in depth and acceleration indicated a fish was alive (Fig. 3). If the fish's depth profile permanently stopped changing more than ± 2 m (maximum change in pressure associated with the tidal cycle) and the fish's acceleration immediately stopped, the tag was considered to have been shed from the fish (Fig. 3). If some acceleration continued for hours to days post cessation of depth changes, the fish was considered to have died, with the diminishing acceleration representing scavenging and slight movements of the carcass on the sea floor (Wegner et al., 2021). Cowcod survival rate was determined using a Kaplan-Meier model (Kaplan and Meier, 1958; Wegner et al., 2021) using the surv() and survfit() functions from the 'survival' package (https://cran.r-project.org/web/packages/survival/survival.pdf) in RStudio (v. 2024.04.1) which takes into account the loss of observations (fish emigration outside detection range of the receivers) over time. In order to examine the effects of fish size and capture depth on cowcod survival, data from this study were combined with those from Wegner et al. (2021) examining larger fish at generally deeper depths and a Cox proportional hazards model (Cox, 1972; Clark et al., 2023) was applied using the coxph() function.

3. Results

Juvenile and small adult cowcod acoustic telemetry data showed regular fluctuations in acceleration and depth allowing for determination of survival status (Fig. 3). Of the 14 cowcod assessed, only one fish was observed to have died (38.1 cm FL, captured from 118 m, death was immediate upon release, Table S1). This resulted in an ultimate survival rate of 92.9 ± 6.9% (± SE) with 95% CIs of 80.3 to 100% based on the Kaplan-Meier model. Fish remained within detection range of the acoustic receivers from 2.0 to 306.0 days (79.1 ± 95.1 days, ± SD, Table S1). During this time, four fish were observed to have shed their acoustic transmitters (35.0 – 166.5 days, mean ± SD = 80.2 ± 58.7 days, Table S1). When combining survival data in the current study with that of Wegner et al. (2021) for larger cowcod, the Cox proportional hazards model showed that fish length had a significant effect on survival (P = 0.0025), while fish capture depth did not (P = 0.9236).

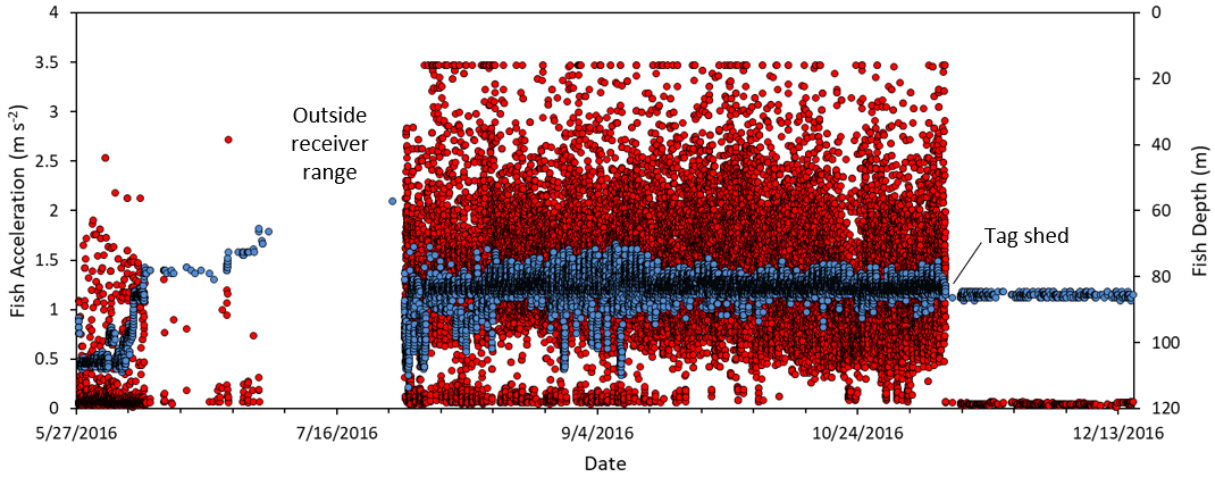

Figure 3: Depth (blue) and acceleration (red) of a 45.5 cm FL cowcod outfitted with a VEMCO 13AP acoustic transmitter released near Del Mar, CA. This fish was consistently detected by acoustic receivers from its release on 5-27-2016 (mm-dd-yyyy) until 6-9, detected sporadically from 6-10 to 7-2, at which point the fish was outside the detection range of the receivers. The fish then returned within range on 7-29 and remained within detection range of the receiver network until the tag was shed from the fish on 11-9-2016, 166 days after capture and release (see Methods for determining the difference between a shed tag and fish mortality).

4. Discussion

This study builds upon recent work by Wegner et al. (2021) that found a strong correlation between cowcod size and mortality, with larger fish experiencing lower post-release survival rates following angler-induced capture and barotrauma. Specifically, the 92.9% (95% CI: 80.3 – 100%) post-release survival rate determined in this study for juvenile and small adult cowcod (n=14, 22.9 – 49.5 cm FL) is significantly greater than the 50.0% (95% CI: 35.7 - 70.5%) survival rate estimated for larger cowcod (n=46, 41.4 – 74.0 cm FL) from Wegner et al. (2021). The

increased susceptibility of larger cowcod to fishing mortality can perhaps best be seen by combining data from the current study with that of Wegner et al. (2021) to determine survival rates according to fish size bins (Table 1). This shows that cowcod <45 cm FL have high survival rates (92.3%), while adult (>45 cm FL) survival decreases fairly steadily with size, with larger adults being more vulnerable to catch-and-release mortality. In particular, all cowcod from Wegner et al. (2021) greater than 70 cm FL (70.5 – 74.0 cm) died upon release (n=6).

Table 1: Post-release survival rates of cowcod (*S. levis*) according to fish size (fork length), as estimated through a Kaplan-Meier model using acoustic telemetry data from this study and Wegner et al. (2021).

Fork length (cm)	Survival (%)	95% CI (%)	n	Depth of capture (m)
<45	92.3	78.9 - 100.0	13	99.8 ± 15.1
45-60	69.4	50.1 - 96.3	18	121.9 ± 23.0
60-65	50.0	25.6 - 97.5	16	117.6 ± 18.2
65-75	26.9	10.5 - 69.3	13	134.0 ± 23.9

Depths of capture are reported as means ± SD.

The higher post-release survival rate of smaller cowcod determined in this study contrasts with predictions that smaller fish should be more susceptible to barotrauma, and capture in general. Such predictions range from hypothesized susceptibility of smaller fish to gas emboli blocking blood flow in smaller diameter critically-important blood vessels (Beyer et al., 1976), to increased sensitivity to thermal shock associated with warm surface waters in smaller-bodied individuals with limited thermal inertia (Davis, 2002). Despite such predictions, most barotrauma studies encompassing a size range of individuals have not shown size-specific mortality rates (Gitschlag and Renaud, 1994; Collins et al., 1999; St John and Syers, 2005; Jarvis and Lowe, 2008; Hannah et al., 2012) or generally weak relationships showing increased mortality and longer recovery times in larger fish (Nichol and Chilton, 2006; Curtis et al., 2015). Hochhalter and Reed (2011) found decreased post-release survival in juvenile yelloweye rockfish in comparison to adults, although this increased mortality was not directly observed, but rather based on fewer mark-recapture returns of smaller individuals. Subsequent work has suggested that yelloweye rockfish recovering from barotrauma are particularly vulnerable to predation, which would disproportionately affect smaller fish (Rankin et al., 2017). For cowcod in southern California, where predators such as lingcod, *Ophiodon elongatus*, are much less abundant (Hart, 1973), we did not observe such predation events.

The cause for elevated mortality rates in larger cowcod remains uncertain. While juvenile cowcod often occur at shallower depths than adults (Love et al., 1990), Wegner et al. (2021) found that depth of capture was not a significant predictor of survival in 46 cowcod (41.4–74.0 cm FL) captured from depths of 82.3–178.3 m, and inclusion of data from the current study to

extend the dataset to 60 cowcod (22.9-74.0 cm FL) from depths of 67.0-178.3 m continues to support that finding. Wegner et al. (2021) rather hypothesized that the observed size-mortality relationship may reflect the likely thicker tissues (e.g., thicker membranes, body cavity walls) of larger individuals that may limit the escapement of expanding high-pressure gas from the body during capture. Angled rockfishes are often observed arriving at the surface surrounded by free gas bubbles that are presumed to represent escaped gas from the swim bladder and body into the surrounding water. If thicker body tissues of larger individuals reduce the ability for gas to escape, this would result in increased pressure of the expanding gas on internal organs and tissues, which could lead to more severe injury. Indeed, a limited number of necropsies we have performed on large cowcod following barotrauma-induced mortality show massive internal hemorrhaging within the visceral cavity (Wegner, personal observation). Examples of the potential benefits of gas escapement can be seen from yellowtail rockfish (*S. flavidus*) and quillback rockfish (*S. maliger*), in which the pharyngeal cleithral membrane has been shown to rupture and release gas, thus alleviating internal pressure and improving post-capture submergence success and presumably survival rates in comparison to other species (Hannah et al., 2008a; Pribyl et al., 2009; Hochhalter, 2012). The ability for gas to escape the body before damage to internal organs occurs may thus help explain both differences in species-specific and ontogenetic mortality rates of rockfishes caught at deeper depths. However, additional studies are needed to confirm potential differences in tissue thicknesses and gas-release pressures among species and fish size classes. For example, examining size-dependent mortality in other large-bodied rockfish species such as the bronzespotted rockfish (*S. gilli*), which is known to be extremely buoyant upon capture (indicating the internal retention of expanded gas and potential for increased pressure-related internal injury) could provide further insight.

In addition to potentially thicker tissues that may inhibit gas escapement, mature cowcod may also have less relative space for gas expansion due to the larger volumes occupied by mature testes and ovaries. This is likely especially true for females nearing parturition, in which ovaries with developing eggs or embryos enlarge, displacing other organs and leading to expansion of the visceral cavity. Gravid females may also have a slightly larger volume of gas in the swim bladder to help offset the added weight of enlarged ovaries and developing embryos which could potentially affect post-release mortality, as a greater internal gas volume increases the potential for gas expansion and related barotrauma. Future work should also therefore consider the potential for sex-dependent mortality estimates.

4.1. Implications for management

With the recent recovery of cowcod populations and associated relaxation of fishing depth and area closures in southern California, more cowcod are likely to be captured as bycatch while targeting other rockfish species. However, cowcod retention remains prohibited within the United States, and these fish must consequently be released. As smaller cowcod are typically found at relatively shallower depths and closer to shore than adults (Love et al., 1990), they are likely to be disproportionately encountered by recreational anglers. Our results indicate that

these smaller cowcod can be successfully released with high survival rates using a descending device. However, while typically found deeper and offshore, larger adult cowcod interactions are also likely to increase as depth and area restrictions are lifted. Wegner et al., (2021) showed that larger cowcod, especially those over ~65-70 cm, have much lower survival rates, indicating that size-dependent survivorship metrics should be considered in the catch and release of this species.

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Table S1: Catch and tagging data for 14 juvenile and small adult cowcod (*S. levis*) used to examine post-release survival rates.

Fish ID	Tag Date	FL (cm)	Capture Depth (m)	Surface interval (min:s)	Barotrauma Score	Post-Release Event	Days to Event	Tagging Vessel	Location
1	4/19/2016	28.5	110.3	2:05	5	Emigration	15.5	Outer Limits	MB Reef
2	5/27/2016	41.9	99.4	2:28	5	Emigration	306.0	Outer Limits	Del Mar
3	5/27/2016	45.5	99.4	2:29	5	Shed tag	166.5	Outer Limits	Del Mar
4	6/17/2016	25.4	100.6	-	0	Emigration	166.9	Outer Limits	Del Mar
5	6/21/2016	25.2	110.3	1:27	3[a]	Emigration	5.4	Outer Limits	MB Reef
6	6/23/2016	34.0	116.1	1:43	5	Emigration	24.8	Outer Limits	MB Reef
7	6/30/2016	27.4	95.9	2:10	5	Emigration	180.9	Outer Limits	MB Reef
8	3/17/2017	49.5	118	-	4[b]	Shed Tag	56.5	New Seaforth	Del Mar
9	3/17/2017	38.1	118	-	5	Mortality	0.0	New Seaforth	Del Mar
10	3/17/2017	35.6	118	-	5	Shed tag	35.0	New Seaforth	Del Mar
11	3/18/2017	35.6	100	-	-	Emigration	3.1	New Seaforth	Del Mar
12	5/3/2017	25.4	88	-	-	Emigration	2.0	New Seaforth	MB Reef
13	5/3/2017	22.9	88	-	-	Shed Tag	62.9	New Seaforth	MB Reef
14	5/18/2017	34.3	67	-	-	Emigration	2.0	New Seaforth	Torrey Pines

Barotrauma score (0-5) represents the total number of five common external barotrauma indicators observed (A. Stiff body, B. Expanded pharyngo–cleithral membrane, C. Esophageal eversion, D. Exophthalmia, E. Ocular emphysema). Due to the extensive fishing effort required to encounter cowcod < 50 cm, individuals captured after 2016 were tagged collaboratively by the crew of the New Seaforth and the surface interval and barotrauma indicators were not always recorded.

[a] stiff body, expanded PC membrane, and exophthalmia

[b] all barotrauma symptoms except ocular emphysema