Fisheries and Oceans Canada
Canada

Pêches et Océans
Canada

Ecosystems and
Oceans Science

Sciences des écosystèmes
et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2019/042

Pacific Region

A Review of the Use of Recompression Devices as a Tool for Reducing the Effects of Barotrauma on Rockfishes in British Columbia

D.R. Haggarty

Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

August 2019

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Haggarty, D.R. 2019. A Review of the Use of Recompression Devices as a Tool for Reducing the Effects of Barotrauma on Rockfishes in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/042. vi + 34 p.

Aussi disponible en français :

Haggarty, D.R. 2019. A Review of the Use of Recompression Devices as a Tool for Reducing the Effects of Barotrauma on Rockfishes in British Columbia. Secr. can. de consult. sci. du MPO, Doc. de rech. 2019/042. vi + 41 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Pacific Rockfish (genus *Sebastes*) suffer high rates of barotrauma when they are brought to the ocean's surface because they have a closed, or physoclistic, gas bladder. Although many jurisdictions recommend the use of descending devices that return recreationally caught fish with barotrauma to depth, little research on the use of these devices and the survival of recompressed fishes has been done in British Columbia. The purpose of this report is to review the literature regarding the effects of barotrauma on rockfishes and the ability of recompression devices to decrease mortality of released fish in the short- and long-term; document types of descending devices and what is known about each; synthesize study results for each species that occurs in BC; and characterize research gaps and uncertainty. Rockfish species are found to demonstrate a remarkable ability to recover from barotrauma and to survive after recompression in the short-term. However, the effects of barotrauma and variation in survival rates are complex in this diverse genus of fishes, and a number of uncertainties remain. Although recompression certainly increases the survival rates of discarded fish that would otherwise be unable to descend and therefore risk predation, keeping what you catch and moving fishing locations to avoid further capture or ceasing to fish once limits have been reached remain better recommendations. Incorporating the voluntary or mandatory use of descending devices in the management of recreational rockfish fisheries will require careful consideration because considerable uncertainty about their effectiveness to mitigate rockfish mortality on a scale that affects populations remains.

1. INTRODUCTION

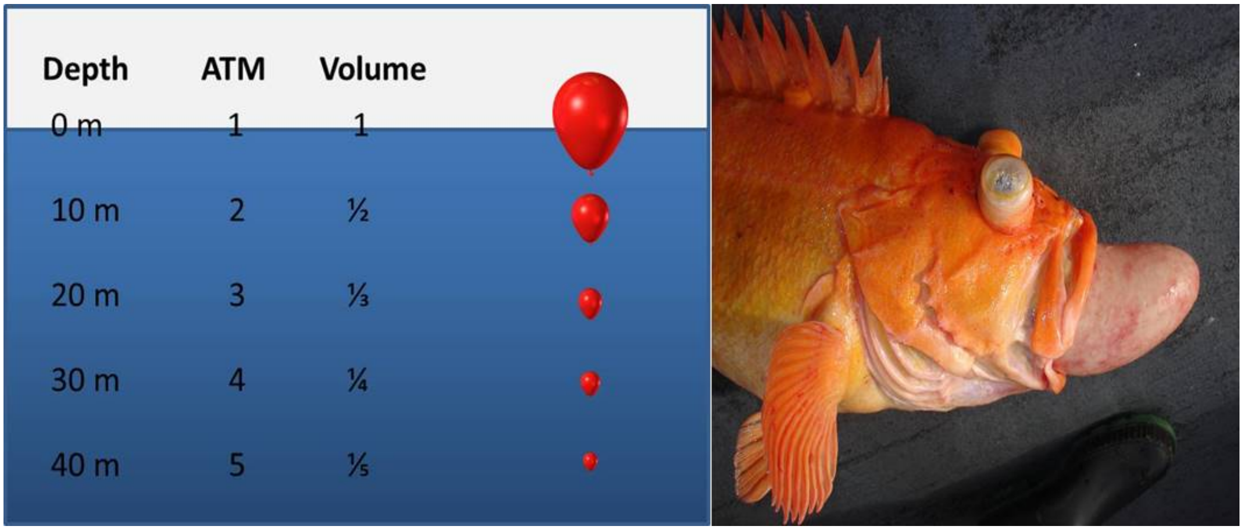
Rockfish (genus *Sebastes*) are a species-rich group, with over 102 species found globally and at least 38 in the coastal oceans of British Columbia (BC). These species all share common life history traits, physiology, and general morphological characteristics (Love et al. 2002). Fisheries and Oceans Canada has grouped rockfish into three categories based on depth distribution along the coast. Slope species (15 species) are generally found in deep water (100-2000 m) and are most abundant in the upper regions of the continental shelf. Shelf species (15 species) are found at depths ranging from 0-600 m and are predominantly found near the edge of the continental shelf. Inshore species (8 species) are most numerous at shallow depths (0-200 m) in rocky areas with high-relief bottoms. These inshore rockfish species are subject to commercial, recreational, and First Nation fisheries, while the shelf and slope rockfishes are targeted by commercial trawl and hook and line fisheries.

BC's inshore rockfish species (Yelloweye, Copper, Tiger, China, Quillback, Black, Blue/Deacon (Frable et al. 2015) and Brown rockfishes) are, like other rockfish species, long-lived (some have lifespans exceeding 100 years), late maturing, have small home ranges, and demonstrate high site fidelity; however, the more pelagic Black and Blue/Deacon Rockfishes mature earlier between 6-8 years of age. Rockfish are viviparous, with the largest and oldest females making significant contributions to the populations by giving birth to over one million larvae in a single breeding season (Love et al. 2002). Most bony fishes have a hydrostatic organ called a gas bladder that is used for buoyancy control and, in some cases, sound production. Rockfishes have a physoclistic gas bladder, meaning there is no connection between the swim bladder and the stomach. Because the swim bladder has no external connections for the release or uptake of gases like in a physostomus fish, physoclists secrete gas from the blood into the swim bladder through a specialized vascular plexus called the *rete mirabile*, and remove gas via the resorption chamber in this organ. The removal of gas is dependent on passive diffusion into the blood stream and then into the water via the gills. The rate of gas removal is therefore dependent on the rate of blood flow and accordingly is not instantaneous (Parker et al. 2006). These reproductive, life history, and physiological characteristics make inshore rockfish susceptible to the impacts of even moderate levels of localized fishing, and associated declines in populations may take decades to reverse.

Rockfish populations along the west coast of North America, including British Columbia, have suffered dramatic population declines since the advent of industrial fishing methods (Parker et al. 2000, Yamanaka and Logan 2010). In 2002, Fisheries and Oceans Canada announced a strategy to conserve inshore rockfishes, which included measures to account for all catch including bycatch and discards, decrease fishing mortality, establish areas closed to all fishing, and improve stock assessment and monitoring (Yamanaka and Logan 2010). Accounting for bycatch and discards and the use of closed areas were important aspects of the conservation strategy because discarded rockfish suffer high mortality associated with decompression effects related to their physiological inability to rapidly vent gas from their swim bladder, as noted above.

The volume and pressure of a contained gas at a constant temperature are inversely related according to Boyle's Law (Figure 1). Therefore, when gas enclosed in a flexible container goes from high to low pressure, such as when it is brought to the surface from depth, the volume of the gas will increase. Accordingly, when a fish with a closed gas bladder is quickly brought to the surface from depth, their swim bladder enlarges and they experience barotrauma. Following Boyle' Law, the change in swim bladder volume is greater in shallow water than the change in volume that occurs when making the same absolute change in depth in deeper water. This creates a narrow zone of neutral buoyancy in shallow waters that results in constraints on a fish's natural vertical movements. It also results in injuries associated with forced decompressions as a fish is brought to the surface during fishing, even when fishing in relatively shallow water (Parker et al. 2006).

As the gas expands, it follows the path of least resistance in the fish, which varies by species, but is usually in an anterior, or forward, direction in rockfishes (Hannah et al. 2008b). The most visible external signs of barotrauma in rockfishes include bulging eyes (exophthalmia) and a protruding esophagus (esophageal eversion) (Figure 1). The protruding esophagus is often thought to be the swim bladder; however, as the expanding gas moves forward it causes the esophagus to "roll out" (Hannah et al. 2008b). Other, less obvious external signs include the tightening of the abdomen, bulging membranes (particularly the branchiostegal membrane near the throat and operculum), gas bubbles in membranes (membrane emphysema) and in the eyes (ocular emphysema), and sometimes a prolapsed cloaca (Jarvis and Lowe 2008). Internal signs include hemorrhages, torn and ruptured swim bladders, organ damage and displacement, and bleeding in the peritoneal cavity and pericardium (Hannah et al. 2008a). When the fish is released live at the surface these internal injuries go unnoticed, but may have significant long-term effects on hunting ability, disease resistance, survival, and reproduction if the animal is able to successfully return to the bottom.



Depth	ATM	Volume
0 m	1	1
10 m	2	½
20 m	3	⅓
30 m	4	¼
40 m	5	⅕

Figure 1. Boyle's Law states that as pressure increases, shown here as Atmospheres (ATM) of pressure associated with water depth (meters), the volume of a gas decreases proportionatly. For rockfishes brought up from depth, this results in barotrauma signs such as those shown in this yelloweye rockfish (picture used with permision from Dayv Lowry, Washington Department of Fish and Wildlife).

In addition to the physiological barotrauma effects, rockfish brought up to the surface and discarded will be "floaters," as they are often unable to return to depth, and are at great risk of predation from birds and mammals while at the surface (Hannah et al. 2008a). As a result, catch-and-release is not an appropriate management tool for rockfishes. Groundfish fisheries managers consider mortality of released rockfish from recreational and commercial fisheries to be 100%; however, the release of rockfishes is prohibited as a condition of license in the commercial fishery and is enforced by electronic or onboard monitoring and audit programs (DFO 2017). Mortality of discarded fish and sub-lethal effects of barotrauma on rockfishes must be considered in management measures, such as the use of Rockfish Conservation Areas (RCAs), other closure zones, and accounting for all catch including bycatch and discards (Yamanaka and Logan 2010). Mortality of releases has also lead to the "Keep What You Catch" guideline, whereby anglers are required to retain rockfish regardless of their size until the daily limit is reached, and to move fishing spots to avoid rockfish rather than releasing them.

The use of recompression devices (Theberge and Parker 2005, Chen 2012) that return rockfish from the surface to their capture depth is currently being explored for inshore BC waters as a mitigation method to reduce mortality of released fishes. Descending devices are recommended for use by recreational fishers in many US jurisdictions (Benaka et al. 2014) and have recently become required in some jurisdictions (Washington and Oregon). Descending devices are commercially available and can also be homemade. Numerous studies have been performed to assess the effectiveness of recompressing different rockfish species (Parker et al. 2006, Hannah and Matteson 2007, Jarvis and Lowe 2008, Hochhalter and Reed 2011, Pribyl et al. 2011, Hannah et al. 2014, Rankin et al. 2017). Most of these studies have focused on immediate post-release mortality, but a few have examined longer-term, sub-lethal impacts on individual fish.

1.1 PURPOSE AND SCOPE OF THE REVIEW

The goals of this report are to:

- Review the literature on the symptoms of barotrauma in rockfishes and the ability of recompression devices to decrease mortality of released fish in the short- and long-term;
- Document types of descending devices and what is known about each.
- Document the current use of descending devices in the management of rockfish in other jurisdictions.
- Synthesize study results for each species that occurs in BC waters;
- Characterize scientific uncertainty and research gaps;
- Identify information needed for management.

To conduct this review, we searched two online resources from DFO’s virtual library, Google Scholar and Web of Science, using a variety of search terms including rockfish and barotrauma, recompression/recompress, decompression, and descending device. In addition, information presented at the “Rockfish Recompression Workshop” on October 28th, 2016 at the SFU Wosk Centre for Dialogue, Vancouver BC, was also reviewed along with published outreach material on rockfish release from the United States.

A limitation in the literature is that little research on the effects of barotrauma and the use of recompression has taken place in BC. Therefore, we must extrapolate from research done in the United States. Much of the research on barotrauma in rockfishes has been conducted in California and is, therefore, focused on southern species that are not found in BC; however, research conducted in Oregon, Washington and Alaska is more pertinent to rockfish species in BC.

2 DISCUSSION

2.1 STUDIES ON ROCKFISH BAROTRAUMA AND RECOMPRESSION

The effects of barotrauma and recompression on rockfish that have been brought to the surface have been studied in both laboratory and field settings. Some laboratory studies use hyperbaric tanks to compress and decompress rockfish. Fish are either held in tanks to observe how they recover for a certain number of days and then sacrificed, or just sacrificed and dissected to examine internal injuries (Parker et al. 2006, Pribyl et al. 2009, Pribyl et al. 2011). Other experiments have used field cage systems equipped with underwater cameras so that fish that are caught are recompressed as the cage is lowered through the water column. Fish were then released immediately upon reaching the desired depth and their behaviour observed (Hannah and Matteson 2007), or held for 48 hours before release (Jarvis and Lowe 2008, Hannah et al. 2012, 2014, Rankin et al. 2017). Some studies focus on effects of barotrauma experienced by various species and do not recompress the fish (Parker et al. 2006, Hannah et al. 2008b, Pribyl et al. 2011), and others examine the barotrauma signs and subsequent ability of fish that have been decompressed to descend when released at the surface (Hannah et al. 2008a, Hochhalter 2012). Rankin et al. (2017) did an experiment on Yelloweye Rockfish with four treatments: one group of fish were sacrificed without recompression; another group was sacrificed after recompression; the other two groups were held and observed in the lab for 15 and 30 days after being recompressed in experimental cages equipped with a camera. Rankin et al. (2017) observed the behaviour of the fish held in the lab and then sacrificed the fish at the end of the trial in order to examine them internally. Studies that examine the internal condition of fishes use necropsies to examine the condition of various organs (Jarvis and Lowe 2008) as well as histological methods (microscopic examination of damage of tissues) (Pribyl et al. 2009, Pribyl et al. 2011, Rankin et al. 2017), and physiological experiments (Parker et al. 2006, Hannah et al. 2008b). Some studies have used x-ray (Rummer and Bennett 2005) or magnetic resonance imaging (MRI) to assess internal effects of barotrauma on snappers and rockfishes, respectively.

A few studies catch, tag, and release fish so that long-term survival after recompression can be studied (Hochhalter and Reed 2011, Wegner et al. 2016[1]). Hochhalter and Reed (2011) tagged and released Yelloweye Rockfish using a deep-water release mechanism (DRM) and then recaptured fish over a period of 17 days. They modeled a survival probability using the Cormack-Jolly-Seber model. Some fish from this study were recaptured 1 or 2 years later in a subsequent study and their reproductive status examined (Blain and Sutton 2016). Bocaccio and Cowcod Rockfishes as well as some other deep-water species in Southern California were tagged using acoustic transmitters that record depth and acceleration and use an acoustic array to collect data over the course of several years (Wegner et al. 2016[1]).

A description of the primary sources relevant to the effects of barotrauma and the survival of rockfish species in BC following recompression are described in Table 1. Several sources of variability including the depth of capture, species studied, temperature differentials, handling procedures, and time on deck, as well as the sex and size of the fish, are also important to consider when reviewing the literature on barotrauma and recompression effects.

---

[1] Wegner, N., L. Bellquist, A. P. Nosal, P. A. Hastings, and J. Hyde. 2016. Post-release survival and behavior of two deep-dwelling rockfishes (Cowcod, Sebastes levis, and Bocaccio, S. paucispinis) suffering from barotrauma: using recompression devices to reduce bycatch mortality. Western Groundfish Conference, Newport, Oregon.

Table 1. References cited in Tables 3 and 4 and methods used in each study. Note that some studies describe more than one experiment.

References	Method	Number
Blain and Sutton 2016	Recaptured fish previously released at depth 1 or 2 years prior and sacrificed	1
Hannah et al. 2007	Cage with video camera, released at depth	2
Hannah et al. 2008a	Not recompressed, sacrificed	3
Hannah et al. 2008b	Released at surface	4
Hannah et al. 2012	Recompressed in cage, held 48 h, released at surface	5
Hannah et al. 2014	Recompressed in cage, held 48 h, released at surface or depth	6
Hochhalter 2012	Released at surface, observed 30 min	7
Hochhalter and Reed 2011	Fish tagged and released at depth with a DRM. Recaptured fish used in a mark-recapture experiment and the average Cormack-Jolly-Seber survival probability and 95% confidence interval determined.	8
Jarvis and Lowe 2008	Not recompressed, sacrificed but initial survival following capture given	9a
Jarvis and Lowe 2008	Recompression in cages then held for 48 hrs before sacrifice (12) or release (54)	9b
Parker et al 2006	Experimental hyperbaric chamber, held for 21 days then sacrificed	10
Pribyl et al. 2009	Fish held in hyperbaric pressure chamber at 4.5 ATA (35 m) for 7-10 d and then rapidly brought to surface, sacrificed and examined.	11
Pribyl et al. 2011	Not recompressed, sacrificed	12
Rankin et al. 2017	Not recompressed, sacrificed	14a
Rankin et al. 2017	Recompression in cages then held for 48 hrs before sacrifice	14b
Rankin et al. 2017	Recompression in cages then held for 48, then held for 15 days before sacrificing	14c
Rankin et al. 2017	Recompression in cages then held for 48, then held for 30 days before sacrificing	14d
Wegner et al. 2016[1]	Captured, acoustic tag, released at depth, followed acoustically for 3 years.	15

2.2 DEPTH OF CAPTURE AND VARIABILITY AMONG SPECIES

The severity of barotrauma experienced by a rockfish due to forced decompression by fishing is influenced by a number of correlated factors, as is how the fish responds to the barotrauma and what its chance of survival is with and without being returned to depth. The absolute change in pressure/depth that the fish experience determines the volume change that the fish's swim bladder will experience (Figure 1). Internal injuries including cardiac injury, hematomas, swim bladder and pericardium ruptures, liver hemorrhages, and digestive system injuries showed clear patterns of increased severity as the pressure increased in a laboratory study of decompression on Gulf of Mexico Snapper (*Lutjanus campechanus*) (Rummer and Bennett 2005). The depth of capture has also been found to significantly affect the severity of barotrauma as well as the fish's subsequent behaviour and survival in rockfishes (Hannah and Matteson 2007, Pribyl et al. 2011, Hannah et al. 2012, 2014); however, depth is not always found to be a significant variable (Jarvis and Lowe 2008, Hochhalter and Reed 2011). The influence of the depth of capture on barotrauma and survival is complicated by the depth selectivity of the numerous rockfish species, their behaviour and anatomy, as well as the confounding effect of temperature change that co-occurs with a change in pressure and depth.

Pribyl et al. (2011) reported a significant role of capture depth on the presence or absence of macroscopic signs of barotrauma in Quillback and Yelloweye Rockfishes. Similar results have been reported by Jarvis and Lowe (2008) whereby increasing depths of capture lead to increasing signs of barotrauma. However, these researchers found that depth was only a partial predictor of initial post-decompression survival. Differences among species is often a better predictor of survival than depth, due to the variability of swim bladder morphology and other species-specific adaptations related to their life history strategies (Hannah et al. 2008a, Jarvis and Lowe 2008, Pribyl et al. 2011).

The numerous species of rockfishes in the genus *Sebastes* have been described in terms of a species flock (Alesandrini and Bernardi 1999, Hyde and Vetter 2007). Rockfish speciation likely occurred along a depth gradient (Ingram 2011). Ingram (2011) showed that there was a strong signal of speciation in the depth habitats and traits that adapt species to different depths, such as the size of the eyes, an adaptation to low light levels. Although Ingram (2011) did not study morphological traits related to the swim bladder, this organ is also likely to be adapted for performance at various depths as well as to benthic or mid-water niches. Morphological differences in swim bladders traits such as shape and membrane thickness have been noted for different species. An extensive comparison of 21 species of rockfish for differences in barotrauma after capture at depths of 18-225 m was conducted by Jarvis and Lowe (2008). Species-specific differences in barotrauma symptoms were observed, and could be attributed to differences in swim bladder morphology, as thin membranes seen in Olive Rockfish (*S. serranoides*) make them more susceptible to bladder injuries than other rockfish species (Copper, Vermillion, and Brown Rockfishes) that have thicker more robust swim bladders. Internal morphology differences between snapper species has also been shown to account for differences in barotrauma injuries, with some species having more internal space to allow for swim bladder expansion without placing pressure on the stomach to cause esophageal eversion (Rummer and Bennett 2005).

Life history will also affect how different species are adapted to pressure changes. Rockfish species that have adapted to vertical movements up and down the pressure gradient have faster gas secretion and resorption capabilities. For example, Black Rockfish are semi-pelagic, and known to move vertically as aggregates/schools within the water column. China rockfish, by contrast, tend to be more solitary, and live in rocky crevices on the bottom. Black rockfish have a much larger, more developed *rete mirabile* and higher red blood cell content than demersal China Rockfish, which enables faster gas transfer rates in the swim bladder as depth frequently and rapidly changes (Parker et al. 2006). Parker et al. (2006) also found significant differences between the species after exposure to pressures equivalent to depths of 30 m in an experimental hyperbaric chamber, with Black Rockfish acclimating (i.e., to be neutrally buoyant) in 48 hours, and China Rockfish needing over 250 hours to acclimate. After comparing the anatomy and physiology of the China and Black Rockfishes, Parker et al. (2006) hypothesized that barotrauma will be worse for demersal species than for semi-pelagic not only because of their lower ability to remove gas but also because they have comparatively more gas in their bladders at the same depth. In order for semi-pelagic fishes, such as Black and Blue Rockfishes to make greater vertical movements (Table 2), they need to be neutrally buoyant at a depth much shallower than their mean depth. The upper extent of the vertical range that they can safely make would be a function of the neutral buoyancy depth and the physical limits of positive buoyancy. Because capture depth may be closer to neutral buoyancy depth for demersal species, semi-pelagic individuals captured at the same depth should show less barotrauma than a demersal species (Parker et al. 2006).

Yellowtail Rockfish, a pelagic species that makes large vertical movements, show low rates of barotrauma and gas bubbles have been observed emanating from under their opercula during ascent (Hannah et al. 2008b, Pribyl et al. 2009). Pribyl et al. (2009) used decompression chambers to simulate decompression from a depth of 35 m and found that when comparing Black, Blue, and Yellowtail Rockfishes, the Yellowtail Rockfish were less likely to suffer from both macroscopic and histopathological injuries. Yellowtail rockfish did not show any external signs of barotrauma except the presence of gas bubbles in the pharyngo-cleithral membrane. Yellowtail rockfish release gas during decompression from the swim bladder via this membrane, so the reduced amount of gas in the swim bladder does not build up enough pressure during decompression to evert the esophagus or cause exophthalmia. Assumptions about how a species handles barotrauma aren't, however, always straightforward. Although we might assume that Quillback Rockfish, a species with a deep-body that exhibits a demersal behaviour with low levels of horizontal and vertical movement, would have low ability to withstand pressure changes, the opposite has been observed. Quillback Rockfish show low levels of esophageal eversion since air escapes through ruptures in the branchiostegal membrane under the operculum (Hannah et al. 2008b, Pribyl et al. 2011).

It is critical to consider the interaction of morphological and physiological attributes when reviewing the literature on this topic. Differences among rockfish species survival after forced decompression and associated barotrauma exist due to their evolutionary history and phylogeny, their physiological capacity to respond to forced decompression, morphological differences, and life history patterns (Parker et al. 2006, Pribyl et al. 2011). The differences in rockfish species' life history, niche, habitats, movements, and depth preferences for the inshore rockfish and some shelf rockfishes are summarized in Table 2 so that barotrauma effects can be viewed with these characteristics in mind.

We do not have any data on the depth range that rockfish species are caught at in recreational fisheries in BC because the information on the capture depth is not collected in the creel survey. Fishery-independent surveys that use recreational hook and line equipment (Richards and Cass 1985, Haggarty and King 2006a, b, Frid et al. 2016) can be used to inform the possible capture depth of rockfishes. However, these surveys are depth-stratified so may not cover the same depth ranges that are recreationally fished. They also use jigging gear so may not be representative of catches by recreational trolling or while targeting Pacific Halibut. The depth of capture of rockfish species from hook and line surveys does, however, show the differences in capture depth by species. Black, Copper, China, and Vermillion Rockfishes were typically caught above 30 m. Most Quillback and Tiger Rockfishes were captured at mid-depths between 30 to 50 m and most Canary, Yelloweye and Yellowtail Rockfishes were caught below 50 m (Figure 2).

*Table 2. Life History characteristics of inshore and nearshore shelf rockfishes in BC. Group (Gp): In=Inshore, Sh=Shelf. Subgenus (SG): a= Sebastosomus, b= Pteropodus, c= Sebastichthys, d= Sebastopyr, e= Rosicola, f= Hispaniscus, g=Acutomenthum, h=Sebastodes. Niche: MW=Mid-water, B=Benthic. Movement: Horizontal (H), Vertical (V): H=High, M=Medium, L=Low, U=Unknown. *Juveniles are found in shallower water. (Richards 1986, Matthews 1990, Love et al. 2002, Hyde and Vetter 2007, Hannah and Rankin 2011).*

Gp	**SG**	**Species**	**Depth Range (m)**	**Typical Depth (m)**	**Niche**	**Habitat**	**Max Size (cm)**	**Max Age**	**Move-ment H/V**
In	a	Black *(S. melanops)*	0-366	0-100	MW	Kelp, high and low relief reefs, high current	69	50	M/M
In	a	Blue/ Deacon (*S. mystinus/ S. diaconus)*	0-549	0-90	MW	Kelp, high relief, exposed reefs	53	44	M/M
Sh	a	Yellowtail (*S. flavidus*)	0-549	90-180*	MW	High relief and sheer rock walls	66	64	H/H
In	b	Copper (*S. caurinus*)	0-183	0-90	B	Kelp, boulder fields and high and low relief reef	66	50	M/M
In	b	Quillback (*S. maliger*)	0-274	0-150	B	Kelp, boulder fields and high and low relief reef, sponges	61	95	L/L
In	b	China (*S. nebulosus*)	3-128	10-100	B	High relief rock with high current	45	79	L/L
In	b	Brown (*S. auriculatus*)	0-135	0-120	B	High and low relief reefs, sand	56	34	L/L
In	c	Tiger (*S. nigrocinctus*)	18-298	50-200	B	High-relief, high complexity reef	61	116	L/L
In	d	Yelloweye (*S. ruberrimus*)	15-549	50-200*	B	High-relief, high complexity reef	91	118	L/L
Sh	e	Vermillion *(S. miniatus)*	6-436	50-300	B	High relief rocks	76	60	L/L
Sh	e	Canary (*S. pinniger*)	0-838	100-200*	B	Pinnacles, high, exposed rock	76	84	H/H

Gp	SG	Species	Depth Range (m)	Typical Depth (m)	Niche	Habitat	Max Size (cm)	Max Age	Move-ment H/V
Sh	f	Greenstriped (*S. elongatus*)	12-495	100-250	B	Boulders, cobble, rock rubble, mud	43	54	U/U
Sh	g	Widow (*S. entomelas*)	24-549	140-210	MW	School over rock outcrops, boulders and high relief.	59	60	U/H
Sh	h	Bocaccio (*S. paucispinis*)	122-478	50-250	B/MW	High relief rocks, boulders, mud	91	50+	H/H

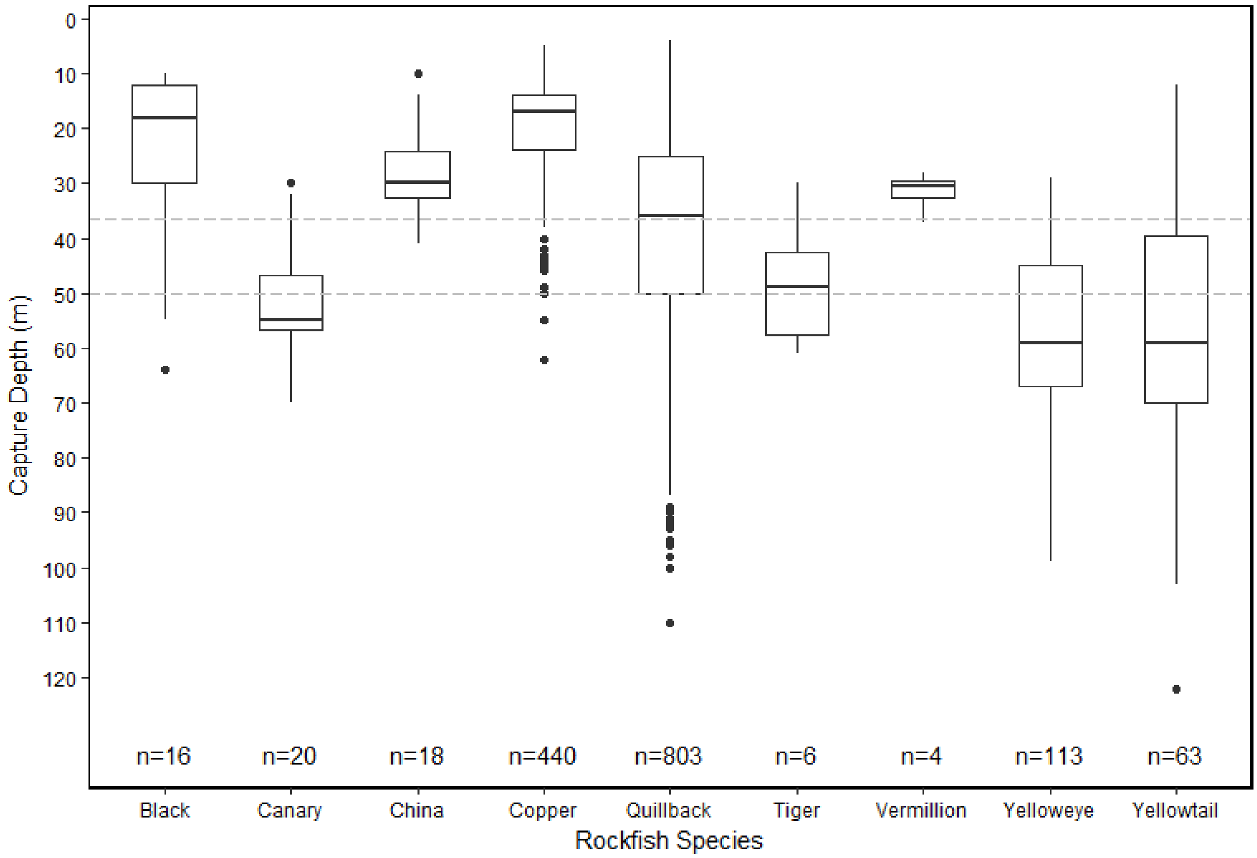


Figure 2. Boxplot of the capture depth of rockfish species on fishery-independent research surveys (data in GFBio and Frid et al. 2016). Dashed lines are shown at 36 and 50 m. The horizontal line in each box is the median depth and the hinges of the boxes are the 25th and 75th percentile. The whiskers or vertical lines are 1.5 times the interquartile range while the points are outliers that are plotted individually.

2.3 OTHER SOURCES OF VARIABILITY AFFECTING SURVIVAL

Temperature differences are also correlated with depth and the temperature difference between the depth of capture and the surface can affect the severity of barotrauma in rockfishes (Pribyl et al 2011). A synergistic effect of barotrauma and surface temperature on mortality of released Largemouth Bass (*Micropterus salmoides*) has been documented during winter tournaments in California lakes (Feathers and Knable 1983). Fish held at the surface or on deck are subject to heat stress, or cold stress, which can be a major cause of mortality (Parker et al. 2003). The temperature differential as well as the handling time significantly affected survival of rockfish species in California (Jarvis and Lowe 2008). Most studies examining specific effects of barotrauma handle fish carefully and keep the time on deck to a minimum. Other sources of variability include hooking and handling injuries and capture stress. However, all of the studies reviewed took care to minimize and control for these physiological (i.e. susceptibility to pressure effects) and physical (i.e. capture-related with respect to depth, temperature and handling) effects.

Fish size may also affect the physiological response of rockfish to barotrauma. Smaller fish may be more susceptible to barotrauma due to smaller blood vessels that are more sensitive to large gas bubbles (Jarvis and Lowe 2008). Hochhalter and Reed (2011) reported that for Yelloweye Rockfish a positive relationship exists between length and recaptures of tagged fish that had been recompressed. Fish under 40 cm were not recaptured in their study, indicating that smaller fish that have suffered barotrauma and been released with a deep-water release devise may suffer greater mortality directly related to barotrauma, or greater predation rates. Lingcod (*Ophiodon elongates*) have been observed preying on rockfish under a length of 40 cm (Beaudreau and Essington 2007).

Differences between sexes may also contribute to the severity of rockfish responses to barotrauma; however this is likely only when highly gravid females are subjected to forced decompression. However, gonad volume did not seem to have a significant impact on recovery of Yelloweye Rockfish (Blain and Sutton 2016). Furthermore, Blain and Sutton (2016) provide evidence of successful breeding of Yelloweye Rockfish after forced decompression and subsequent release at depth. This phenomenon has also been confirmed by the Washington Department of Fish and Wildlife, who tagged and recompressed several Yelloweye Rockfish as part of a mark-recapture and population genetics study in 2015-16 and subsequently observed gravid females with a remotely operated vehicle in an area where no captured fish were initially gravid (Dayv Lowry, Washington Department of Fish and Game, Olympia, Washington, Pers. Comm).

2.4 THE PHYSICAL EFFECTS OF BAROTRAUMA IN ROCKFISH (SEBASTES)

Fishers using hook and line often notice obvious signs of barotrauma such as “pop eye” (exophthalmia) and an everted esophagus in rockfish as a result of increased gas pressure in their physoclistic swim bladder. If the anglers do not keep the rockfish, the fish is often released back into the water at the surface. Juvenile rockfishes can also be caught as bycatch in traps, such as prawn traps (Favaro et al. 2010), and discarded to the same effect. Discarded rockfish are so positively buoyant that they float on the surface, and often succumb to predation and/or thermal stress (Hannah et al. 2008a). Predation is likely the most immediate and obvious cause of post-release mortality in rockfish suffering from barotrauma. However, there are other short- and long-term effects of barotrauma.

Hannah et al. (2008b) describe a physical model that explains the development of the common signs of barotrauma observed in rockfishes. Their work indicates that expanding gas in the swim bladder can escape without visibly rupturing the swim bladder, perhaps as a result of greater permeability as the bladder expands. The escaping gas tends to move along the path of least resistance in a forward direction in the fish, infusing the tissues in and around the head kidney, heart, and post-cranial musculature. Gas collecting here leads to bulging and gas bubbles in the branchiostegal membrane below the fish's operculum. As the gas volume increases in these areas, it can also cause the esophageal tissue to "roll out" of the fish's mouth, causing an everted esophagus or, rarely, stomach (Hannah et al. 2008b). For some species, such as Quillback Rockfish and Yellowtail Rockfish, esophageal eversions are not common; likely because of ruptures to the branchiostegal or pharyngeo-cleithral membranes reduce the pressure exerted on the pharyngeal tissue (Hannah et al. 2008b, Pribyl et al. 2009). Consistent with the observation that most of the gas moves in an anterior direction, prolapsed clocoa, or anal vents, are infrequently observed in rockfishes (Jarvis and Lowe 2008), although 42% of female Yelloweye Rockfish that were recaptured had suffered a prolapse (Blain and Sutton 2016). Pockets of gas also collect within the orbits and leads to a condition called exophthalmia ('pop eye') where the eye is pushed out of the head and the optic nerves are stretched. Gas bubbles may also collect in the eyeball or cornea, or connective tissue of the eye (Hannah et al. 2008b, Rogers et al. 2008). Rogers et al (2008) used magnetic resonance imaging (MRI) to study the internal effects of barotrauma on two species of rockfish (honeycomb rockfish (*S. umbrosus*) and Greenblotched Rockfish (*S. rosenblatti*)). These researchers reported optic nerve stretching and inflation of the orbital space behind the eye, likely caused by gas leaking from the swim bladder, rupturing the peritoneum, and entering the cranium. These signs of sublethal visual damage due to barotrauma, detectable only through the use of MRI, provide important information that can be used to better understand secondary effects of barotrauma, such as impaired vision and increased susceptibility to predation or the decreased ability to find forage. Both of these behavioral impairments have implications for the long-term survival of rockfish that have suffered from barotrauma. Although little research has been done on the visual acuity of rockfish following exophthalmia, one study on Rosy Rockfish (*S. rosaceus*) showed improvements in eye function one month, as compared to 4 days after exopthalmia (Rogers et al. 2011).

Internal damage from barotrauma that is not obvious unless the fish is dissected and examined, sometime at the tissue level (histologically), include hemorrhages, organ damage and displacement, swim bladder tears and ruptures, emphysema, and embolisms; however, internal injuries are important to consider because they may cause mortality or long-term health problems (Hannah et al. 2008b, Pribyl et al. 2011). Causes of mortality include bleeding into the abdominal cavity and vascular gas embolism interfering with cardiovascular function. Damage to the liver and other internal organs, as indicated by hemorrhages, from severe or moderate organ displacement or torsion, as well as damage to the kidney, head kidney or heart, can all lead to longer term health deficits (Hannah et al. 2008b). Tears or ruptures to the swim bladder, either as a partial tear to the outer membrane, the tunica externa, or a full rupture if both layers of the bladder, can result in behavioral issues as the fish has trouble regulating its buoyancy (Rankin et al. 2017). However, Parker et al. (2006) found that Black Rockfish have a good ability to heal following a swim bladder rupture post simulated capture; 77% of the ruptured swim bladders had at least partially healed and were holding gas upon dissection after 21 days in the lab.

The common external and internal barotrauma signs found in rockfishes are described in Table 3. I have also summarized the findings in the literature of barotrauma signs that have been found on inshore rockfishes (Table 4) and some shelf rockfishes (Table 5) found in BC. Methods used in the references cited are given in Table 1.

Table 3. Barotrauma signs and symptoms observed in rockfishes. The abbreviations listed in this table are used in Tables 4 and 5. Due to infrequent reporting of internal signs, we report detailed signs noted in the literature and listed here as internal hemorrhages and internal embolisms to facilitate comparisons.

External

Abbreviation	Barotrauma Sign	Description
TA	Tight Abdomen	Abdomen swollen, tight to touch, or distended
BM	Bulging Membrane	Outward bulge in the branchiostegal membrane
ME	Membrane Emphysema	Air spaces or bubbles visible within the branchiostegal membrane and/or pharyngeo-cleithral membrane.
EX	Exophthalmia	Eye protruding outward from the orbit
OE	Ocular Emphysema/Corneal Emphysema	Gas present within the eye or connective tissue surrounding the eye; also called corneal emphysema
EE	Esophageal Eversion/Stomach Eversion	Eversion of esophageal tissue at least 1 cm into the buccal cavity
PC	Prolapsed Clocoa	Everted anal vent

Internal

Abbreviation	Barotrauma Sign	Description
ST	Swim bladder Tear	Swim bladder can be partially ruptured (ruptured tunica external) or fully ruptured indicated as a visible tear in both layers of the bladder. A full tear is also indicated by the swim bladder holding no gas or collapsing under light finger pressure.
OD	Organ Displacement/Torsion	The liver, stomach, intestines and other abdominal organs are pushed towards or into the pharynx.
HE	Internal hemorrhage	Hemorrhages are noted in the literature as unspecified hemorrhages or as hemorrhages in the liver, pericardium or swim bladder and as blood in the peritoneal cavity.
IE	Internal embolism	Any embolism or emphysema noted internally upon dissection or histological investigation including the heart ventricle, *rete mirabile*, head kidney, or as an arterial embolism.
HP (HE)	Pericardium Hemorrhage	Blood in the pericardium
HL (HE)	Liver Hemorrhage	Blood in the liver or torn liver
BP (HE)	Blood in Peritoneal Cavity	Some or severe blood in the peritoneal cavity noted
HVE (IE)	Heart Ventricle Emphysema	Histological evidence of gas bubbles visible in the heart ventricle
ERM (IE)	Emboli in the Rete Mirabile	Histological evidence of embolism
HKE (IE)	Head Kidney Embolism	Histological evidence of emboli in the vessels of the head kidney
AE (IE)	Arterial Embolism	Presence of gas embolisms in pericardial chamber and swim bladder

*Table 4. Summary of external and internal barotrauma signs, behavioural effects, submergence, and survival of inshore rockfish following decompression. Values are in percentages. See Table 5 for information about the references cited. * indicates the sign was not reported. ** indicates sign was grouped as “severe barotrauma”. Survival: u=unknown, s=sacrificed. The subscript in the survival column denotes the time period over which survival was measured or the CI around the estimate. The subscript in the behaviour score (behav.) column indicates the maximum possible score in the study.*

Black

External (%)									Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
10--19	27	85	7	4	0	0	0	*	*	*	*	*	*	u	4
12--39	16	81	31	19	6	6	38	*	*	*	*	*	3.8_4	u	2
16--49	44	77	66	61	18	7	62	*	71	70	57	*	*	s	3
20--29	51	98	75	57	6	0	71	*	*	*	*	*	*	u	4
26--46	16	*	*	*	19	0	88	*	63	*	*	67	*	s	12
30--39	73	93	84	77	5	0	100	*	*	*	*	*	*	u	4
30	90	100	100	*	*	100	*	*	*	P	100	*	*	97_{21d}, s	10
35	12	100	100	70	40	40	80	*	80	*	*	58	*	s	11
40--51	46	89	96	74	28	7	100	*	*	*	*	*	*	u	4
40--99	18	100	94	78	33	17	94	*	*	*	*	*	2.9_4	u	2
9--64	144	*	*	*	30**	30**	30**	*	*	*	*	*	5.5_8	90_{48h}	5

Blue

External (%)									Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
10--19	17	88	18	0	0	0	0	*	*	*	*	*	*	u	4
12--39	17	41	24	6	6	0	35	*	*	*	*	*	3.2_4	u	2
20--29	56	100	20	2	0	0	7	*	*	*	*	*	*	u	4
20--48	16	*	*	*	6	6	81	*	44	*	*	67	*	s	12
35	9	100	50	60	20	20	40	*	100	*	*	11	*	s	11
30--40	25	84	12	36	4	0	100	*	*	*	*	*	*	u	4
40--52	6	50	50	17	17	0	100	*	*	*	*	*	*	u	4
40--99	18	56	78	50	17	6	89	*	*	*	*	*	1.0_4	u	2
9--54	36	*	*	*	20**	20**	20**	*	*	*	*	*	4.5_8	78_{48h}	5

Brown

External (%)									Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
24--53	4	*	*	*	25	0	75	25	0	0	25	*	*	s	9a

Copper

External (%)									Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
28--54	10	*	*	*	10**	10**	10**	*	*	*	*	*	6.0_8	100_{48h}	5
53--69	7	*	*	*	86	71	29	14	0	29	43	*	*	s	9a

China

	External (%)								Internal (%)						
Species Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
9--45	3	*	*	*	35**	35**	35**	*	*	*	*	*	5.0_{8}	100_{48h}	5

Quillback

	External (%)								Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
25--74	65	45	*	22	40	10	5	2	*	*	*	*	*	u	7
29--77	16	*	*	*	13	13	6	*	6	*	*	39	*	s	13
31--55	5	100	100	100	40	20	0	*	0	0	80	*	*	s	3
40--54	9	89	100	89	67	22	22	*	*	*	*	*	*	u	4
40--99	5	100	100	100	60	0	20	*	*	*	*	*	2.5_{4}	u	2
28--64	28	*	*	*	45*	45*	45*	*	*	*	*	*	6.5_{8}	100_{48h}	5

Tiger

	External (%)								Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
40--99	5	100	100	100	20	20	80	*	*	*	*	*	2.3_{4}	u	2

Yelloweye

	External (%)								Internal (%)						
Capture Depths (m)	**N**	**TA**	**BM**	**ME**	**EX**	**OE**	**EE**	**PC**	**ST**	**OD**	**He**	**IE**	**Behav.**	**Survival**	**Ref.**
15--74	95	90	*	35	10	1	90	2	*	*	*	*	*	u	7
15--75*	28	61	*	*	7	4	71	25	61	*	*	*	*	s	1
19--54	25	*	*	*	22	0	83	*	*	*	*	*	3.0_{8}	100_{48h}	5,6
19--74	182	70	*	*	2	0	65	*	*	*	*	*	*	$98_{(C50\text{-}99)}$	8
40--99	19	84	100	95	42	11	95	*	*	*	*	*	3.1_{4}	u	2
46--54	11	*	*	*	45	19	100	*	*	*	*	*	*	100_{48h}	6
55--64	20	*	*	*	65	5	80	*	*	*	*	*	*	95_{48h}	6
65--74	20	*	*	*	45	20	90	*	*	*	*	*	*	95_{48h}	6
75--84	20	*	*	*	60	25	70	*	*	*	*	*	*	95_{48h}	6
135--174	10	*	*	*	100	40	80	*	*	*	*	*	*	90_{48h}	6
44--146	7	43	100	100	14	86	100	*	58	86	100	*	*	s	3
37--194	17	*	*		65	41	94	*	24	*	*	39	*	s	13
110--194	15	100	100	100	80	53	100	*	*	*	*	*	2.0_{4}	u	2
140--150	6	*	*	100	83	83	100	*	33	*	83	50	*	s	14a
140--150	6	*	*	0	0	0	0	*	0	*	100	0	*	s	14b
140--150	5(1)	*	*	0	0	0	0	*	20	*	100	60	1.0_{2}	80_{15d}, s	14c
140--150	5(1)	*	*	0	0	0	0	*	0	*	40	20	1.0_{2}	80_{30d}, s	14d

*Table 5. Summary of external and internal barotrauma signs, behavioural effects, submergence, and survival of shelf rockfish following decompression. Values are in percentages. See Table 5 for information about the references cited. * indicates the sign was not reported. Survival: u=unknown, s=sacrificed. The subscript in survival column denotes the time period over which survival was measured or the CI around the estimate. The subscript in the behaviour score (behav.) column indicates the maximum possible score in the study.*

Canary

External (%)									Internal (%)						
Capture Depths (m)	N	TA	*BM*	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
100--194	6	83	100	100	33	17	67	*	*	*	*	*	2.2_4	u	2
12--39	10	90	100	100	30	20	100	*	*	*	*	*	2.5_4	u	2
20--29	5	100	100	80	40	0	60	*	*	*	*	*	*	u	4
22--141	14	71	100	100	21	43	86	*	43	93	50	*	*	s	3
24--146	17	*	*	*	71	47	77	*	29	*	*	39	*	s	12
30--41	6	100	100	100	17	0	100	*	*	*	*	*	*	u	4
40--53	40	93	95	95	50	18	100	*	*	*	*	*	*	u	4
40--99	32	91	100	97	56	38	88	*	*	*	*	*	2.9_4	u	2
46--54	5	*	*	*	100	20	100	*	*	*	*	*	*	100_{48h}	6
55--64	13	*	*	*	55	30	85	*	*	*	*	*	*	100_{48h}	6
65--74	11	*	*	*	70	35	72	*	*	*	*	*	*	91_{48h}	6
75--84	15	*	*	*	70	45	72	*	*	*	*	*	*	80_{48h}	6
135--174	10	*	*	*	100	70	90	*	*	*	*	*	*	20_{48h}	6
19--64	41	*	*	*	35	13	65	*	*	*	*	*	4.5_8	100_{48h}	5,6

Silvergray

External (%)									Internal (%)						
Capture Depths (m)	N	TA	BM	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
100--194	12	92	100	100	83	75	100	*	*	*	*	*	2.5_4	U	2

Vermillion

External (%)									Internal (%)						
Capture Depths (m)	N	TA	BM	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
35--96	35	*	*	*	71	57	40	14	6	26	74	*	*	s	9a
55--86	75	*	*	*	81	52	92	0	8	15	85	69	*	75_{48h}, s	9b

Widow

External (%)									Internal (%)						
Capture Depths (m)	N	TA	BM	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
53	9	*	*	*	0	0	100	11	33	100	33	*	*	s	9b
40--99	10	50	90	60	30	10	100	*	*	*	*	*	2.5_4	u	2

Bocaccio

External (%)									Internal (%)						
Capture Depths (m)	N	TA	BM	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
57--89	66	*	*	*	33	29	92	0	0	33	100	25	*	80_{48h}, s	9b
80--180	41	*	*	*	*	*	*	*	*	*	*	*	*	92_{3y}	15

Yellowtail

			External (%)						Internal (%)						
Capture Depths (m)	N	TA	BM	ME	EX	OE	EE	PC	ST	OD	He	IE	Behav.	Survival	Ref
20--29	6	100	50	33	0	0	0	*	*	*	*	*	*	u	4
30--42	17	35	71	88	0	0	0	*	*	*	*	*	*	u	4
35 (4.5ATA)	12	0	0	90	0	0	0	*	20	*	*	0	*	s	11
31--145	15	-	-	-	0	0	0	*	0	*	*	57	*	s	12
40--55	27	26	41	93	0	0	0	*	*	*	*	*	*	u	4
40--99	4	25	100	50	0	0	0	*	*	*	*	*	2.5_4	u	2

2.5 SURVIVAL AFTER RECOMPRESSION

Some studies measure survival, but it is usually over a short period of time, such as 48 hours (Tables 4 and 5). Jarvis and Lowe (2007) did some of the earliest research to examine the potential benefits of rapid recompression to alleviate barotrauma and increase post-capture survival of rockfish. Rockfish were caught at depth (50-89 m), placed into a cage, and returned to capture depth where they were monitored for 2 days, examined, and then released. They calculated an overall 2-day survival rate of 68% across all species with a range of 36% to 82% by species. However, this study was done in California and many of the species studied are not found in BC, and many of those that were included were not caught in great enough abundance for the survival after recompression data to be reported. They reported a 2-day survival rate of 75% and 80% for Vermillion and Bocaccio Rockfishes, respectively (Table 5).

Hannah et al. (2012) similarly held fish in a cage after recompression. They compared the recovery of seven species of rockfish (Black, Canary, Blue, Quillback, Yelloweye, Copper, and China Rockfishes) captured by hook-and-line at depths of 9-64 m, and with a 3 min (average) surface time, after fish were returned to depth in a recompression cage. Survival in cages 48 hours later was 100 % for all species and depths, except for Black and Blue Rockfishes that showed an inverse relationship between capture depth and survival and had survival rates of 90 and 78%, respectively. Hannah et al. (2014) used the same cages and compared Canary Rockfish with Yelloweye Rockfish, but at much greater depths (though in the range of anglers) of 46-174 m. Survival in cages 48 hours later was measured and found to be 95% across all depths for the Yelloweye Rockfish, although slight declines in survivorship were seen with depth (Table 4), while the Canary Rockfish survival declined rapidly to only 20% at capture depths greater than 135 m (Table 5). Capture depth and signs of barotrauma in the Canary Rockfish were negatively correlated with survival, while a significant correlation was not detected for Yelloweye Rockfish. Survival of neither species was correlated with temperature differentials between the surface and the capture depth. Fish of both species that died were found to have blood pooling under the pharyngo-cleithral membrane, in the abdominal cavity, and/or the pericardial cavity. A further study of Yelloweye Rockfish found an similar (89%) survival rate after being recompressed and held for 48hrs (Rankin et al. 2017).

A mark-recapture study was initiated in Alaska to determine the survival of Yelloweye Rockfish caught between 19 and 74 m (most between 25-55 m) and released at depth using a deep-water release device (Hochhalter and Reed 2011). The fish were tagged with passive integrated transponder (PIT) tags as well as external, individually numbered T-bar tags. The tagged fish were monitored for 17 days and their survival was compared with the survival of fish released at the surface. Only 22% of Yelloweye Rockfish released at the surface were able to submerge, suggesting a low survival rate without recompression. They estimated survival for the recompressed fish using a mark-recapture model. Their Cormack-Jolly-Seber survival probability estimate was 0.988 with a wide 95% confidence interval equal to 0.478 to 0.999.

One of the concerns about recompression of rockfish is regarding long-term effects on reproduction. Yelloweye Rockfish from Alaska that were part of the barotrauma mark-recapture study previously described (Hochhalter and Reed 2011), were resampled 1 and 2 years later (Blain and Sutton 2016). The rockfish were examined for external signs of reproductive maturity and sampled for blood plasma indicators of sex and female reproductive status. The results indicate that reproduction of the Yelloweye Rockfish was not compromised and recaptured females remained reproductively viable even after two recompression events.

Rockfish survival following recompression has also been measured using acoustic telemetry (Wegner et al. 2016[1]). Cowcod, Bocaccio, and Bank Rockfishes implanted with acoustic tags equipped with depth sensors and accelerometers were monitored over time through detections on receivers located around the release site. The tagged fish were returned to depth (91 – 183 m) using recompression devices. An array of receivers located on the bottom monitored the movement of these fish. Detections from these fish indicate a 72% survival for all species combined for over 10 days, and no mortalities for up to 4 months of monitoring, although some fish left the detection array. Bocaccio, the only species from this study found in BC, had a 92% survival rate over a three year time period (not including fish that left the array) (Table 5).

Long-term impacts on survival of rockfish following recompression were addressed in a laboratory-based study that examined various physiological indicators of fish health and, presumably, survival. The results of this study by Pribyl et al. (2012) demonstrate that Black Rockfish captured at depths from 35 m, have a good chance for recovery and survival if recompressed immediately after capture. Additionally, they found overall handling stress can result in greater physiological impacts than barotrauma alone. Black Rockfish held in the lab for 21 days had a 97% survival rate (Table 4) (Parker et al. 2006).

2.6 SUB-LETHAL AND BEHAVIORAL IMPAIRMENT

Because estimates of survival for rockfishes that have been recompressed are limited, researchers have also assessed behaviour of fishes upon release after being recompressed. The behaviour of nine species after recompression and release were examined by Hannah and Matteson (2007) using video cameras attached to release cages. A composite behavioral score was based on the fish's ability to orient vertically within the cage and while exiting the cage, and if the fish was able to swim and how long this took (see Tables 4 and 5 for the composite score noting that lower scores denote greater impairment). The behaviorally impaired rockfish were found to have difficulty maintaining their vertical orientation and were slow to leave the release cage. The effects of depth on behavioral impairment were species-specific, with lower behavioral scores for Black Rockfish, Blue Rockfish, and Yelloweye Rockfish at increased depths. Blue rockfish that were caught at depths of 40-99m, had the most seriously impaired behaviour of the species studied (Hannah and Matteson 2007).

Behavioral impairment in Yelloweye Rockfish was examined by Rankin et al. (2017) both during recompression and after recompression. They found that during the recompression descent, the positively buoyant fish were disoriented and upside down or lying on their sides in the cages. Upon reaching the bottom, those fish captured in shallow water (54-89 m) were immediately oriented upright. By contrast, half of the deep captured (122-199 m) fish remained lying on their sides for approximately one hour. When the cage was opened, the fish caught in shallow water exhibited "vision-dependent" behaviour (defined as fish avoiding an opaque barrier in the cage), while most (75%) of those rockfish caught at depth did not avoid the barrier, exhibiting impaired "vision-dependent" behaviour. The cause of the impaired vision in Yelloweye Rockfish is attributed to the presence of ocular emphysema, which can take up to 48 hours at depth to resolve (Hannah et al. 2012, Rankin et al. 2017). Rogers et al. (2011) used an optokinetic reflex test to assess the time for recovery of visual performance following barotrauma and recompression in Rosy Rockfish. They found that vision was functional after 4 days, and improved further after one month. In the second part of the study, Rankin et al. (2017) observed two other behavioral traits: if the fish was oriented upright while swimming and if it was neutrally buoyant. They made these observations on Yelloweye Rockfish that had been caught between 140-150 m and recompressed in cages for 48 hours, then subsequently held for 15 or 30 days, depending on the treatment, in order to observe behavioral and sublethal effects. Although all of the fish were able to orient upright, none of the fish in either treatment were able to maintain neutral buoyancy. The consequences of negative buoyancy include energetic costs, difficultly acquiring prey and interacting with conspecifics, increased predation risks as a result of labored or atypical swimming patterns, and general problems with movement (Rankin et al. 2017). At the conclusion of the 15- and 30-day trials, the fish were all sacrificed and internal barotrauma signs were noted including severe internal bleeding and extensive hemorrhages in the swim bladders. Although most of the swim bladders were partially intact, one was completely ruptured and all others remained damaged. They observed gas between the swim bladder and body wall and within the tunica layer, inflammations, ruptured tunica externas, brown fluid in swim bladders, and a swollen, discoloured *rete*. The findings presented in Rankin et al. (2017) reveal severe and lasting injuries as well as behavioural compromise of recompressed deep-water Yelloweye Rockfish. Black Rockfish held in the lab have demonstrated swim bladder recovery at a rate of 77% over 21 days (Parker et al. 2006) and 50-80% over 31 days (Pribyl et al. 2012), indicating that although swim bladder repair is possible, recovery in some proportion of fish will take an extended amount of time. Pribyl et al. (2012) also note that swim bladder recovery in a laboratory setting might not be representative of fish in the wild because food is available and predators are absent in the lab. It is unknown how this injury will affect survival in the wild.

2.7 SYNTHESIS OF RESULTS BY SPECIES IN BC

2.7.1 Yellowtail Rockfish

Yellowtail Rockfish appear to be the species least affected by barotrauma as a result of their ability to vent gas from their pharyngo-cleithral membrane (Hannah et al. 2008b, Pribyl et al. 2009). This reduces the signs of barotrauma. Yelloweye rockfish are a mid-water schooling fish that makes large vertical migrations naturally and is, therefore, better adapted to handle pressure changes.

2.7.2 Bocaccio

Bocaccio have also been observed making high vertical movement changes. They also seem to survive being recompressed well after barotrauma events (Jarvis and Lowe 2008, Wegner et al. 2016[1]).

2.7.3 Quillback Rockfish

Quillback Rockfish are a deep-bodied demersal species, not known to make large vertical or horizontal migrations (Hannah and Rankin 2011). It is, therefore, surprising, that they appear to show fewer external barotrauma signs and survive recompression well (Table 4). Similar to Yellowtail Rockfish, Quillback have been observed venting gas from their branchiostegal membranes, which reduces pressure placed on the esophagus and leads to low incidence of esophageal eversion (Hannah et al. 2008b). Short-term survival (48 hours) was high (Hannah et al. 2012). Long-term survival, behaviour, and sub-lethal studies have not been done on Quillback Rockfish.

2.7.4 Copper and Brown Rockfishes

Closely related to Quillback Rockfish, we might expect similar barotrauma effects and survival for Copper and Brown Rockfishes, which have not been studied in as great of detail. 48-hour survival was high at 100%, although sample sizes were small (Hannah et al. 2012).

2.7.5 Black Rockfish

Black Rockfish are a mid-water species that have been extensively studied. Despite high rates of external and internal barotrauma signs, short term (48 hr) survival was high (90%) (Hannah et al. 2012) and longer term (21 days) survival in the lab was 97% (Parker et al. 2006). Survival has been related to the depth of capture (Hannah et al. 2012).

2.7.6 Blue and Deacon Rockfishes

Blue Rockfish occupy a similar niche to the closely related Black Rockfish. Their survival was lower than Black Rockfish over a 2-day experiment and related to capture depths (Hannah et al. 2012). All work on Blue Rockfish and barotrauma and recompression has been focused on *S. mystinus*. A recent study shows that Blue Rockfish in BC are likely a separate species, the Deacon Rockfish (*S. diaconus*) (Frable et al. 2015). Unpublished research on Deacon Rockfish conducted in Oregon showed that Deacon Rockfish caught above 27 m, re-descended and held for 24 hrs had 100 % survival, but survival dropped to 78% and 71% between 28-36 m and 37-45 m, respectfully. Survival of Deacon Rockfish caught between 46-54 m dropped to only 25%, indicating that deeper caught Deacon Rockfish are quite fragile (Polly Rankin, Oregon Department of Fish and Wildlife, Newport, Oregon, Pers. Comm.).

2.7.7 China and Tiger Rockfish

Little work has been done on China and Tiger Rockfishes, however a small sample (three) of China Rockfish showed 100% 48 hour survival (Hannah et al. 2012). Physiological examination of China Rockfish has shown much slower ability to reabsorb gas than Black Rockfish, which is consistent with its benthic, sedentary lifestyle (Parker et al. 2006). Tiger Rockfish, which similarly have a sedentary, benthic lifestyle, but which are typically found deeper than China Rockfish might be expected to have low survival rates. Tiger Rockfish have shown high rates of external barotrauma signs (Table 4) (Hannah and Matteson 2007).

2.7.8 Yelloweye Rockfish

Barotrauma and recompression of Yelloweye Rockfish have been extensively studied (Hannah and Matteson 2007, Hannah et al. 2008a, Hochhalter and Reed 2011, Hannah et al. 2012, Hochhalter 2012, Hannah et al. 2014, Blain and Sutton 2016, Rankin et al. 2017). Short-term (48 hr) survival rates of Yelloweye Rockfish have all been very high (90-100%) with a trend of decreased survival with increased capture depth (Table 4). A long-term tag-recapture experiment on fish that had been released at depth revealed a high probability of survival, 0.98 over 17 days; however, this study produced wide confidence intervals (0.48-0.99). The capture depth for this study was also relatively shallow, 19-74 m; however, most fish were captured above 55 m (figure 1 in Hochhalter and Reed 2011). Another interesting finding of this study was that fish under 40 cm in length were not recaptured. This leads to questions about increased mortality from barotrauma or increased risk of predation for smaller rockfish (Beaudreau and Essington 2007). Yelloweye Rockfish occupy deeper depths than most other inshore rockfishes (Table 2). Depth of capture is therefore a concern. Although short-term (48 hr) survival of Yelloweye caught between 135-174 m of depth was still relatively high (90%) (Hannah et al. 2014), work by Rankin et al. (2017) on the extensive internal damage of Yelloweye Rockfish caught between 140-150 m cannot be ignored. They conclude “the findings of these two studies, which reveal severe and lasting injuries, as well as behavioral compromise of recompressed deep-water Yelloweye Rockfish reinforce the importance of avoiding fishing contact with deep-dwelling Yelloweye Rockfish and maintaining spatially-managed rockfish conservation area closed to fishing.”

2.7.9 Canary Rockfish

Canary Rockfish have also been extensively studied (Hannah and Matteson 2007, Hannah et al. 2008a, Hannah et al. 2008b, Pribyl et al. 2011, Hannah et al. 2012, 2014). Although Canary Rockfish show high 48-hour survival in shallow water (Hannah et al. 2012), survival is greatly reduced with depth of capture below 75 m and was as low as 20% at depths of 135-174 m (Hannah et al. 2014). Hannah et al. (2014) conclude that there may be a critical capture depth for some rockfish species at which post-recompression survival decreases rapidly, as it did for Canary Rockfish.

2.8 BAROTRAUMA MITIGATION

2.8.1 Venting

There have been various methods developed to mitigate the effects of barotrauma on rockfish. One approach is to ‘vent’ the fish, by inserting a hypodermic needle directly into the swim bladder to remove the trapped gas (Theberge and Parker 2005). This method relies heavily on the skill and experience of the person venting the fish, because improper technique can cause extensive damage to the fish. Lethal injuries associated with puncturing of vital organs, swim bladder punctures and hemorrhage, and in the case of gravid females puncturing of gonad and release of eggs into the coelomic cavity, have been reported for Australian Bass (*Macquaria novemaculeata*) (Roach et al. 2011). Additionally, some anglers misidentify the everted esophagus protruding from the mouth of the fish as the swim bladder and puncture this organ instead. As a result of injuries and infections in the fish’s body cavity that can be caused by venting, or “fizzing” rockfishes, Washington, California and Alaska all recommend that anglers not vent rockfish (e.g., Washington Department of Fish and Wildlife – Protecting Washington’s’ Rockfish). There is also potential for injury to the person venting a rockfish because of the large venomous spines in some species of rockfish (Theberge and Parker 2005). A recent review of catch-and-release fisheries and barotrauma treatments compared the relative risk of mortality associated with using descenders to venting found that although both methods improved risk, there was no statistical difference between venting and descending (Eberts and Somers 2017).

2.8.2 Hyperbaric Chambers

Pressure tanks can also be used to recompress fish prior to release, and have been shown to be highly effective in laboratory settings (Parker et al. 2006, Smiley and Drawbridge 2007, Pribyl et al. 2009). These tanks are, however, predominantly used by public aquariums that are collecting specimens for display or for scientific research (Pribyl et al. 2012). Because they are large and can be expensive, they are not practical for use by recreational or charter fishers.

2.8.3 Descending/Recompression Devices

Another method to mitigate barotrauma in rockfish is to use recompression devices to force the return of the affected fish to depth. A variety of devices have been designed to recompress a broad diversity of fish. Commercially available fish descender devices range from simple mechanical devices that clip to a line or fishing rod, to more technologically advanced depth/pressure release devices) (Theberge and Parker 2005, Chen 2012, Hudson 2015) (Figure 3). Some devices attach to the lower jaw of the fish by piercing the soft membrane and are deployed using an independent fishing rod, accompanied by a weight sufficient to rapidly drag fish to the bottom, or in-line with fishing gear. After lowering the fish back to depth, a jerk of the rod releases the fish. Other devices attach to the lower jaw of the fish without piercing the membrane, and fish are lowered with a light weight to the preferred depth and then released, either by a shake of the rod, or, in some devices by pressure sensor in the device. The fish is lowered to depth with a light weight and a firm shake of the rod will open the clamp to release the fish. (see California Department of Fish and Wildlife – Rockfish Barotrauma Information). Homemade devices are also in use, such as an inverted barbless hook with a weight (at least 3 pounds for a large Yelloweye Rockfish), an upside-down milk crate or crab pot that is weighted and attached to a rope, and a modified “The Fish Grip” (Figure 3).

Each method has pros and cons and some devices require practice to handle and use well and efficiently. For instance, when using a barbless inverted hook, which is relatively straight-forward and familiar to most fishers, it is important to keep the hook from puncturing the extruded esophagus and the line from cutting the eyes during release. This method works best with small fish. When a weighted milk crate is used, the crate is dropped over the fish and then, with the buoyant fish inside, lowered to depth until the fish can swim out on its own. In rough seas, however, the crate can bang against a fish's extended eyes and cause additional damage (California Sea Grant 2008). When currents are strong, the crate can drift substantially, making it difficult to reach the appropriate release depth. It is unknown how effectively recreational fishers use descending devices (Chen 2012) and little research has been undertaken to compare or evaluate fish survival with the various methods. A recent study showed that recreational fishers preferred using the pressure release devices for ease of use with the weighted crate being the second preference. These two methods also had the highest proportion of successful descents whereas other devices didn't always release the fish at depth (Lyall Bellquist, Western Groundfish Conference, Seaside California, February 13-16, 2018). The pressure release devices do, however, require regular maintenance and recalibration in order to function properly (John Harms, Western Groundfish Conference, Seaside California, February 13-16, 2018). The ideal depth that a fish should be returned to is also unknown. Some agencies recommend at least ½ the capture depth, or 60 feet, or return to the capture depth.

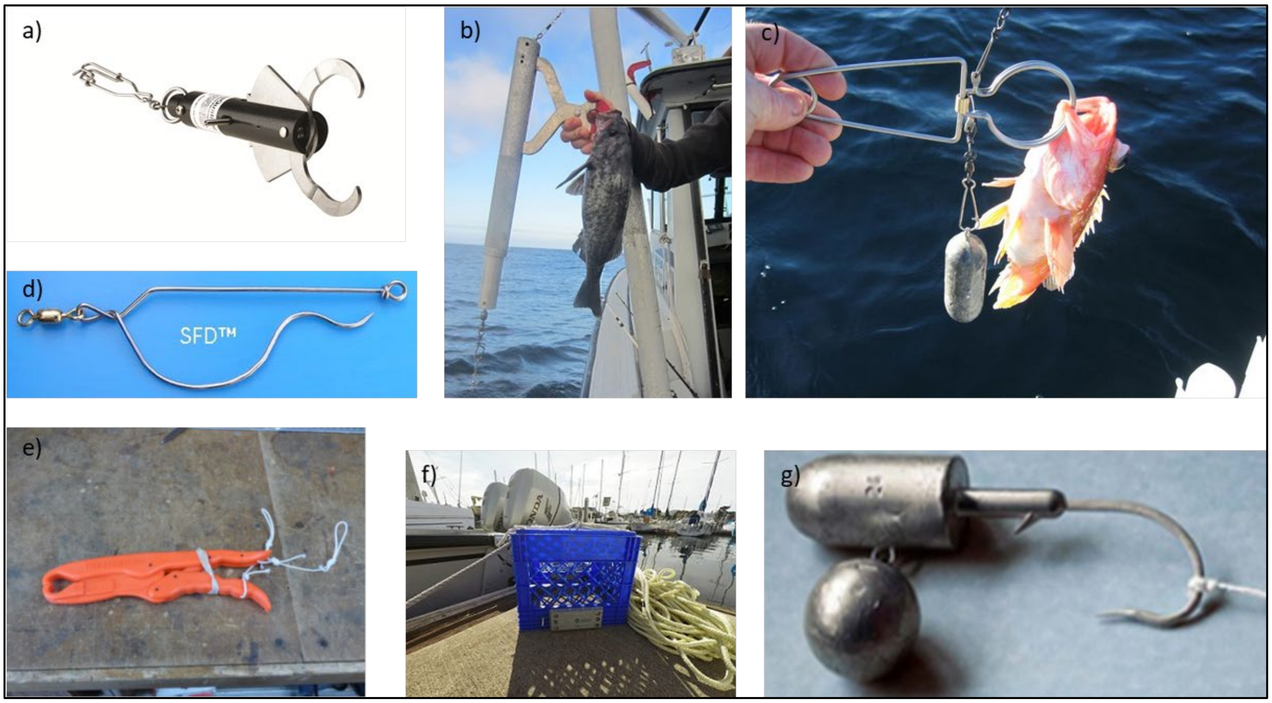


Figure 3. Commercially available and home-made descending devices. a) SeaQuilizer, b) Blacktip's Catch and Release Recompression Tool, c) RokLees Descender Device by EcoLeeser, d) Shelton's Fish Descender, e) "The Fish Grip" modified descending device, f) a weighted milk crate, g) a barbless, weighted hook.

When considering the use of recompression devices for recreational anglers, there are other factors that can influence the success of the devices, such as how the rockfish was initially caught. Researchers studying barotrauma mitigation methods for released Australian bass (Roach et al. 2011) found that the location of the hook in the captured fish had a significant impact on survival – despite whether or not recompression was used. Hooks can cause various types of injuries to fish depending on the anatomical location of the hook on the fish. These researchers found that post-capture mortality was significantly higher if the fish had ingested the hook, as opposed to being hooked in the lip or mouth.

The time a fish spent at the surface was been found to be the most significant predictor of short-term survival of rockfish that had been recompressed (Jarvis and Lowe 2008). Parker *et al.* (2006) recommends rapid recompression, and suggests that minimal time and handling at the surface will reduce the impacts of physiological stress on the fish. Stress involved in the forced ascent and handling cause increases in lactic acid and tissue CO_2, which lowers pH and the solubility of blood gases, which can contribute to embolisms. Reduced time on the surface will also reduce the negative impacts of low pressure, thermal stress, and asphyxia and improve post-recompression survival. Scientific studies on barotrauma all control for surface time; however, the amount of time it actually takes fishers to recompress rockfish is unknown and is likely dependent on the device used and the experience of the fisher.

Washington, Oregon, California, and Alaska have all developed best practices outreach material on how fishers should recompress rockfishes. For instance, Washington State recommends the following points (WDFW 2013):

1. Get the rockfish down quickly-have your descending device ready to use. Fish returned to depth within 2 minutes have a better chance of survival. Survival can decrease in half every 10 minutes the fish is out of the water.
2. Avoid rough handling; avoid dropping the fish; touch fish as little as possible. Use a wet towel or wet your hands to avoid removing the protective slime coat.
3. Return the fish back to the depth of capture or at least 60 feet (20 m).
4. Use the descending device that works for you-consider the fishing location, depth, and type of boat you have.

2.9 THE USE OF DESCENDING DEVICES IN RECREATIONAL FISHERY MANAGEMENT OF ROCKFISHES IN THE UNITED STATES

Fish are managed by the National Marine Fisheries Service (NMFS) wing of the National Oceanic and Atmospheric Administration (NOAA) (aka NOAA Fisheries) between 3 and 200 miles from shore (i.e., within the Economic Exclusive Zone of the United States) using regional fishery management councils. These councils include representatives from federal, state, and industry interests and are informed by data from academia and the public at large. State agencies are responsible for fisheries within three miles of their respective coasts, including all inland bays and estuaries. The Pacific Fishery Management Council (PFMC) is one of eight regional management councils established by the Magnuson Fishery Conservation and Management Act of 1976 and manages fisheries off Washington, Oregon, and California. At the state-level, agencies establish seasons, harvest methods, and bag limits for recreational and commercial fishing in nearshore waters. The state-level commissions can adopt rules that are more restrictive than federal rules but not less restrictive and, in practice, rules often align reasonable well between state- and federally-managed waters. The North Pacific Fishery Management Council is the fisheries management council responsible for overseeing fisheries in the Gulf of Alaska, the Bering Sea, and the Arctic Ocean. Information pertinent to the current use of descending devices from these agencies is provided here.

2.9.1 Pacific Fishery Management Council

The PFMC has developed mortality rates for rockfishes released at the surface as well as fish released at depth with a descending device. The PFMC prescribes discard mortality rates for 21 species of rockfishes caught at 0-18, 19-36, 37-55, >55 m (0-10, 11-20, 21-30, >30 fathoms). All species except Yellowtail and Black rockfishes were considered to have 100% discard mortality when captured from depths greater than 55 m (30 fathoms) and released at the surface (Table 6) (Pacific Fishery Management Council 2012). To determine the discard mortality rate for rockfish released with a descending device, the PFMC used a Bayesian hierarchical model, which accounted for variation between species and the sample size of each species. Proxy species were used to bolster the sample size in each depth bin. The PFMC adopted buffers for uncertainty based on the upper 90% confidence interval estimate of the short-term mortality for use in management in 2014 (Benaka et al. 2014). They developed mortality rates for Canary, Yelloweye, and Cowcod Rockfishes (Table 7) because these stocks faced significant conservation challenges and were of special management concern (Pacific Fishery Management Council 2012). To increase the sample size per depth bin, they used the following “proxy” species: 19-55 m: Canary, Yelloweye, Copper, and Quillback Rockfishes; 56-91 m: Yelloweye Rockfish; >91 m: Cowcod (*S. levis*), Bocaccio, Bank (*S. rufus*) and Sunset (*S. crocotulus*) Rockfishes. The mortality estimates shown in Table 7 were made before the publication of two important studies described above that showed that Canary Rockfish mortality declines dramatically to 20% below 135 m (Hannah et al. 2014) and the sub-lethal and behavioural effects of barotrauma on deep-dwelling Yelloweye Rockfish may impact long-term survival (Rankin et al. 2017). In addition, they made the assumption that the proxy species used to increase the sample sizes in each depth bin are appropriate and have similar life history characteristics, and react similarly to rapid depressurization. This assumption is counter to much of the evidence presented in this literature review that points to high variability among species (Hannah and Matteson 2007, Jarvis and Lowe 2008, Pribyl et al. 2009, Pribyl et al. 2011), particularly species within different guilds such as demersal Yelloweye Rockfish and the more mid-water Bocaccio Rockfish (Love et al. 2002). Note that the greatest percent savings in mortality estimates for recompressed fishes as compared to estimates of fish released at the surface (M Savings, Table 7) occurs in the deeper depth bins that have the greatest uncertainty concerning long-term survival rates.

Table 6. PFMC discard mortality rates (%) by depth bin of rockfish released at the surface. Only rockfish species found in BC are shown.

	Depth Bins			
Fathoms	**0-10**	**11-20**	**21-30**	**>30**
Meters	**0-18**	**19-36**	**37-55**	**>55**
Species	**Depth Bins**			
Black	11	20	29	63
Blue	18	30	43	100
Bocaccio	19	32	46	100
Brown	12	22	33	100
Canary	21	37	53	100
China	13	24	37	100
Copper	19	33	48	100
Quillback	21	35	52	100
Tiger	20	35	52	100
Vermillion	20	34	50	100
Widow	21	36	52	100
Yelloweye	22	39	56	100
Yellowtail	10	17	25	50

Table 7. PFMC recommendations for total discard mortality (M) (%) for Canary and Yelloweye Rockfishes reflecting the use of descending devices (DD) incorporating short-term mortality, long-term mortality, unaccounted for mortality, and upper 90% confidence interval as precautionary buffers for uncertainty. The mortality rate used when the fish is discarded at the surface and the difference between the surface mortality and mortality with descending device is also given (M Savings).

	Depth Bins				
Fathoms	**0-10**	**11-20**	**21-30**	**30-50**	**>50**
Meters	**0-18**	**19-36**	**37-55**	**56-91**	**>92**
Canary					
Surface M	21	37	53	100	100
DD M	20	20	20	33	31
DD M 90% CI	21	21	21	37	45
M Savings	0	16	32	63	55
Yelloweye					
Surface M	22	39	56	100	100
DD M	20	20	20	22	31
DD M 90% CI	21	21	21	27	45
M Savings	1	18	35	73	55

2.9.2 California

The Californian Department of Fish and Wildlife (CDFW) use the mortality estimates adopted by the PFMC (Table 7), as well as depth-stratified mortality rates for rockfishes that are released at the surface, in their management of recreational fisheries. Applying these mortality estimates in management requires the following information: the disposition of the discard (was the fish discarded at the surface or with a descending device); the species (mortality rates associated with descending device use are species-specific); and the depth of capture to ascribe catch to a depth bin. In addition, data are stratified by month, district (six districts with different disposition rates), depth (10-fathom depth bins), and fishing mode (commercial passenger fishing vessels (party boats) or private/rental boats). The California Recreational Fisheries Survey (CRFS) samplers collect information about recreational fishing in a creel survey, enter data into a database, and apply estimation methods. Many changes were required to account for the use of descending devices. More than 80 CRFS samplers had to be trained to collect additional information including use of descending devices and the depth fished, the database needed to be updated with additional fields and codes to account for disposition, and the estimation program needed to be updated to run the algorithms to account for the use of descending devices. CDFW has also used data collected in the creel surveys on the use of descending devices to direct outreach amongst low-use areas and has collaborated with fishing clubs to generate support for descending devices. They have explored the mandatory versus voluntary use of descending devices but would rather incentivize and motivate use instead of mandate their use due to logistical issues associated with enforcement (Burdock 2016[2]).

2.9.3 Oregon

No one from the Oregon Department of Fish and Wildlife (ODFW) presented at the Rockfish Recompression Workshop in October 2016; however, recreational rockfish management information is found on the ODFW website. The use of descending devices in Oregon has recently been made mandatory. The regulation is as follows:

"Any vessel fishing for, or possessing bottomfish, including flatfish species or Pacific Halibut in the ocean must have a functional descending device onboard, and use when releasing any rockfish outside 30 fathoms (55 m). Functional descending device means one that is ready to be used." (ODFW 2018)

Mortality rates for Yelloweye Rockfish by depth bin for fish released at the surface or by descending device developed by the PFMC are used. Advice received by anglers in 2016 supported making descending devices mandatory rather than shortening the fishing season (ODFW 2016).

2.9.4 Washington

Within the vast majority of Puget Sound (i.e., the inland marine waters of Washington state) Canary and Yelloweye Rockfishes were listed as threatened, and Bocaccio were listed as endangered, under the Endangered Species Act in 2010. In response, the Washington Department of Fish and Wildlife (WDFW) accelerated recovery planning already in progress, closed many commercial fisheries, prohibited the recreational retention of all rockfish species, and prohibited fishing for bottomfish in waters deeper than 36.6 m (120 feet) in Puget Sound. One of the recovery strategies taken by WDFW, NOAA, and their Tribal partners is to promote the descent of rockfishes. Although retention of rockfish is illegal, bycatch mortality still occurs and is managed to an annual target of 5,000 pounds (2268 kg) by all fisheries. Recreational fishery effort is monitored with a randomized telephone interview of anglers conducted in two-month "waves" throughout the year, and catch is estimated through systematic creel surveys. The phone and dockside interviews collect information on catch and bycatch by species, management area, and target type (salmon, bottomfish, halibut, and other). Sampled catch and bycatch composition is applied to effort levels from phone surveys to produce interaction estimates of catch (Lowry 2016[3]). In 2013, a question about the release of rockfish was added to the angler interview and in 2014, a question on the use of descending devices was also added (Wargo 2016[4]). In order to estimate mortality of released rockfish, the WDFW uses information on the proportion of each species found in water less than 36.6 m from fishery-independent surveys (ROV, trawl, drop camera, and dive surveys). They also apply the PFMC mortality estimates for species caught shallower than 36.6 m and released at the surface (Table 6). Fish caught deeper than 36.6 m are assumed to have 100% mortality, as are fish that are

---

[2] Burdock, J. 2016. Accounting for the use of descending devices in management in California. Rockfish Recompression Workshop, SFU Wosk Centre for Dialogue, Vancouver BC.

[3] Lowry, D. 2016. The management of rockfish in Puget Sound: where do descending devices come in? Rockfish Recompression Workshop, SFU Wosk Centre for Dialogue, Vancouver BC.

[4] Wargo, L. 2016. Protecting Washington's rockfish: barotrauma-descending devices, angler outreach and education. Rockfish Recompression Workshop, SFU Wosk Centre for Dialogue, Vancouver BC.

retained. An example of how this calculation is applied with and without the use of descending devices is as follows:

Copper Rockfish Mortality Calculation Example: if 29 Copper Rockfish are retained and 1561 are released and where:

- P= 0.8 (The Proportion of Copper Rockfish in shallow water, estimated from fishery-independent data)
- S=0.33 (Surface Mortality post-release)
- M_{total} = Total Mortality without descending devices:

  $M_{total} = M_{retained} + S(P^*(M_{released})) + ((P-1)^*(M_{released}))$

  $M_{total} = 29 + 0.33(0.8^*(1561)) + (0.2^*1561)$

  $M_{total} = 753$

- M_{total} with descending devices:

  Angler interview data suggest only 5-7% voluntary use of descenders (D), so D=0.07

  $M_{total} = M_{retained} + (1-D)(S(P^*(M_{released})) + P-1(M_{released}))$

  $M_{total} = 29 + 0.93(0.33(0.8^*(1561)) + (0.2^*1561))$

  $M_{total} = 703$

Therefore, 50 coppers are estimated to be “saved” by the use of descending devices, assuming 100% survival upon release (Lowry 2016[3]). WDFW have also undertaken outreach and education aimed at recreational anglers to increase awareness of barotrauma and its impacts, describe the benefit of descending rockfish back to depth, and present the best techniques and tools to descend fishes. It includes materials and information on rockfish species identification and web, poster, and brochure information on “sending that rockfish down’ (WDFW 2013, Wargo 2016[4]). Despite considerable outreach, overall use of descending devices is low and is estimated to be between 5% and 7%, depending on area and species (Lowry 2016[3], Wargo 2016[4]). In 2017 the WDFW made it mandatory that all recreational anglers targeting bottomfish have a descending device onboard, rigged, and ready for use when fishing in state waters, including along the outer coast. The proposal to enact this rule change came from a prominent recreational angling group after several years of collaborative outreach and education efforts that indicated voluntary use was at levels too low to be meaningful to conservation efforts. Due to the mandatory use as well as considerable outreach by WDFW, reported use of descenders climbed to 20% in 2017 (Dayv Lowry, Washington Department of Fish and Game, Olympia, Washington, Pers. Comm.).

2.9.5 Alaska

There was also no participation from Alaska at the 2016 Rockfish Recompression Workshop. The management of recreational fisheries in Alaska appears to be complex with numerous management areas and management boards. Information on the proper use of various descending devices is given on the Alaska Department of Fish and Game (ADFG) website; however, the use of descending devices is a voluntary guideline and catch-and-release fishing for rockfishes is discouraged. The ADFG has been conducting research to measure the effectiveness of devices that allow rockfish to be released at depth. The ADGF find the results from an Alaskan study for increased short-term survival of Yelloweye Rockfish encouraging (Hochhalter and Reed 2011); however, they caution that further research is required before the long-term effects on growth or reproduction are certain. The ADFG states that the first conservation tool for rockfish is prevention. They recommend avoiding catching unwanted rockfishes while targeting Halibut and Lingcod by keeping jigs and bait 3-4.5 m (10-15 feet) off the bottom and avoiding rockfish habitats of boulders, ridges, and pinnacles. Like in BC, they recommend moving to a different fishing spot when rockfish are being caught unintentionally. Other methods to prevent catch that are given are to target other species first, to avoid excessive rockfish harvest, and to use release-friendly tackle such as circle-hooks. The second conservation tool listed is the use of descending devices. When using descending devices, anglers are encouraged to send the fish back down as quickly as possible to the depth of capture or 45 m (150 feet). In some management areas, anglers may be required to retain the first one or two non-pelagic rockfishes caught.

3 KNOWLEDGE GAPS AND UNCERTAINTY

3.1 SCIENTIFIC UNCERTAINTY

Although the recompression of rockfishes through the use of descending devices has the potential to greatly reduce the mortality of released rockfish, several important knowledge gaps remain, particularly for species in BC. Limited information based on very small sample sizes exists for Copper, Brown, China, and Tiger Rockfishes, as well as many shelf species, regarding the effects of rapid recompression. Even less information on survival after recompression exists, especially for the depth and temperature ranges relevant to BC. There is no information on the newly described Deacon Rockfish, although it presumably will behave similar to the closely related Blue Rockfish. Even the species that have been studied to a greater extent, Black, Canary, Yelloweye, and Quillback Rockfishes, largely lack long-term survival information in the wild across typical depth ranges where the species are caught. A major uncertainty is the critical depth at which recovery plummets by species, and if such a depth does indeed exist for all, or most, of these species. Canary Rockfish survival rates drastically dropped from 80% to 20% between 75 m and 135 m. If this depth were to be known, a management regulation could be put into place prohibiting fishing below a certain depth. However, this critical depth likely varies by species because Yelloweye Rockfish survival was not as drastically reduced across the same depths (Hannah et al. 2014). Recreational fishing with hook and line for all species of bottomfish is prohibited by the WDFW below 36.6 m in Puget Sound, WA in an effort to conservatively address this uncertainty about species-specific rockfish mortality.

More information on behavioral and sub-lethal effects of barotrauma in recompressed rockfish across a depth gradient would greatly help elucidate the value of descending devices in rockfish conservation and management. Rankin et al. (2017) showed that lasting and severe internal damage to swim bladders and other organs persisted after 30 days post-recompression in deep-dwelling Yelloweye Rockfish. These fish also remained negatively buoyant throughout the 15- and 30-day experiments. Pribyl et al. (2012) also found that the primary problem Black Rockfish experience following recompression is negative buoyancy from a ruptured swim bladder. They explain that a mid-water fish such as a Black Rockfish may be more greatly affected by negative buoyancy than a sedentary, benthic species, but the effects of negative buoyancy on survival is difficult to infer from lab studies because the fish are fed and predators are absent. Clearly some energetic and behavioral costs exist, such as their ability to move effectively, find refuge and prey, and avoid predators upon release (Rankin et al. 2017). The effect of these costs to rockfish populations is, however, unclear.

Predation risk that recompressed fish experience is also likely not equal across species, or for smaller fish within a species. Tagged Yelloweye Rockfish under 40 cm had lower survival rates and may have had greater predation pressure post-recompression (Hochhalter and Reed 2011).

More tag-recapture or acoustic tagging studies are needed on rockfish species to better understand these risks (Pribyl et al. 2012).

The survival rates of recompressed rockfish that are found in the literature are from scientific studies, and survival rates when fish are recompressed by recreational fishers are likely to be different. The difference in stress, injury, and the resulting mortality rate will vary depending on the experience level of the angler handling the fish and their regard for the survival of fish (Pacific Fishery Management Council 2012). Handling time, hooking injuries, temperature, and time on deck are all factors known to affect survival, which are difficult to manage for in a recreational fishing context. No research exists on the most successful descenders to use or the optimal depth to which a fish should be returned. There is also a lack of information about survival rates when fish are caught in fisheries other than hook and line fisheries, such as in traps or trawls; however, mortality on inshore rockfishes from traps and trawls is much lower than it is from hook and line fisheries. Additional injuries associated with these fisheries might affect survival after recompression. Another information gap concerns the effect of multiple captures on the survival and health of a fish.

3.2 INFORMATION REQUIRED FOR MANAGEMENT

How to best incorporate descending devices into recreational management is also yet to be determined. In order to develop appropriate mortality rates for the use in discounting catch, information on capture depth by species would be required. Currently, we have no information on the capture depth from the recreational fishery and the species identification of rockfishes remains uncertain. Catch monitoring programs (Creel survey and iRec) would also need to be expanded to collect data on the identity of rockfish species released by fishers, the depth of capture, and the proportion of fishers using descending devices.

The PFMC has made an effort to determine mortality rates for recompressed Yelloweye and Canary Rockfishes; however, estimates do not take into account more recent research results on short- and long-term mortality rates for these species when caught in deep water (Hannah et al. 2014, Rankin et al. 2017) and rely on data from proxy species that may not be appropriate.

Enforcement of the use of descenders may realistically be limited to the mandatory possession of a descender, as it is in Oregon. It is unlikely if using a device correctly can be enforced. Compliance with existing rockfish conservation measures and knowledge of recreational management regulations has been shown to be low (Lancaster et al. 2015, Haggarty et al. 2016, Lancaster et al. 2017). Therefore, outreach and education programs to teach recreational fishers how to identify rockfishes and how to properly handle and return fish to depth them would be imperative to ensure successful mitigation of rockfish mortality.

4 CONCLUSION

Rockfish species show a remarkable resiliency in their ability to recover from barotrauma and to survive after recompression. However, the effects of barotrauma and the survival rates are complex in this diverse genus of fishes and a number of uncertainties remain. Although recompression certainly increases the survival rates of discarded fish that would otherwise be unable to descend, and therefore remain at risk of predation by birds and mammals, keeping what you catch and moving fishing locations to avoid capture or ceasing to fish once limits have been reached remains a better recommendation. Maintaining spatially managed rockfish conservation areas closed to fishing is also a critical component to rockfish conservation and rebuilding plans. Incorporating the voluntary or mandatory use of descending devices in the management of recreational rockfish fisheries will require careful consideration because considerable uncertainty about their effectiveness to mitigate rockfish mortality remains.

5. REFERENCES CITED

Alesandrini, S., and G. Bernardi. 1999. Ancient Species Flocks and Recent Speciation Events: What Can Rockfish Teach Us About Cichlids (and Vice Versa)? Journal of Molecular Evolution **49**:814-818.

Beaudreau, A. H., and T. E. Essington. 2007. Spatial, temporal, and ontogenetic patterns of predation on rockfishes by lingcod. Transactions of the American Fisheries Society **136**:1438-1452.

Benaka, L. R., L. Sharpe, L. Anderson, K. Brennan, J. E. Budrick, C. Lunsford, E. Meredith, M. S. Mohr, and C. Villafana. 2014. Fisheries Release Mortality: Identifying, Prioritizing, and Resolving Data Gaps. NOAA Technical Memorandum NMFS-F/SPO-142, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Blain, B. J., and T. M. Sutton. 2016. Reproductive Status and Blood Plasma Indicators of Sex and Gonad Maturation Status for Yelloweye Rockfish Following Barotrauma and Recompression Events. Transactions of the American Fisheries Society **145**:1234-1240.

California Sea Grant. 2008. Bring that rockfish down.*in* C. S. Grant, editor. California Department of Fish and Game.

Chen, I. 2012. Putting Rockfish Back Where They Belong. Science **338**:600-601.

DFO. 2017. Pacific Region integrated fisheries management plan, groundfish, effective February 21, 2017. Fisheries and Oceans Canada, 2017, Vancouver BC

Eberts, R. L., and C. M. Somers. 2017. Venting and Descending Provide Equivocal Benefits for Catch-and-Release Survival: Study Design Influences Effectiveness More than Barotrauma Relief Method. North American Journal of Fisheries Management **37**:612-623.

Favaro, B., D. T. Rutherford, S. D. Duff, and I. M. Côté. 2010. Bycatch of rockfish and other species in British Columbia spot prawn traps: Preliminary assessment using research traps. Fisheries Research **102**:199-206.

Feathers, M. G., and A. E. Knable. 1983. Effects of Depressurization Upon Largemouth Bass. North American Journal of Fisheries Management **3**:86-90.

Frable, B. W., D. Wagman, T. N. Frierson, A. Aguilar, and B. L. Sidlauskas. 2015. A new species of Sebastes (Scorpaeniformes: Sebastidae) from the northeastern Pacific, with a redescription of the blue rockfish, S. mystinus (Jordan and Gilbert, 1881). Fishery Bulletin **113**:355-377.

Frid, A., M. McGreer, D. R. Haggarty, J. Beaumont, and E. J. Gregr. 2016. Rockfish size and age: The crossroads of spatial protection, central place fisheries and indigenous rights. Global Ecology and Conservation **8**:170-182.

Haggarty, D. R., and J. R. King. 2006a. CPUE as an index of relative abundance for nearshore reef fishes. Fisheries Research **81**:89-93.

Haggarty, D. R., and J. R. King. 2006b. Hook and line survey of lingcod (*Ophiodon elongatus*) and rockfish (*Sebastes spp.*) in southern Strait of Georgia (statistical areas 18 and 19) June 19-29, 2005.

Haggarty, D. R., S. J. D. Martell, and J. B. Shurin. 2016. Lack of recreational fishing compliance may compromise effectiveness of Rockfish Conservation Areas in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences **73**:1587-1598.

Hannah, R. W., and K. M. Matteson. 2007. Behavior of nine species of Pacific rockrish after hook-and-line capture, recompression, and release. Transactions of the American Fisheries Society **136**:24-33.

Hannah, R. W., S. J. Parker, and K. M. Matteson. 2008a. Escaping the surface: The effect of capture depth on submergence success of surface-released Pacific rockfish. North American Journal of Fisheries Management **28**:694-700.

Hannah, R. W., and P. S. Rankin. 2011. Site Fidelity and Movement of Eight Species of Pacific Rockfish at a High-Relief Rocky Reef on the Oregon Coast. North American Journal of Fisheries Management **31**:483-494.

Hannah, R. W., P. S. Rankin, and M. T. O. Blume. 2012. Use of a Novel Cage System to Measure Postrecompression Survival of Northeast Pacific Rockfish. Marine and Coastal Fisheries **4**:46-56.

Hannah, R. W., P. S. Rankin, and M. T. O. Blume. 2014. The divergent effect of capture depth and associated barotrauma on post-recompression survival of canary (*Sebastes pinniger*) and yelloweye rockfish (S. ruberrimus). Fisheries Research **157**:106-112.

Hannah, R. W., P. S. Rankin, A. N. Penny, and S. J. Parker. 2008b. Physical model of the development of external signs of barotrauma in Pacific rockfish. Aquatic Biology **3**:291-296.

Hochhalter, S. J. 2012. Modeling submergence success of discarded yelloweye rockfish (Sebastes ruberrimus) and quillback rockfish (Sebastes maliger): Towards improved estimation of total fishery removals. Fisheries Research **127-128**:142-147.

Hochhalter, S. J., and D. J. Reed. 2011. The Effectiveness of Deepwater Release at Improving the Survival of Discarded Yelloweye Rockfish. North American Journal of Fisheries Management **31**:852-860.

Hudson, S. 2015. How to release bottomfish right; Alleviate barotrauma in bottomfish with these fish descender devices. Sport Fishing. Posted June 11, 2015. (Accessed January 29, 2019)

Hyde, J. R., and R. D. Vetter. 2007. The origin, evolution, and diversification of rockfishes of the genus *Sebastes* (Cuvier). Molecular Phylogenetics and Evolution **44**:790-811.

Ingram, T. 2011. Speciation along a depth gradient in a marine adaptive radiation. Proceedings of the Royal Society B-Biological Sciences **278**:613-618.

Jarvis, E. T., and C. G. Lowe. 2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, Sebastes spp.). Canadian Journal of Fisheries and Aquatic Sciences **65**:1286-1296.

Lancaster, D., P. Dearden, and N. C. Ban. 2015. Drivers of recreational fisher compliance in temperate marine conservation areas: A study of RCAs in British Columbia, Canada. Global Ecology and Conservation:645-657.

Lancaster, D., D. R. Haggarty, J. Volpe, P. Dearden, and N. C. Ban. 2017. Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas. Aquatic Conservation: Marine and Freshwater Ecosystems **27**:804-813.

Love, M., M. Yoklavich, and L. Thorsteinson. 2002. The Rockfishes of the Northeast Pacific. University of California Press, Los Angeles.

Matthews, K. R. 1990. An experimental study of the habitat preferences and movement patterns for copper, quillbak, and brown rockfishes (*Sebastes spp*.). Environmental Biology of Fishes **29**:161:178.

ODFW (Oregon Department of Fish and Wildlife). 2018. Summarized History of Oregon Marine Sport Fishing Regulations – Groundfish, Offshore Pelagic Species and Nongame fish.

ODFW (Oregon Department of Fish and Wildlife) 2016. Oregon 2017 bottomfish (groundfish) season. (Accessed January 29, 2019)

Pacific Fishery Management Council, P. 2012. Groundfish Management Team progress report on developing mortality rates for rockfish released using descending devices. Pacific Fishery Management Council, Portland, OR. , Agenda Item I.3. (Accessed January 29, 2019)

Parker, S. J., S. A. Berkeley, J. T. Golden, D. R. Gunderson, J. Heifetz, M. A. Hixon, R. Larson, B. M. Leaman, M. S. Love, J. A. Musick, V. M. O'Connell, S. Ralston, H. J. Weeks, and M. M. Yoklavich. 2000. Management of Pacific rockfish. Fisheries **25**:22-30.

Parker, S. J., H. I. McElderry, P. S. Rankin, and R. W. Hannah. 2006. Buoyancy regulation and barotrauma in two species of nearshore rockfish. Transactions of the American Fisheries Society **135**:1213-1223.

Parker, S. J., P. S. Rankin, R. W. Hannah, and C. B. Schreck. 2003. Discard mortality of trawl-caught lingcod in relation to tow duration and time on deck. North American Journal of Fisheries Management **23**:530-542.

Pribyl, A. L., M. L. Kent, S. J. Parker, and C. B. Schreck. 2011. The Response to Forced Decompression in Six Species of Pacific Rockfish. Transactions of the American Fisheries Society **140**:374-383.

Pribyl, A. L., C. B. Schreck, M. L. Kent, K. M. Kelley, and S. J. Parker. 2012. Recovery potential of black rockfish, Sebastes melanops Girard, recompressed following barotrauma. Journal of Fish Diseases **35**:275-286.

Pribyl, A. L., C. B. Schreck, M. L. Kent, and S. J. Parker. 2009. The Differential Response to Decompression in Three Species of Nearshore Pacific Rockfish. North American Journal of Fisheries Management **29**:1479-1486.

Rankin, P. S., R. W. Hannah, M. T. O. Blume, T. J. Miller-Morgan, and J. R. Heidel. 2017. Delayed effects of capture-induced barotrauma on physical condition and behavioral competency of recompressed yelloweye rockfish, Sebastes ruberrimus. Fisheries Research **186**:258-268.

Richards, L. J. 1986. Depth and habitat distributions of 3 species of rockfish (*Sebastes*) in British-Columbia - observations from the Pisces-iv. Environmental Biology of Fishes **17**:13-21.

Richards, L. J., and A. J. Cass. 1985. 1985 Research catch and effort data on near shore reef-fishes in the Strait of Georgia B.C. (Statistical Areas 15 and 16). Canadian Manuscript Report of Fisheries and Aquatic Sciences 1851: 68 p. (Accessed January 29, 2019)

Roach, J. P., K. C. Hall, and M. K. Broadhurst. 2011. Effects of barotrauma and mitigation methods on released Australian bass *Macquaria novemaculeata*. Journal of Fish Biology **79**:1130-1145.

Rogers, B. L., C. G. Lowe, and E. Fernández-Juricic. 2011. Recovery of visual performance in rosy rockfish (Sebastes rosaceus) following exophthalmia resulting from barotrauma. Fisheries Research **112**:1-7.

Rogers, B. L., C. G. Lowe, E. Fernandez-Juricic, and L. R. Frank. 2008. Utilizing magnetic resonance imaging (MRI) to assess the effects of angling-induced barotrauma on rockfish (*Sebastes*). Canadian Journal of Fisheries and Aquatic Sciences **65**:1245-1249.

Rummer, J. L., and W. A. Bennett. 2005. Physiological Effects of Swim Bladder Overexpansion and Catastrophic Decompression on Red Snapper. Transactions of the American Fisheries Society **134**:1457-1470.

Smiley, J. E., and M. A. Drawbridge. 2007. Techniques for live capture of deepwater fishes with special emphasis on the design and application of a low-cost hyperbaric chamber. Journal of Fish Biology **70**:867-878.

Theberge, S., and S. J. Parker. 2005. Release methods for rockfish. Oregon State University, Corvallis. Oregon Sea Grant Publication, ORESU_G_05-001. (Accessed January 29, 2019)

WDFW (Washington Department of Fish and Wildlife). 2013. Protecting Washington's Rockfish. (Accessed January 29, 2019)

Yamanaka, K., and G. Logan. 2010. Developing British Columbia's Inshore Rockfish Conservation Strategy. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science **2**:28-46.