ABSTRACT

THE EFFECTS OF BAROTRAUMA ON THE CATCH-AND-RELEASE SURVIVAL OF SOUTHERN CALIFORNIA NEARSHORE AND SHELF ROCKFISHES (SCORPAENIDAE, *SEBASTES* SPP.)

By

Erica T. Jarvis

May 2007

Three experiments were used to assess initial capture survival, and short- and long-term post-release survival of line-caught (18 to 225 m) southern California rockfish following recompression. Initial capture survival of 19 rockfishes held in a live well for a 10 min period following capture was 68% overall (95% CI: 60% to 75%; n = 168). Two-day survival of 17 rockfishes following recompression in cages was also 68% overall (95% CI: 62% to 73%; n = 256). External and internal signs of barotrauma were not significant predictors of initial capture survival or short-term survival. The most significant predictor of short-term survival was surface holding time (logistic regression model: $X^2 = 8.63$, $p = 0.003$, OR = 0.95). Fish recaptures and 2-year monitoring data of acoustically tagged rockfish (n = 84) provided evidence of long-term post-release survival of rockfish of at least 690 days.

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A THESIS

Presented to the Department of Biological Sciences

California State University, Long Beach

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

By Erica T. Jarvis

B.S., 2000, California State University, Long Beach

May 2007

WE, THE UNDERSIGNED MEMBERS OF THIS COMMITTEE,

HAVE APPROVED THIS THESIS

THE EFFECTS OF BAROTRAUMA ON THE CATCH-AND-RELEASE SURVIVAL

OF SOUTHERN CALIFORNIA NEARSHORE AND SHELF ROCKFISHES

(SCORPAENIDAE, *SEBASTES* SPP.)

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ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr. Chris Lowe, for inspiring me and providing words of encouragement during both my undergraduate and graduate career. I am indebted to Dr. Jim Allen, my mentor and friend, for entrusting me with a greater level of responsibility and providing me with the training necessary for success in graduate school. I am also grateful to Dr. Ray Wilson for his insightful comments on my thesis and for Taco Tuesdays; Drs. Fernández-Juricic, Archie, and Ritter for guidance in statistical analyses; Jimmy Cvitanovich and the support staff of the RV *Yellowfin* without whom the Two-Day Cage Trials would not have been so successful; and my boss, Chuck Valle, of CDF&G for being so patient while I completed my thesis. I am extremely grateful to my generous funding sources: USC Sea Grant, CNSM Boeing Scholarship, SCAS Research Grant, SCTC Marine Biology Foundation, and the CSULB Richard B. Loomis Research Award. I would also like to thank Mary Blasius for being an awesome friend and colleague and for helping me record my field data. I also want to recognize Darin Topping, Lyall Belquist, JoAnn May, Heather Gliniak, Eugene Chae, Shannon Delaquilla, Kim Anthony, Keri Loke, Chris Mull, Chris Martin, Kate Jirik, and all of the volunteer fishers and divers in the Lowe Lab and the Aquarium of the Pacific. I also would like to thank my wonderful family for their undying enthusiasm and support of my research. And finally, I am especially indebted to my fiancé, Tom Mason, for his countless hours of help with my research and for his constant love and encouragement.

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CHAPTER 1

INTRODUCTION

Rockfish catches have been an important component of the winter recreational fishery in southern California since the 1950s (Dotson and Charter, 1998). In the early 1980s, however, rockfish catches began to decline dramatically due to a combination of oceanographic and fishing effects (Mearns et al., 1980; Archibald et al., 1983; Love et al., 2002). Despite the implementation of a reduced catch limit and depth of capture restrictions, several populations of rockfish are now considered overfished (Love et al., 1998 a,b; Mason, 1998; Mac Call, 1999; Butler et al., 2003). In addition to recruitment overfishing, there is strong evidence indicating that rockfish populations have been subjected to growth overfishing over the last two decades. The average size of rockfish caught has decreased (Love et al., 1998b; Mason, 1998), and rockfish assemblages on fished reefs are dominated by smaller species of rockfish, “dwarf species” that are not harvested (Love et al., 2002). Because rockfishes are long-lived, take a long time to reach sexually maturity, and show episodic recruitment, it is estimated that it will take decades for these rockfish populations to recover (Mac Call, 1999; Butler et al., 2003)

Current Pacific coast rockfish regulations include bag limits and season closures that require the release of incidentally caught rockfish. In addition to fishers throwing back species they cannot retain, fishers will discard most unwanted incidentally caught fish and/or illegally practice “high-grading” where they trade out smaller fish for larger fish, tossing smaller fish overboard until a bag limit of larger-sized fish is reached[1] (Jennings et al., 2001). Because of a reduction in size due to overfishing of large mature individuals, these types of harvest restrictions put increased pressure on immature fish. Furthermore, they do not provide a means of reducing discard mortality because rockfishes are particularly susceptible to pressure related injury known as barotrauma[2].

Rockfishes are physoclistic species possessing a closed, discrete, swim bladder, and when a fish is rapidly brought to the surface, the swim bladder over-inflates causing internal injury and positive buoyancy. As a result, these positively buoyant fish are unable to swim down deep enough to force recompression of gases within their bodies and swim bladders and therefore many succumb to thermal shock and/or bird or marine mammal predation at the surface. Expanded gases within the swim bladder, tissues, and blood vessels will often result in external signs of barotrauma that are obvious once a fish is landed. External signs of barotrauma include stomach eversion, exophthalmia (bulging eyes), corneal gas bubbles, fin hemorrhage, and subcutaneous gas bubbles (Gotshall, 1964; Gitschlag and Renaud, 1994; Keniry et al., 1996, Lea et al., 1999). Internal signs of angling-induced barotrauma that occur as a result of expanding gases include swim bladder rupture, hematoma, hemorrhage, and organ torsion. At the surface, immediate mortality associated with barotrauma may occur as a result of arterial embolism (Rummer and Bennett, 2005). Upon release, if a fish is able to swim to depth on its own, internal trauma and/or physiological stress (Morrissey et al., 2005), may cause delayed mortality

[1] *http://www.dfg.ca.gov/mrd/nfmp/section1_chap2.html#legality*, Downloaded March 26, 2007

[2] *http://www.pcouncil.org/groundfish/gffmp.html*, Downloaded March 26, 2007

in the hours or days following release. Post-release survival of other physoclistic fishes has been found to be dependent on the depth of capture, with fish caught at deeper depths showing more severe signs of barotrauma (Feathers and Knable, 1983; Wilson and Burns, 1996; Morrissey et al., 2005; St. John and Syers, 2005).

Despite the economic value of rockfishes in southern California, surprisingly few, if any, studies have characterized external and internal signs of angling-induced barotrauma in rockfishes, or the effects of angling-induced barotruama on initial capture survival or post-release survival. There are assumptions that certain signs of barotrauma are more lethal than others; however, there are no data supporting these assumptions. A recent study conducted by Hannah and Matteson (2007) reported species-specific differences in the extent of external signs of angling-induced barotrauma in rockfishes from central California. It is possible that both external and internal signs of angling-induced barotrauma in southern California rockfishes may also be species-specific. Several studies on other species of physoclists have found no correlation between extent of barotrauma and survival (Gitschlag and Renaud, 1994; Rummer and Bennet, 2005). However, Hannah and Matteson (2007) documented alleviation of angling-induced external signs of barotrauma following recompression of rockfishes, suggesting that if fishers assist discarded fish back to the seafloor instead of leaving them to float at the surface, post-release survival may be increased. Even so, the effects of internal barotrauma on initial capture survival and/or post-release survival are not known.

Some studies have evaluated the effectiveness of deflating swim bladders, "venting", to increase survival of over-inflated fish by relieving excess gas with a hypodermic needle which enables fish to swim to depth on their own following release

(Gotshall, 1964; Bruesewitz et al., 1993; Keniry et al., 1996; Collins et al., 1999). However, venting is still controversial because the results of these studies are not definitive and because experience using this method is necessary to avoid accidental puncture of vital organs (Kerr, 2001). A variety of assisted release (i.e. recompression) methods, including weighted milk crates and "fish descenders", currently exist to return unwanted and over-inflated fish to depth following capture (Theberge and Parker, 2005). Releasing rockfish at depth aims to decrease the probability of discard mortality, but the practice can only be effective if evidence indicates that a high enough percentage of fish which are returned to depth recover and survive. Recent studies have attempted to quantify post-release survival of rockfishes following assisted release with the use of pressure chambers or cages (Parker et al., 2006; Hannah and Matteson, 2007). Although these studies suggest high survival and recovery ability of rockfishes, the studies have either not simulated natural conditions such as effects from hooking, temperature shock, and fighting stress, or have made predictions about survival based on initial release condition.

My study aims to quantify the effects of angling induced barotrauma on both initial capture survival and short-term survival of rockfishes recompressed to depth. An understanding of post-recompression survival in rockfishes will enable fisheries managers to assess the utility of catch-and-release regulations not only in southern California, but along the west coast and offer resource managers more accurate population parameters for stock assessments. Further, if it is shown that rockfishes have high post-release survival, implementation of catch-and-release may support long-term sustainability of the resource. The primary objectives of my study were to 1) characterize external and internal signs of angling-induced barotrauma in rockfishes and 2) quantify initial survival (within 10 min of capture), short-term (two-day) survival following recompression in cages, and 3) investigate long-term (two-year) survival.

CHAPTER 2

METHODS

Characterization of Barotrauma and Initial Capture Survival

Nearshore and shelf rockfishes were captured by hook-and-line from the Palos Verdes peninsula (30 – 70 m), near Southeast Bank off Huntington Beach (50 – 90 m), at offshore petroleum platform Gilda off the Ventura coast (55 m), and near Two Harbors at Catalina Island (18 – 96 m) between October 2004 and March 2006 (figure 1). All fishing targeted demersal species. Bottom depth, time of day fish was landed, and standard length were recorded, in addition to the presence of external signs of barotrauma including stomach eversion (SE), exophthalmia (EX), corneal gas bubbles (CB), subcutaneous gas bubbles (SB), and prolapsed cloaca (PC). Handling time to measure and examine fish was kept to less than two minutes. Fish were placed in a live well or cooler with fresh seawater for 10 min, after which each fish was assessed for signs of gill ventilation as an indicator of initial capture survival. Fourteen greenspotted rockfish (*Sebastes chlorostictus*) were donated from a private fishing vessel and therefore no survival data were obtained for these fish. After noting survival, fish were euthanized by placing them in an ice bath of sea water for 30 min. Euthanized fish were refrigerated and dissected within 24-48 hr after capture. Internal signs of barotrauma were recorded as presence of swim bladder ruptures (SR), organ torsion (OT), hemorrhage (HE), and presence and location of arterial gas embolisms in the pericardial chamber and at the swim bladder (AE). Swim bladder ruptures were identified as obvious tears in the swim bladder wall.

To characterize barotrauma condition and initial capture survival, the percent occurrence of external and internal signs of barotrauma and survival was calculated for each species and for all species combined. La Place Point Estimates of percent survival were also reported in cases where survival was either 0% or 100%. Correlation analysis was used to test whether the number of observed external signs of barotrauma was related to the number of observed internal signs of barotrauma. A General Linear Model (GLM) (Statistica Release 7) analysis was used to examine the relationship between depth of capture and the total number of external and internal signs of barotrauma, using species as the categorical variable and depth as the continuous variable. To determine whether the absence of a specific sign of barotrauma increased survival, a Fisher's Exact test was used compare the proportion of survivors with and without a given sign of barotrauma. To account for fish showing various combinations of barotrauma, a logistic regression analysis (Binary Logistic Regression, Minitab v14) was used to examine whether the extent of barotrauma was a predictor of initial survival, (Barotrauma Model I – External Signs; Barotrauma Model II – Internal Signs). Extent of barotrauma was a single, categorical, independent variable. Additionally, within each regression model output, survival of fish showing each specific combination of barotrauma was reported relative to fish showing no signs of barotrauma.

<u>Characterization of Barotrauma and Two-Day Survival Post-Recompression</u>

Nearshore and shelf rockfishes were captured by hook-and-line aboard the R/V *Yellowfin* near Southeast Bank, a rocky outcrop approximately eight kilometers west of

Huntington Beach (50 – 89 m; figure 1). This site was selected because it is a popular rockfish fishing site, has an assemblage of both nearshore and shelf rockfishes, and is within the typical sportfishing depth range for rockfishes (< 110 m). For each fish, bottom depth, time of day of landing, and standard length were recorded, in addition to the presence of external signs of barotrauma. Each fish was externally tagged for individual identification on the left side of the body with a 4 cm long Floy dart tag inserted one centimeter lateral to the anterior dorsal fin and placed in a live well at sea surface temperature prior to release. Fish were then transferred to PVC coated wire mesh cages (4 x 4 cm mesh, 1.2 m x 1.2 m x 1.5 m supported with an 18 kg rebar frame). Up to six cages were deployed each trip with as many as 12 fish per cage. Each cage was lowered to the original fish capture depth and left for two days on soft substratum to avoid entanglement on the reef. Where possible, fish were transferred to cages and immediately dropped to the sea floor within 20 min of capture. To account for differences in total surface holding duration among individuals, the exact time of each cage deployment was recorded. Two cages per trip were deployed with StowAway temperature data loggers (Onset Computers, Inc) to account for differences in temperature differential experienced among fish on different trips. Temperature differentials were recorded as the difference in water temperature between the sea floor and sea surface.

Two days following fish collection and recompression, each cage was pulled to a depth of 20 m where a team of divers met the cage and assessed each fish for mortality and external signs of barotrauma. This observation depth was chosen to reduce the probability of barotrauma injury resulting from the second decompression event. All dead fish and a subset of live fish per cage were saved for examination of internal barotrauma injury as described above; all remaining live fish were released.

The percent occurrence of external signs of barotrauma and percent survival was calculated for each species and for all species combined. Chi-square Tests of Independence were used to test for species-specific differences in the occurrence of each sign of barotrauma and survival. The extent of barotrauma observed for each species was defined as the number of signs of barotrauma occurring frequently (e.g. occurring in at least 50% or more individuals) and was compared with each species survival. Fisher's Exact tests were used to test for differences in percent survival of fish with and without each external sign of barotrauma for each species and for all species combined. Similarly, Fisher's Exact tests were used to test for differences in percent survival of fish with and without each internal sign of barotrauma for each species and for all species combined. Logistic regression analysis (Binary Logistic Regression, Minitab v14) was used to examine the effects of the presence of specific combinations of external signs of barotrauma on survival (Barotrauma Model). Finally, logistic regression (Proc Logistic, SAS v9) was used to model the effects of other variables recorded in the field that could affect survival such as depth, species, length of fish, cage density (i.e. the number of fish in each cage), temperature differential (e.g. surface temperature – sea floor temperature), and surface holding duration (Overall Model). A Reduced Model was then designed using only variables in the Overall Model found to be significant. Because many of the variables included in the model could not be controlled for in the field, no interactions were included in the model. To account for differences in species survival, an ANOVA was used to compare temperature differential experienced by each species upon capture.

Similarly, Kruskal-Wallis was used to test for differences in median surface times experienced by each species prior to recompression.

Long-term Survival

Tag Recaptures

In addition to a unique tag number, all external dart tags used in the cage experiments contained a phone number for reporting recaptured rockfish. To record evidence of longer-term survival, all tag returns were logged by tag identification number, species, date fish was recaptured, location of capture, and fisherman contact.

Acoustic Monitoring

Long-term (two-year) acoustic monitoring data on rockfishes tagged at three southern California oil/petroleum platforms (figure 1) were analyzed for evidence of longer-term survival of rockfishes following hook-and-line capture and release. These data were collected peripheral to the current study to quantify site fidelity of rockfishes to oil/petroleum platforms of the Santa Barbara Channel. Ninety rockfish comprising 12 species were captured by hook-and-line at Platforms Gail (225 m, n = 7), Grace (96 m, n = 38), and Gilda (63 m, n = 45) during the summer of 2004.

All fish were caught via hook-and-line and brought to the surface where they were anaesthetized and surgically fitted with a uniquely coded Vemco V8 or V13 acoustic transmitter. Fish were also tagged externally with a Floy dart tag inserted lateral to the anterior dorsal fin. Swim bladders were vented with an 18 gauge hypodermic needle. Standard length was recorded and barotrauma condition was recorded for some, but not all fish. The majority of fish were released to depth with milk crates from the surface, and all fish were released within 10 min of capture (Lowe et al., 2007). A subsample of fish (n = 11) were recompressed to depth in cages for a two-day period and later observed at 20 m to assess short-term survival (See Methods, Two-Day Survival Post-Recompression). Tagged fish presence was monitored at each platform using two Vemco automated VR2 acoustic receivers mounted to support vessel mooring cables (depth 20 m). Receivers recorded the date, time, and identification code from tagged fish when unobstructed transmitter signals were within the 800 m detection range of the receivers. Acoustic receiver data was downloaded every two months over a two-year period.

Because of the strong currents at the platforms, it was assumed that dead or dying tagged fish would quickly drift or be carried away from the tagging site, away from detection range of the receivers. Detections of each of the caged fish were plotted over the study period. In addition, the total number of individual fish detected at all platforms was plotted over the two-year monitoring period to examine temporal trends in fish presence that might indicate mortality or emigration. Because not all of the fish were tagged on the same date, days detected for each fish was normalized to the respective tagging date.

CHAPTER 3

RESULTS

Barotrauma and Initial Capture Survival

One-hundred and sixty-eight rockfish representing 21 species were captured over a one-and-a-half-year period from depths of 18 to 96 m; vermilion rockfish, *Sebastes miniatus*; greenspotted rockfish, *S. chloristictus*; olive rockfish, (*S. serranoides*); halfbanded rockfish (*S. semicinctus*), rosy rockfish (*S. rosaceous*), and honeycomb rockfish (*S. umbrosus*) comprised the majority of the catch (table 1). Although the occurrence and degree of barotrauma appeared to vary by species (table 2), percent initial capture survival of rockfish was 68% overall (95% CI: 60% to 75%).

The most common external signs of barotrauma observed in the overall catch (n = 168) were subcutaneous gas bubbles (SB, 76%), stomach eversion (SE, 63%) and exophthalmia (EX, 52%), while the most common signs of internal barotrauma were arterial embolism (AE, 68%), hemorrhage (HE, 64%), and organ torsion (OT, 33%; figure 2). Although subcutaneous gas bubbles and arterial embolism were the most common signs of barotrauma, these variables were not accounted for in all fish and therefore not included in species-specific analyses of barotrauma percent occurrence. The percent occurrence of each barotrauma type and the number of frequently occurring signs of barotrauma (i.e. signs occurring in greater than 50% of individuals) was species-specific (table 2). Stomach eversion occurred frequently among several species including brown rockfish (*S. auriculatus*), flag rockfish (*S. rubrivinctus*), greenspotted, halfbanded, honeycomb, rosy, starry rockfish (*S. constellatus*), treefish (*S. serriceps*), and widow rockfish (*S. ensifer*). Swim bladder ruptures (SR) occurred frequently (82%) only in olive rockfish. For the catch as a whole, there was a significant positive correlation between the number of external signs and the number of internal signs of barotrauma (r = 0.28, $p < 0.01$). The degree of barotrauma was greatest for the two species caught deepest, rosy and greenspotted rockfish. There was a significant positive relationship between depth and the total umber of traumas observed in rockfish individuals (R^2 = 0.35, F = 3.61, GLM: p < 0.001). Subcutaneous gas bubbles and arterial embolism were not accounted for in the correlation and GLM analyses (n = 168).

Percent initial capture survival was 68% overall; however, initial capture survival varied by species (figure 3). Eight of twelve species (with n > 3) had greater than 75% initial capture survival, while olive and rosy rockfish had low survival. Although fish caught at deeper depths generally showed higher numbers of trauma, there was no apparent negative relationship between species survival and the capture depth of each species (figure 3).

Overall percent survival was significantly higher for fish without arterial embolism (85%) than fish with arterial embolism (58%; two-sided Fisher's Exact test, p = 0.002). Percent survival was also significantly higher for fish without swim bladder ruptures (73%) than fish with swim bladder ruptures (42%; two-sided Fisher's Exact test, p = 0.002). Fifty-four percent of dead fish with arterial embolism were rosy and olive rockfish, and 87% of dead fish with swim bladder ruptures were olive rockfish. There was no significant effect of external or internal barotrauma category on survival

(Barotrauma Model I – External Signs, e.g. No signs, EX/CB, SE, SE/EX, SE/EX/CB, Logistic regression: $X^2 = 8.82$, d.f. = 4, p = 0.07; Barotrauma Model II – Internal Signs, e.g. No signs, AE, HE, AE/HE, AE/OT, AE/SR, HE/OT, HE/OT/AE, Logistic regression: $X^2 = 13.71$, d.f. = 7, p = 0.06). Within Barotrauma Model II, fish showing both arterial embolism and swim bladder ruptures showed significantly lower survival than fish showing no signs of barotrauma (p = 0.02. O.R. = 0.05). Olive rockfish was the only species with AE/SR.

Barotrauma and Two-Day Survival Post-Recompression

During the summer months of 2005 and 2006, 344 rockfish comprising 17 species were captured over seven trips. Of these, 328 fish were assessed for external signs of barotrauma, and 257 fish were recompressed to original capture depth in over 42 cage deployments. A minimum of three fish and a maximum of 12 were recompressed in a single cage; the average number of fish per cage (= cage density) was seven. The average capture depth was 71 m and ranged from 55 to 81 m. Five species, including vermilion rockfish, bocaccio (*S. paucispinis*), flag, squarespot rockfish (*S. hopkinsi*), and honeycomb rockfish comprised the majority (82%) of the catch (table 3). Vermilion, flag, honeycomb, halfbanded, greenspotted, olive, starry, and rosy rockfish were species that were captured in both the Initial Capture Survival Experiment and the Two-day Survival Post-recompression Experiment (=Two-day Cage Trials). Overall two-day survival of rockfishes following capture and recompression was 68% (95% CI: 62% to 73%), despite species-specific differences in the incidence and extent of barotrauma observed upon capture. Although external signs of barotrauma were common upon capture, virtually none of the caged fish (< 1%) showed external signs of barotrauma two days post-recompression.

Summary data for the five most abundant species indicated an average capture depth of 72 m; bocaccio were caught deepest and vermilion rockfish were caught most shallow (table 4). On average, cage densities for each species were seven fish per cage, but the mean cage density for flag and honeycomb rockfish was eight fish. Bocaccio experienced the greatest temperature differential between the sea floor and sea surface and honeycomb rockfish experienced the least (table 4). Surface holding duration was on average 16 min, but mean surface holding durations ranged from 14 min for flag rockfish to 21 min for squarespot rockfish. Length-frequency plots indicated that the majority of captured vermilion rockfish were juveniles while the majority of flag, honeycomb, and squarespot rockfish were adults (figure 4, table 4). Juvenile and adult bocaccio were caught in comparable numbers. Length frequency distributions of bocaccio survivors and mortalities showed no relationship between length and survival (figure 5).

The most common signs of external barotrauma observed upon capture were stomach eversion (SE, 88%), exophthalmia (EX, 47%) and corneal gas bubbles (CB, 36%) (N = 328). The occurrence of prolapsed cloaca was not common (PC, 7%). Two days following release, 75% of fish were observed with cloudy eyes. Initially, the cloudy eyes were assumed to be a residual effect of ocular trauma due to the initial capture event, but only 56% of fish showing signs of ocular trauma upon capture had cloudy eyes two-days post-recompression. Even after excluding fish that only showed exophthalmia and not corneal gas bubbles, the percentage of fish having cloudy eyes was roughly the same (54%).

The degree of external signs of barotrauma observed upon capture was species-specific (table 5). Flag, starry, and vermilion rockfish each showed three signs of barotrauma frequently (e.g. occurred in greater than 50% of individuals). In contrast, only one sign of barotrauma, stomach eversion, occurred frequently in bocaccio, halfbanded, speckled rockfish (*S. ovalis*), and squarespot rockfish. Honeycomb rockfish showed only exophthalmia and stomach eversion frequently. Among the five most abundant species, the occurrence of exophthalmia and corneal gas bubbles significantly differed by species (exophthalmia, $X^2 = 44.61$, d.f. = 4, $p \leq 0.001$; corneal gas bubbles, $X^2 = 24.86$, d.f. = 4, $p \leq 0.001$); however, there was no significant difference in the occurrence of stomach eversion among species ($X^2 = 3.05$, d.f. = 4, $p > 0.05$).

Percent survival in the Two-day Cage Trials (68%) was similar to percent survival found in the Initial Capture Survival Experiment (also 68%); however, for most species that were captured in both experiments, two-day survival post-recompression (figure 6) was lower than initial capture survival (figure 3). Two-day survival in the cage trials varied by species and ranged from 36% (95% CI: 21% to 56%) for squarespot rockfish (n = 27) to 82% (95% CI: 51% to 96%) for starry rockfish (n = 11). There was a significant difference in species survival among the five most abundant species ($X^2 = 21.6$, d.f. = 5, $p \leq 0.0001$) (figure 6); squarespot rockfish showed the lowest survival while bocaccio showed the highest survival (95% CI: 79 to 89%). Survival of these species was not related to the extent of barotrauma. For example, bocaccio (high survival) and squarespot rockfish (low survival) both showed only one frequently occurring sign of barotrauma. For each species there were no significant differences in the proportion of survivors among fish with or without each sign of barotrauma (two-sided, Fisher's Exact,

$p > 0.05$). However, the results of these analyses for stomach eversion were inconclusive because sample sizes for fish without stomach eversion were small for flag, squarespot, honeycomb, and vermilion rockfish. If all species were pooled, there were significantly higher mortalities in fish having stomach eversion (33%) than fish without (0%) (two-sided Fisher's Exact, $p < 0.001$), with vermilion, bocaccio, and squarespot rockfish comprising 62% of these mortalities. In the Barotrauma Model, barotrauma category had no effect on survival (e.g. No signs, EX/CB, SE, SE/EX, SE/EX/CB; Logistic regression: $X^2 = 1.33744$, d.f. = 4, $p = 0.855$).

A total of 51 rockfish were dissected to assess internal signs of barotrauma (alive: n = 36; dead: n = 15) two days after being recompressed in cages. Fewer dead fish than live fish were dissected because 24% of dead fish observed in cages were decomposing carcasses; likely scavenged by hagfish and/or amphipods during the two-day period. Because sample sizes were limited among species, a two-sided Fisher's Exact test was used to test the effect of each internal sign of barotrauma across the entire rockfish assemblage. Fifty-percent of fish with organ torsion suffered mortality compared to 28% of fish without organ torsion; however, this difference was not significant (two-sided Fisher's exact, $p = 0.22$). There were also no significant differences in percent mortality for fish with and without hemorrhage, swim bladder rupture, or arterial embolism (two-sided Fisher's Exact, $p > 0.05$).

In the Overall Model of two-day survival post-recompression, which only included data on the five most abundant species, cage density, depth, and fish length had no significant effect on survival, and hence, were removed from the model (table 6). Species, surface holding duration, and temperature differential were significant predictors of survival in the Reduced Model (table 6). Surface holding duration and temperature differential showed a negative relationship with the predicted probability of two-day survival post-recompression (figure 7). Odds ratio (OR) estimates revealed the odds of mortality two-days post-recompression increase 1.7 x with every 10 min increase in surface holding time (e.g. 1/(0.95)10; table 6). The odds of mortality two-days post-recompression increase 1.96 x with every 1°C increase in temperature differential (e.g. $1/(0.51)^1$). The Reduced Model predictions were in concordance with the observed data 75% of the time (Likelihood Ratio test, $p < 0.0001$; Goodness of Fit tests, $p > 0.1$).

The median surface holding duration experienced by the five most abundant species was 13 min. There was no significant difference in median surface holding duration among species (Kruskal Wallis, H = 2.96, p = 0.56). The average temperature differential between the seafloor and the surface experienced by these rockfishes was 9.2 °C (table 4). There was no significant difference in average temperature differential experienced among species (ANOVA, F = 0.60, p = 0.66).

Long-term Survival

Tag Recaptures

A total of 125 rockfish were released alive from cages at 20 m two-days after capture. Out of the 125 fish released, three percent (two honeycomb rockfish and two bocaccio) were recaptured by local fishers near the areas where they were released. Twenty-five percent of the eight honeycomb rockfish and 5% of the 41 bocaccio that were released alive were recaptured. Days at liberty for the two recaptured honeycomb rockfish were 14 and 208 days. The third recaptured fish, a bocaccio, was reported after 28 days at liberty. The final report of a recaptured bocaccio was approximately 90 days after the last tagging event; however, the fisherman provided no other additional information (i.e. tag number, date of capture) and so actual days at liberty are unknown.

Acoustic Monitoring

A total of 90 rockfish were tagged and released at offshore petroleum platforms in the Santa Barbara Channel, with a majority (61%) being vermilion rockfish (table 7). Six rockfish (2 copper, 4 vermilion) out of the 11 that were recompressed in cages to assess short-term (2 –day) survival were assumed dead because the cages were lost. The remaining fish recompressed in cages (5 vermilions, 20 -28 cm TL) survived following the two-day period and showed no external signs of barotrauma. These fish were continuously detected by the underwater acoustic receivers at Platform Gilda at various intervals over the two-year period (figure 8). The last date of detection for one of these fish was seven days after tagging whereas the last dates of detection for the other four fish were after 58, 201, 479, and 690 days. For a 10 day period during October 2004 there was no acoustic receiver coverage at Platform Gilda due to regularly scheduled mooring maintenance.

Excluding fish that were lost in cages, there was a total of 84 fish released and detected by acoustic receivers among all platforms. The number of fish detected by acoustic receivers declined most sharply over the first six days (figure 9). Within the first two days, 78 fish (93%) were still being detected and by day six, 49 fish (58%) were detected. The decline over the first six days was steady and linear with a loss of approximately 8 fish per day. This rapid decline was followed by a gradual decrease to 42 fish (46%) detected over the following 129 days (one fish lost per two week period). Soon after, the number of fish detected declined at a slightly faster rate to 21 fish (25%)

during the period of 130 to 220 days since tagged (3 fish lost per two week period). For the remainder of the study period, the number of fish detected remained relatively stable with 20 fish being detected by the acoustic receivers at the end of the study. On the last day of the study, a mobile Vemco VR100 acoustic receiver onboard the *D.R. Nelson* was used to relocate fish around each platform. The exact location and time of detection was compared with VR2 acoustic receiver records to determine whether some fish were in locations around the platform where they might not be detected by the stationary VR2 acoustic receivers. The total number of fish detected by the VR2s and VR100 on the last day of the study was 32 (comprising 10 of the 12 species tagged), which was 38% of the original 84 fish tagged and released and 65% of the total fish remaining at the platforms following the first six days.

CHAPTER 4

DISCUSSION

Barotrauma and Initial Capture Survival

Nearshore and shelf rockfishes captured in southern California by hook-and-line between 18 m and 96 m showed species-specific differences in the types and degree of barotrauma (table 2). While stomach eversion, hemorrhage, and exophthalmia were common signs of barotrauma in the overall catch, these signs did not occur in the same frequency within or among species, suggesting some species are more susceptible to certain types of barotrauma. Further, species that were caught in deeper water (> 60 m) generally had a higher number of frequently occurring signs of barotrauma than species caught shallower (< 60 m; table 2). Other studies on fish decompression have shown that the extent of barotrauma increases with increased capture depth (Feathers and Knable, 1983; Wilson and Burns, 1996; Morrissey et al., 2005; Rummer and Bennet, 2005; St. John and Syers, 2005). While my study found a significant relationship between depth and the total number of external and internal signs of barotrauma, depth explained only 34% of the variability in the degree of barotrauma, suggesting other factors are influencing the degree of barotrauma observed among individuals.

Barotrauma results from over-expansion of gases in both the swim bladder and blood vessels. Over-inflated swim bladders may rupture or leak, and if not, may cause damage or torsion in other internal organs. Expanding gases in the blood may cause embolism and release of gases within the skin and eyes, resulting in subcutaneous gas bubbles or exophthalmia. The intra-species variability in barotrauma responses of individuals captured at similar depths (table 2) may be due to differences in the relative volume of the swim bladders when fish are caught (Rogers et al., 1986; Arnold and Walker, 1992; Rummer and Bennett, 2005). For example, during rapid decompression, the relative expansion of a swim bladder that is only partially inflated (negatively buoyant) will not be as great as one that is neutrally buoyant (Tytler and Blaxter, 1973). Further, it is possible that species-specific differences in swim bladder morphology influence inter-specific variation in the occurrence of barotrauma. During dissections, olive rockfish were found to have delicate, thin swim bladders compared to a thicker, more robust swim bladder found in vermilion, copper, and brown rockfish. A delicate swim bladder may be more prone to rupture than a robust swim bladder (Feathers and Knable, 1983), given the high occurrence of swim bladder ruptures in olive rockfish observed in this study relative to the other species. Although olive rockfish showed high mortality and high occurrence of swim bladder ruptures, all other rockfish with swim bladder ruptures lived except for two (n = 17).

Despite species-specific differences in the types and degree of angling-induced barotrauma, most rockfishes showed greater than 75% initial capture survival (figure 3), suggesting that degree of barotrauma is not a good predictor of mortality within the first 10 min of capture. Previous studies found that gas bubble formation in the blood as a result of decompression induces high initial mortality in other fish species (Stephens et al., 2002; Feathers and Knable, 1983). Although my study reports higher mortality for fish suffering arterial embolism than any of the other signs of barotrauma, half of the rockfish with arterial embolism survived 10 minutes after capture. Beyer et al. (1976) reported that some bubbles present in the blood could be tolerated by coho salmon (*Onchorhynchus kisutch*), while large gas bubbles in vital areas such as the heart were lethal. Rosy rockfish and olive rockfish comprised the majority of dead fish with arterial embolism, suggesting these species may be more susceptible to lethal gas embolism than other species. Inter- and intra-specific variation in susceptibility to barotrauma might explain why higher mortality was not observed in fish with arterial embolism.

Another factor shown to induce initial capture mortality is fish exhaustion from fighting during capture and/or struggling to maintain an upright position while floating at the surface (Davis, 2002). Exhaustive exercise in fish causes lactic acid build-up in muscles and lowers the pH of the blood (Kieffer, 2000), which may restrict the ability of the opercular muscles to pump water past the gills. Beyer et al. (1976) reported that progressive rigor mortis observed in small coho salmon depressurized from 370.00 cm Hg (5 atm, 52 m) was likely due to opercular muscles ceasing function. All of the olive rockfish and many rosy rockfish were moribund directly upon capture, suggesting these two species may be susceptible to exhaustion. This exhaustion, in combination with the high incidence of arterial embolism observed in dead individuals, may account for the higher initial capture mortality of these two species relative to the other rockfish species (figure 3).

Barotrauma and Two-Day Survival Post-Recompression

Nearshore and shelf rockfishes captured in southern California by hook-and-line between 55 m and 89 m showed species-specific differences in the occurrence and extent of barotrauma (table 5). Species that were caught in both the Initial Capture Survival Experiment and the Two-day Survival Post-recompression Experiment (= Two-day Cage Trials) generally showed lower two-day survival post-recompression than initial capture survival (figure 3, 6), indicating rockfish recompressed to depth may suffer delayed mortality. Presence of specific external signs of barotrauma was not a clear indication of two-day survival post-recompression as has been found in other studies (Gitschlag and Renaud, 1994; Rummer and Bennet, 2005); however, survival following recompression was significantly higher for fish without stomach eversion. Stomach eversion may occur as a result of a ruptured swim bladder and/or gas leaks at the oval. Not all rockfish with stomach eversion showed swim bladder ruptures (e.g. obvious tears in the swim bladder wall).

Delayed mortality in fish with stomach eversion may be a result of internal organ torsion displacement associated with the occurrence of stomach eversion and/or internal organ damage (e.g. rupture or puncture of organs, internal bleeding, organ tissue damage) resulting from the over-inflated swim bladder compressing or crushing organs (Keniry et al., 1996; Rummer and Bennett, 2005). In my study, mortality of fish with organ torsion (50%) did not significantly differ from mortality of fish without organ torsion (28%); however, this may have been an artifact of low sample size (n = 8) among fish with organ torsion. Rummer and Bennett (2005) reported that internal organ damage of red snapper (*Lutjanus campechanus*) increased with depth of capture due to the progressive expansion of the swim bladder from posterior to anterior regions of the body cavity. Rummer and Bennet (2005) concluded that as displacement and compaction injuries become more severe, red snapper were likely to suffer immediate mortality. Because swim bladder morphology and body shape in rockfishes varies (e.g. narrow- versus deep-bodied), swim bladder rupture thresholds and the space allowable for swim bladder expansion may also vary. Thus, the extent of organ damage in rockfishes may differ among species with different body shapes and/or swim bladder morphologies, even at similar capture depths. For example, both squarespot rockfish and bocaccio, two narrow-bodied species, frequently showed stomach eversion, but had very different survival rates. Squarespot rockfish have thin, delicate swim bladder morphology similar to olive rockfish, widow rockfish, and halfbanded rockfish. Of the 51 rockfish dissected for assessment of internal injury in the Two-day Cage Trials, squarespot rockfish comprised half of all the swim bladder ruptures. In contrast, bocaccio have somewhat thicker swim bladders that may be less prone to rupture. It is important to note that swim bladder ruptures, although common in some species, may not be deleterious, at least in the short-term. Several studies indicate a remarkable ability of physoclistic species to repair ruptured swim bladders within a few days or even hours (Nichol and Chilton, 2006; Parker et al., 2006; Burns and Restrepo, 2002; Shasteen and Sheehan, 1997; Wilson and Burns, 1996).

Although the degree of barotrauma in rockfishes can be partially attributed to depth (see Results, Barotrauma and Initial Capture Survival), depth was not a significant predictor of two-day survival of rockfishes post-recompression. Depth has been shown in numerous studies to significantly affect post-release survival in other physoclistic species (Feathers and Knable, 1983; Wilson and Burns, 1996; and Morrissey et al., 2005; St. John and Syers, 2005). Nevertheless, because rockfishes exhibit a wide-range of foraging behavior (e.g. benthic ambush predators versus water-column planktivores) and differ in swim bladder morphology as discussed above, depth effects on rockfish survival corresponding to barotrauma are likely to differ by species (Hannah and Matteson, 2007; Lea et al., 1999).

In addition to depth, there was no evidence that fish size affected two-day survival of rockfishes post-recompression. It has been hypothesized that smaller fish may be more susceptible to gas embolism due to the relationship between critical blood vessel size and the size of expanded bubbles in the blood (Beyer et al., 1976), and thermal shock may occur more quickly in smaller fish than larger fish (Davis, 2001). However, other studies report no effect of fish length on short-term survival (Collins et al., 1999; Gitschlag and Renaud, 1994). In my study, bocaccio was the only species for which juveniles and adults were caught with similar frequency. A length-frequency plot of captured bocaccio grouped by survivors and mortalities further demonstrated no trend in survival according to length of fish (figure 6).

Although cage density was not found to affect two-day survival post-recompression, it is possible that cage abrasion and high stress levels due to the confinement of the cages contributed to some mortality (Gliniak et al., 2006). Because the cages were left on soft substratum for a two-day period rather than the natural reef, the presence of scavengers could have further exacerbated stress levels in fish that had not suffered immediate mortality.

Seventy-five percent of fish showed cloudy eyes two-days following recompression; however, upon observation of several fish rubbing and bumping into the sides of the cages, and after finding that not all fish showing signs of ocular trauma had cloudy eyes, it was determined that cloudy eyes were likely a symptom of keratitis as a result of cage abrasion (St. John and Syers, 2005). Recompression appeared to reverse or alleviate signs of barotrauma observed in rockfish upon capture. Similarly, other studies documenting fish condition following recompression showed no external signs of injury post-recompression (Hannah and Matteson, 2007; Parker et al., 2006; St. John and Syers, 2005). Still, it is unclear whether ocular trauma may result in long term visual impairment. For example, fish which are significantly visually impaired may be less capable of avoiding predators, capturing prey, and successfully mating.

Rapid recompression may reduce the likelihood of arterial embolism, hemorrhaging, and cellular damage, thus increasing survival of rockfish caught by hook-and-line. In my study, surface holding time prior to recompression was a significant predictor of two-day survival. The Reduced Model predicted 78% probability of two-day post-recompression survival following a 10 minute surface holding duration (figure 7). This probability of survival increases to 83% within 2 minutes. Parker et al. (2006) reported 97% survival (up to 21 days) of black rockfish (*S. melanops*) recompressed within 30 seconds of decompression (from 4 atm) in pressure chambers. Surface holding duration may explain species-specific differences in survival in my study. Of the five most abundant species caught (e.g. vermilion, bocaccio, flag, honeycomb, and squarespot rockfish), honeycomb and squarespot rockfish showed the lowest survival. Although the factors affecting honeycomb survival are less clear, surface holding duration most likely affected squarespot rockfish survival. This species was held at the surface on average five minutes longer than the other four species (table 4). This difference in surface holding duration, although not statistically significant between the other species, may be biologically significant.

Fish held at the surface for long periods of time are exposed to thermal stress and the physiological effects of barotrauma for prolonged periods (Feathers and Knable, 1983; Gliniak et al., 2006). In addition, the likelihood of exhaustion from struggling to achieve upright orientation due to positive buoyancy may also increase the longer a fish is held at the surface. Following decompression, rockfish typically float on their backs or on their side, which limits the uptake of oxygen at the gills. Intravascular gas bubbles may also limit blood flow to the heart and eventually cause air embolism. Reduced blood flow may be especially detrimental in warmer surface waters where oxygen demand is higher. Feathers and Knable (1997) reported a synergistic effect of barotrauma and surface temperature on mortality of released largemouth bass (*Micropterus salmoides*). Due to the effects of temperature on survival, it is possible that post-release survival probabilities relative to surface holding duration may increase during winter months when sea surface temperatures vary less from sea floor temperatures.

Long-term Survival

The results of both the tag recapture and acoustic monitoring data show strong evidence of long-term post-release survival (at least up to two-years) in line-caught rockfishes following recompression. Despite surgical implantation of acoustic transmitters and venting in the acoustic monitoring study, two-day survival of acoustically tagged rockfishes post-recompression was actually higher (93%) than two-day survival of rockfish in the Two-day Cage Trials. Nevertheless, the initial rapid decline in detections of acoustically tagged rockfish did not level out until after the first 6 days of tagging, suggesting that delayed mortality of line-caught rockfish continues within the first week following recompression. Cage recompression studies on line-caught red snapper and red grouper (*Epinephelus morio*) found delayed mortality continued up to 10 days, although the majority of deaths occurred within the first two days (Gitshlag and Renaud, 1994; Wilson and Burns, 1996). Declines in rockfish detections over the remainder of the Long-term Survival Investigation were much less dramatic and suggest emigration and/or natural mortality more so than capture-related mortality (figure 9).

The majority of vermilion rockfish tagged for the acoustic monitoring study were juveniles, and juvenile vermilion rockfish are thought to move into deeper water as they mature (Love et al., 2002; Lea et al., 1999). It is possible that many of these juvenile vermilion rockfish emigrated into deeper waters (out of detection range of the receivers) onto rocky outcrops and/or oil platform pipeline. Lowe et al. (2007) report 10 rockfish (8 vermilion, 2 copper) which emigrated from Platform Gilda, the shallowest platform (63 m), to Platform Grace, a deeper platform (96 m). One of these fish was a caged vermilion used in the initial survival experiment (figure 8). It is also likely that smaller rockfish may be preyed upon at the platforms by larger rockfish or lingcod (*Ophiodon elongatus*) that are known to be common around these platforms (Love et al., 2003). The 32 rockfish that remained at the platforms after the two-year period provide evidence of the remarkable ability of rockfishes to not only survive hook-and-line capture from depths at least within 230 m, but to survive additionally traumatizing surgery.

Fisheries Management Implications

The results of this research provide evidence of both short-term and long-term post-release survival of line-caught southern California nearshore and shelf rockfishes recompressed to capture depth (from 18 m to 221 m). The results are encompassing of rockfishes and depths commonly fished by recreational fishers in southern California, and suggest the potential for greatly reducing rockfish discard mortality, regardless of extent of barotrauma. The data from my study also suggest the use and success of recompression devices (e.g., Shelton Fish Descender™, Get-R-Down (patent pending)) is high, and if properly used (i.e. within minutes of capture) could potentially enhance rockfish conservation.

Between 1993 and 2002, an estimated two million rockfish were discarded in southern California (PSMFC, 2006). The majority of fish (58 %) discarded were from private boats. Dwarf species (i.e. honeycomb, squarespot, halfbanded rockfish) comprise a large proportion of rockfish discards (M. Horezcko, California Department of Fish and Game, pers. comm.), which likely suffer mortality. These species are among the common rockfishes caught in southern California (Love et al, 1998b), although they are seldom kept by fishers due to their small sizes. In fact, over the past 10 to 15 years, dwarf species have come to dominate rocky reefs, and very few of the larger species of rockfish (e.g., cowcod (*Sebastes levis*), bocaccio, yelloweye rockfish (*Sebastes ruberrimus*)) are now found in this habitat (Love et. al., 2004; Love et. al., 2002; Lea et al., 1999). The practice of using assisted release in the recreational rockfish fishery may help to increase overall biodiversity on rocky reefs in southern California, which in turn, would help to increase ecosystem function and resilience to fishery collapse (Worms et. al., 2006).

Minimum size limits are currently not considered a useful management tool for rockfishes, but federal and state mandates require development of methods to reduce groundfish bycatch (= incidental catch + discards) mortality. Implementation of assisted release methods would increase the practicality of size limits as an alternative to current nearshore and shelf rockfish regulations. However, in order for minimum size limits to be effective in conserving rockfish stocks, fish that are recompressed to depth after capture must live long enough to reach size at maturity. For long-lived species such as rockfishes, it is important to consider cumulative mortality risk, which increases exponentially with every recapture (Bartholomew and Bohnsack, 2005). However, based on rockfish recapture rates from this study and those reported from the Nearshore Groundfish Tagging Project (3%, Hanan and Associates, Inc., 2006), rockfish recapture rates in southern California appear uncommon. Other factors, including vision impairment and/or stress impacts on growth, that may lower rockfish longevity following capture and recompression, need further exploration.

APPENDICES

APPENDIX A

TABLES

TABLE 1. Sample Size, Percentage (= Percent.) of Catch, Cumulative (= Cum.) Percent, and Depth of Capture of Nearshore and Shelf Rockfishes Captured by Hook-and-Line in Southern California (Initial Capture Survival Experiment), October 2004 to March 2006)

Common name	Scientific name	N	Percent. of Catch	Cum. Percent	Depth (m)
Vermilion rockfish	*Sebastes miniatus*	35	21	21	35-96
Greenspotted rockfish	*Sebastes chlorostictus*	19	11	32	75-189
Olive rockfish	*Sebastes serranoides*	16	10	42	23-53
Halfbanded rockfish	*Sebastes semicinctus*	15	9	51	53-64
Rosy rockfish	*Sebastes rosaceous*	12	7	58	54-152
Honeycomb rockfish	*Sebastes umbrosus*	12	7	65	46-76
Widow rockfish	*Sebastes entomelas*	9	5	70	53
Flag rockfish	*Sebastes rubrivinctus*	9	5	76	55-60
Copper rockfish	*Sebastes caurinus*	7	4	80	53-69
Calico rockfish	*Sebastes dalli*	7	4	84	53
Treefish	*Sebastes serriceps*	5	3	87	18-53
Brown rockfish	*Sebastes auriculatus*	4	2	89	24-53
Starry rockfish	*Sebastes constellatus*	4	2	92	46-68
Chilipepper	*Sebastes goodei*	3	2	93	140
Greenstriped rockfish	*Sebastes elongatus*	2	1	95	177
Squarespot rockfish	*Sebastes hopkinsi*	2	1	96	61-69
Freckled rockfish	*Sebastes lentiginosus*	2	1	97	61-76
Bocaccio	*Sebastes paucispinis*	2	1	98	76-79
Kelp rockfish	*Sebastes atrovirens*	1	1	99	30
Yellowtail rockfish	*Sebastes flavidus*	1	1	99	53
Canary rockfish	*Sebastes pinniger*	1	1	100	53
Total	--	168	100	--	--

TABLE 2. Percent Occurrence of Barotrauma in Nearshore and Shelf Rockfishes (Only Species with N>3) Following Hook-and-Line Capture from 18 to 189 m in Southern California (Initial Capture Survival Experiment, October 2004 to March 2006)

			Percent occurrence of barotrauma[a]							No. of traumas
			External signs				Internal signs			
Common name[b]	Scientific name	N	ES	EX	CB	PC	SR	HE	OT	> 50%
Olive rockfish	*Sebastes serranoides*	16	20	7	7	0	*87*	13	0	1
Treefish	*Sebastes serriceps*	5	*60*	40	20	0	20	*80*	0	2
Halfbanded rockfish	*Sebastes semicinctus*	15	*67*	13	0	13	27	*60*	*53*	3
Widow rockfish	*Sebastes entomelas*	9	*100*	0	0	11	33	33	*100*	2
Brown rockfish	*Sebastes auriculatus*	4	*75*	25	0	25	0	25	0	1
Calico rockfish	*Sebastes dalli*	7	43	29	14	43	14	29	43	0
Copper rockfish	*Sebastes caurinus*	7	25	*75*	*63*	13	0	38	25	2
Flag rockfish	*Sebastes rubrivinctus*	9	*100*	33	22	11	0	*100*	*78*	3
Starry rockfish	*Sebastes constellatus*	4	*100*	*100*	25	0	0	*100*	0	3
Honeycomb rockfish	*Sebastes umbrosus*	12	*92*	42	25	8	0	*67*	17	2
Vermilion rockfish	*Sebastes miniatus*	35	40	*71*	*57*	14	6	*74*	26	3
Rosy rockfish	*Sebastes rosaceous*	12	*55*	*82*	*64*	0	0	*73*	*55*	5
Greenspotted rockfish	*Sebastes chlorostictus*	19	*94*	*94*	*81*	6	6	*100*	38	4

[a]Values in italics indicate signs of barotrauma occurring in at least 50% of individuals.
[b]Species are arranged in order of most frequent capture depth.

EX = exophthalmia; CB = corneal gas bubbles; SE = stomach eversion; PC = prolapsed cloaca; SR = swim bladder rupture; HE = hemorrhage; OT = organ torsion

TABLE 3. Sample Size, Percentage (= Percent.) of Catch, Cumulative (= Cum.) Percentage, and Depth of Capture of Nearshore and Shelf Rockfishes Captured by Hook-and-Line in Southern California (Two-Day Survival Post-Recompression Experiment, Summer 2005 and 2006)

Common name	Scientific name	N	Percent. of Catch	Cum. Percent	Depth (m)
Vermilion rockfish	*Sebastes miniatus*	73	28.5	28.5	55 - 86
Bocaccio	*Sebastes paucispinis*	64	25.0	53.5	57 - 89
Flag rockfish	*Sebastes rubrivinctus*	29	11.3	64.8	55 - 89
Squarespot rockfish	*Sebastes hopkinsi*	28	10.9	75.8	55 - 83
Honeycomb rockfish	*Sebastes umbrosus*	17	6.6	82.4	56 - 84
Starry rockfish	*Sebastes constellatus*	11	4.3	86.7	58 - 89
Speckled rockfish	*Sebastes ovalis*	11	4.3	91.0	80 - 84
Chilipepper	*Sebastes goodei*	7	2.7	93.8	57 - 84
Halfbanded rockfish	*Sebastes semicinctus*	5	1.6	95.3	59 - 84
Greenspotted rockfish	*Sebastes chlorostictus*	3	1.2	96.5	80 - 83
Olive rockfish	*Sebastes serranoides*	2	0.8	97.3	56, 83
Copper rockfish	*Sebastes caurinus*	2	0.8	98.0	56, 84
Yellowtail rockfish	*Sebastes flavidus*	1	0.4	98.4	84
Rosy rockfish	*Sebastes rosaceous*	1	0.4	98.8	82
Greenstriped rockfish	*Sebastes elongatus*	1	0.4	99.2	84
Freckled rockfish	*Sebastes lentiginosus*	1	0.4	99.6	82
Canary rockfish	*Sebastes pinniger*	1	0.4	100.0	89
Total	--	257	100.0	--	--

TABLE 4. Species Summary Data of Survival Variables for the Five Most Abundant Rockfishes Captured by Hook-and-Line in Southern California and Recompressed to Original Capture Depth in Cages (Two-Day Survival Post-Recompression Experiment, Summer 2005 and 2006)

Common name	Scientific name	Standard Length (cm) Mean ± (1 SD)	Depth (m) Mean ± (1 SD)	Cage Density Mean ± (1 SD)	Temperature Differential (°C) Mean ± (1 SD)	Surface Holding Duration (min) Mean ± (1 SD)
Bocaccio	*Sebastes paucispinis*	35.24 (7.4)	83.25 (4.3)	7 (2)	9.70 (0.7)	14.38 (6.7)
Flag rockfish	*Sebastes rubrivinctus*	21.45 (2.7)	69.86 (13.1)	8 (2)	9.39 (0.6)	13.59 (9.3)
Honeycomb rockfish	*Sebastes umbrosus*	16.34 (1.7)	76.71 (10.8)	8 (3)	8.23 (0.7)	14.94 (9.1)
Squarespot rockfish	*Sebastes hopkinsi*	19.91 (1.3)	70.18 (12.0)	7 (2)	9.34 (0.7)	21.46 (21.2)
Vermilion rockfish	*Sebastes miniatus*	24.27 (4.0)	63.81 (11.5)	7 (2)	8.98 (1.0)	15.89 (9.7)
	Overall Mean ± (1 SD)	25.99 (8.1)	72.42 (12.9)	7 (2)	9.2 (0.9)	15.78 (11.3)

TABLE 5. Percent Occurrence of Barotrauma in Nearshore and Shelf Rockfishes (Only Species with N>10) Following Hook-and-Line Capture from 55 to 89 m in Southern California (Two-Day Survival Post-Recompression Experiment, Summer 2005 and 2006)

			Percent Occurrence of Barotrauma[a]									
			External Signs					Internal Signs[b]				
Common name	Scientific name	N	EX	CB	SE	PC	N	SR	HE	OT	AE
Bocaccio	*Sebastes paucispinis*	66	33	29	*92*	0	12	0	*100*	33	25
Flag rockfish	*Sebastes rubrivinctus*	32	*63*	*59*	*84*	13	5	0	*80*	0	40
Halfbanded rockfish	*Sebastes semicinctus*	41	12	7	*93*	12	0	--	--	--	--
Honeycomb rockfish	*Sebastes umbrosus*	28	*57*	46	*82*	4	2	--	--	--	--
Speckled rockfish	*Sebastes ovalis*	13	8	15	*85*	23	0	--	--	--	--
Squarespot rockfish	*Sebastes hopkinsi*	40	25	15	*88*	15	7	43	*100*	29	29
Starry rockfish	*Sebastes constellatus*	11	*82*	*64*	*91*	0	4	25	*100*	0	*50*
Vermilion rockfish	*Sebastes miniatus*	75	*81*	*52*	*92*	0	13	8	*85*	15	*69*

[a]Values in italics indicate signs of barotrauma occurring in at least 50% of individuals.
[b]Internal signs of barotrauma were assessed in a subsample of line-caught rockfish recompressed to original capture depth in cages.

EX = exophthalmia; CB = corneal gas bubbles; SE = stomach eversion; PC = prolapsed cloaca; SR = swim bladder rupture; HE = hemorrhage; OT = organ torsion; AE = arterial embolism.

TABLE 6. Logistic Regression Results of the Overall and Reduced Models of Two-day Survival of Rockfishes Captured by Hook-and-Line in Southern California from 55 to 89 m and Recompressed in Cages to Original Capture Depth (Two-Day Survival Post-Recompression Experiment, Summer 2005 and 2006)

Predictor of survival	d.f.	*β*	X^2	*p*	OR
Overall Model					
Species	4	--	11.23	*0.0240*	--
Surface time (min)	1	-0.626	9.69	*0.0020*	0.94
Depth (m)	1	-0.0277	2.22	0.1360	0.97
Fish length (SL, cm)	1	0.0419	0.99	0.3190	1.04
Cage density	1	-0.0462	0.26	0.6140	0.96
Temperature difference (°C)	1	-0.6512	7.57	*0.0060*	0.52
Reduced Model					
Species	4	--	19.76	*0.001*	--
Surface time (min)	1	-0.0566	8.6312	*0.003*	0.95
Temperature difference (°C)	1	-0.6705	8.4990	*0.004*	0.51

d.f. = degrees of freedom; OR = odds ratio

TABLE 7. Sample Size, Total Length (=TL), and Tagging Location of Rockfishes Captured by Hook-and-Line at Oil/Petroleum Platforms Gilda, Gail, and Grace in the Santa Barbara Channel (Long-Term Survival Investigation, Summer 2004)

Common Name	Scientific Name	Total tagged	Size Range (TL = cm)	Platform Tagged Gilda (65 m)	Gail (225 m)	Grace (97 m)
Blue rockfish	*Sebastes mystinus*	1	29	0	0	1
Brown rockfish	*Sebastes auriculatus*	3	24-27	3	0	0
Copper rockfish	*Sebastes caurinus*	9	20-35	8	0	1
Flag rockfish	*Sebastes rubrivinctus*	1	21	0	0	1
Greenspotted rockfish	*Sebastes chlorostictus*	4	30-41	0	4	0
Greenstriped rockfish	*Sebastes elongatus*	1	25	0	1	0
Mexican rockfish	*Sebastes macdonaldi*	2	52, 58	0	2	0
Rosy rockfish	*Sebastes rosaceous*	3	22-23	0	0	3
Starry rockfish	*Sebastes constellatus*	1	22	0	0	1
Treefish	*Sebastes serriceps*	1	24	0	0	1
Vermilion rockfish	*Sebastes miniatus*	60	20-41	34	0	26
Widow rockfish	*Sebastes entomelas*	4	29-36	0	0	4
Total		90		45	7	38

Modified from Lowe et al. (2007)

APPENDIX B

FIGURES

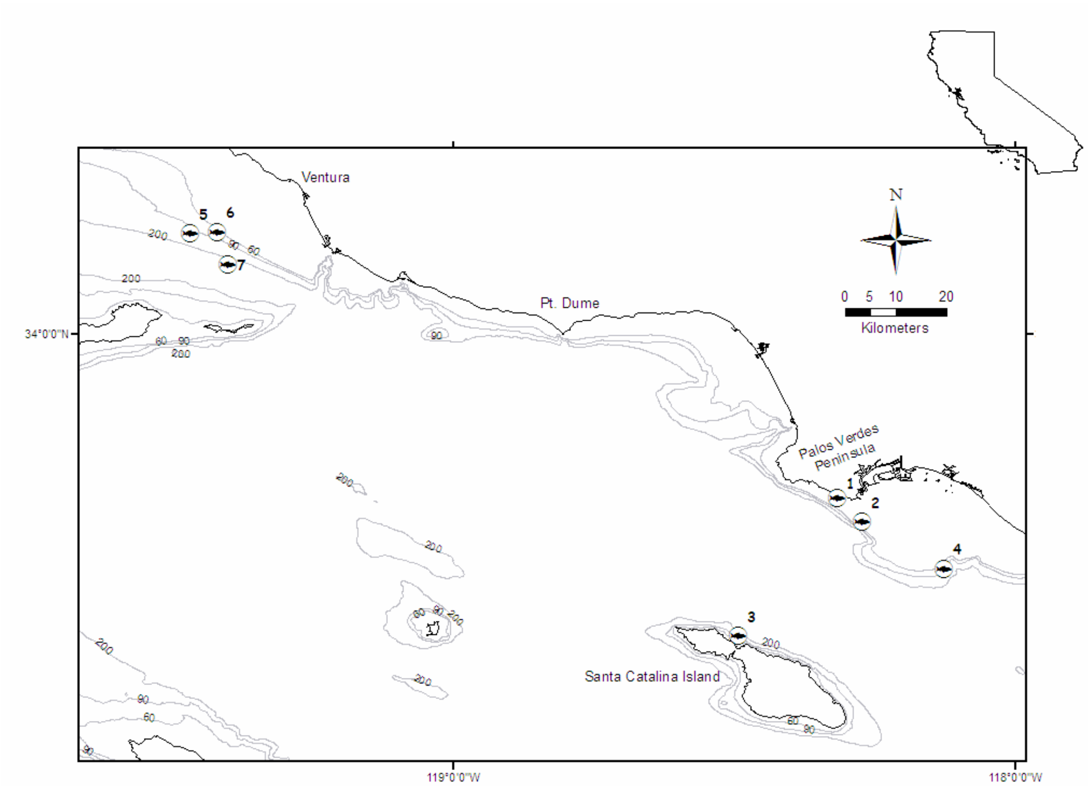

FIGURE 1. Fishing locations of nearshore and shelf rockfish captured by hook-and-line in southern California from 18 to 220 m (October 2004 to August 2006). 1) White's Point outfall pipe, 2) Rockpile, 3) Ship Rock, 4) Southeast Bank, 5) Platform Grace, 6) Platform Gilda, 7) Platform Gail). Gray lines represent 60, 90, and 200 m depth contours.

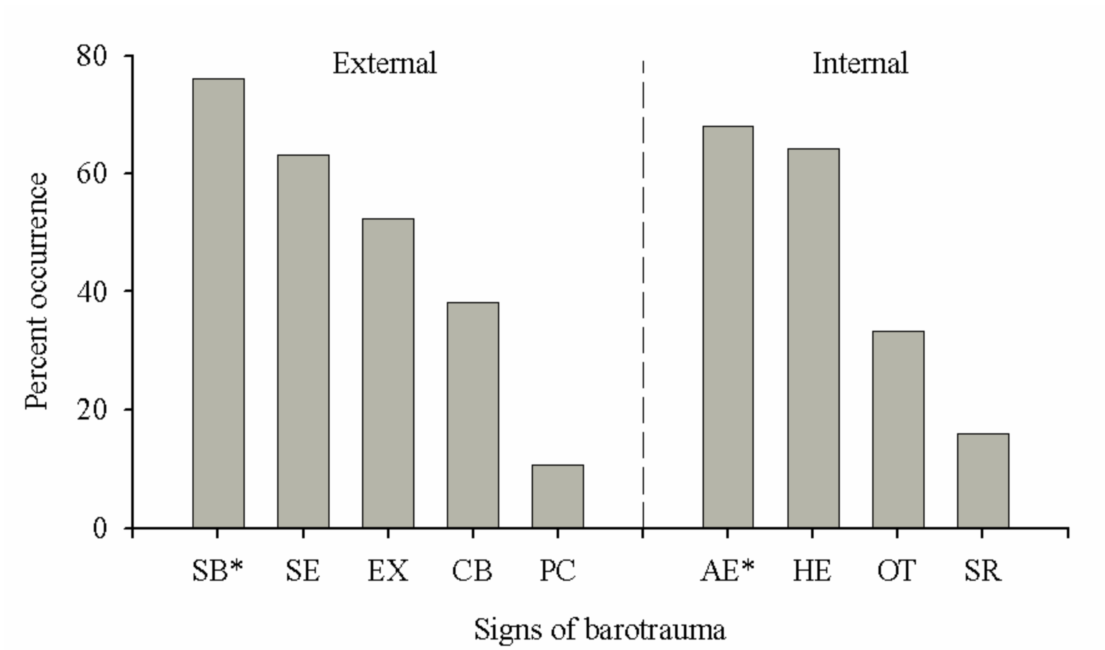

FIGURE 2. Percent occurrence of external and internal signs of barotrauma observed in nearshore and shelf rockfish (N = 168) captured by hook-and-line from 18 to 189 m in southern California (Initial Capture Survival Experiment, October 2004 to March 2006). *Trauma not accounted for in all fish; N = 157 (SB), N = 144 (AE). SB = subcutaneous blisters; SE = stomach eversion; EX = exophthalmia; CB = corneal gas bubbles; PC = prolapsed cloaca; AE = arterial embolism; SR = swim bladder rupture; HE = hemorrhage; OT = organ torsion.

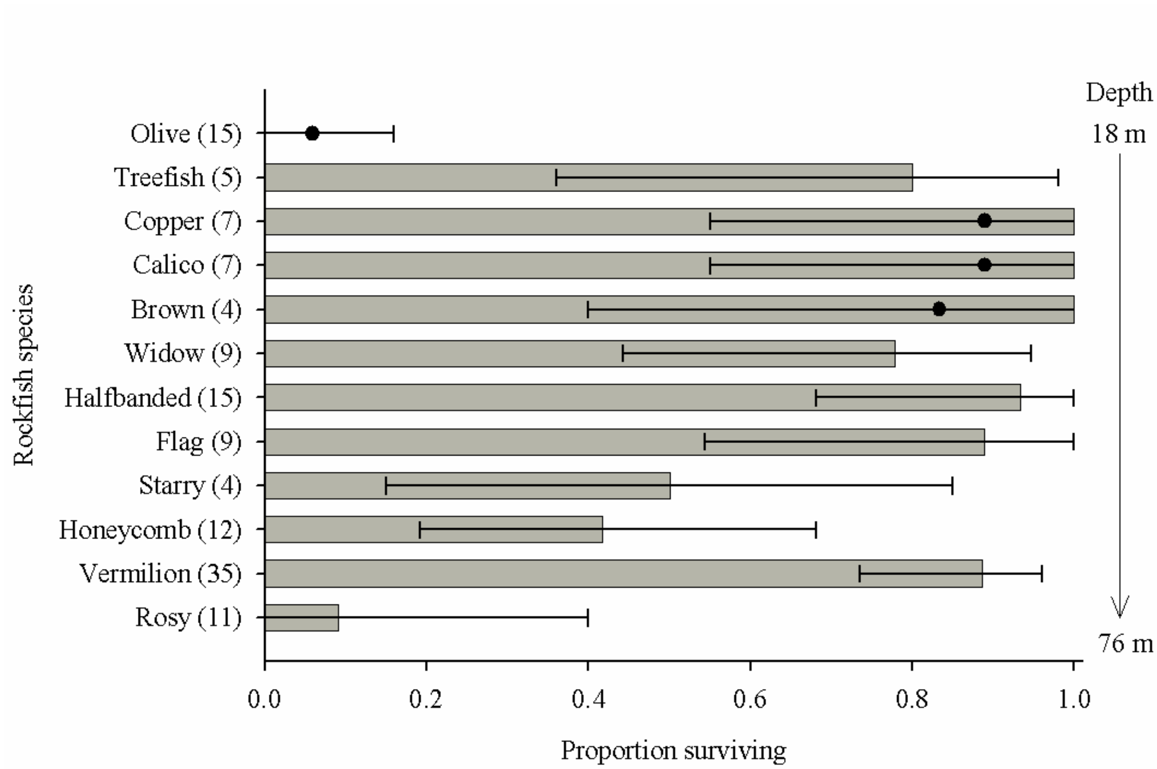

FIGURE 3. Initial capture survival (± 95% binary confidence intervals) of line-caught (from 18 to 96 m) southern California nearshore and shelf rockfishes (only species with N>3) following a 10 minute holding period on deck in a live well (Initial Capture Survival Experiment, October 2004 to March 2006). Species are arranged in order of capture depth. Numbers in parentheses indicate sample sizes. Closed, black circles represent LaPlace Point Estimates for species whose survival was either 0% or 100%.

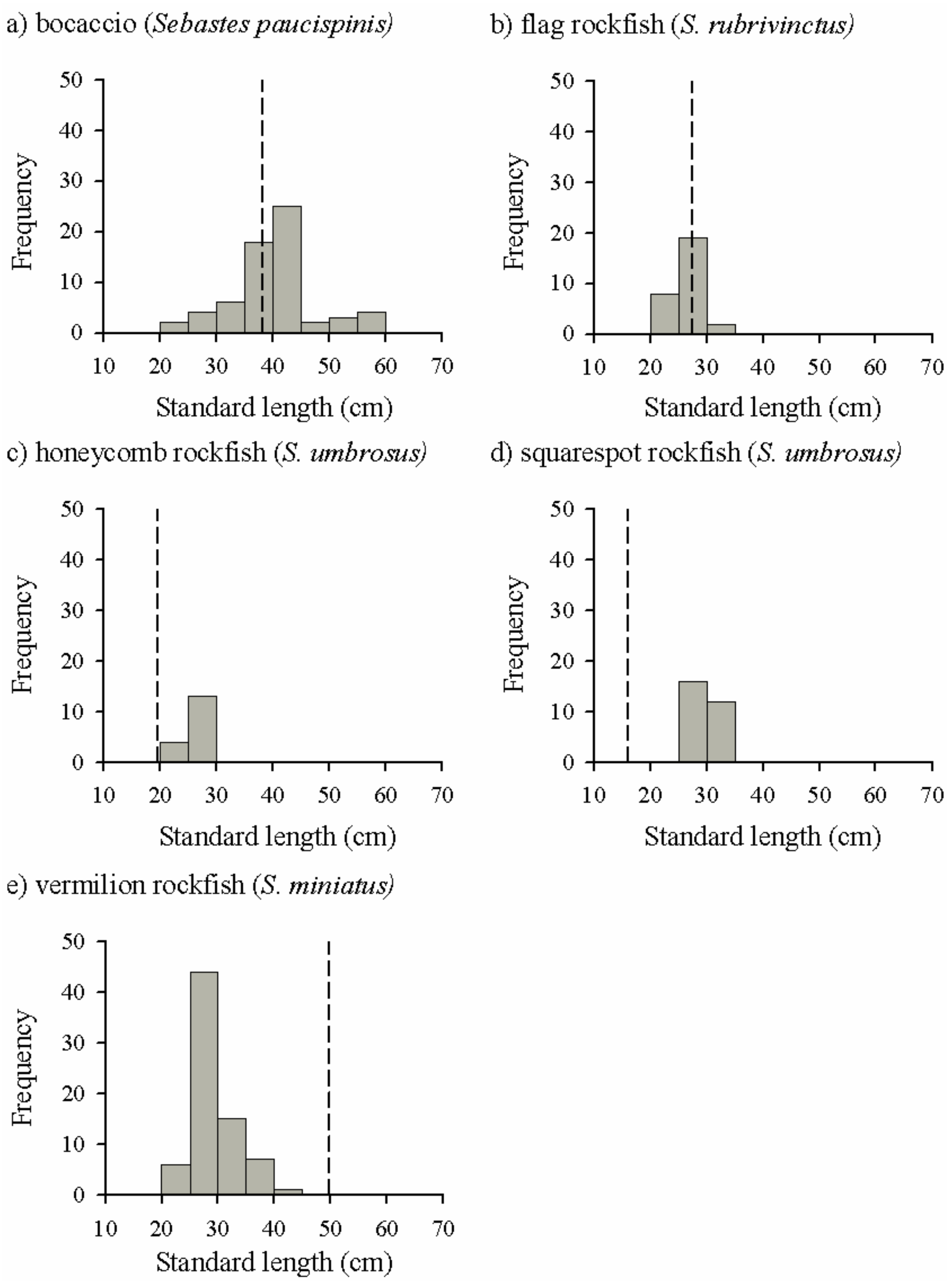

FIGURE 4. Length-frequency distribution of the five most abundant species captured by hook-and-line in southern California from 55 to 89 m (Two-day Survival Post-Recompression Experiment, summer 2005 and 2006). Dashed lines indicate size at which 50% of juveniles become mature (Love et al., 2002).

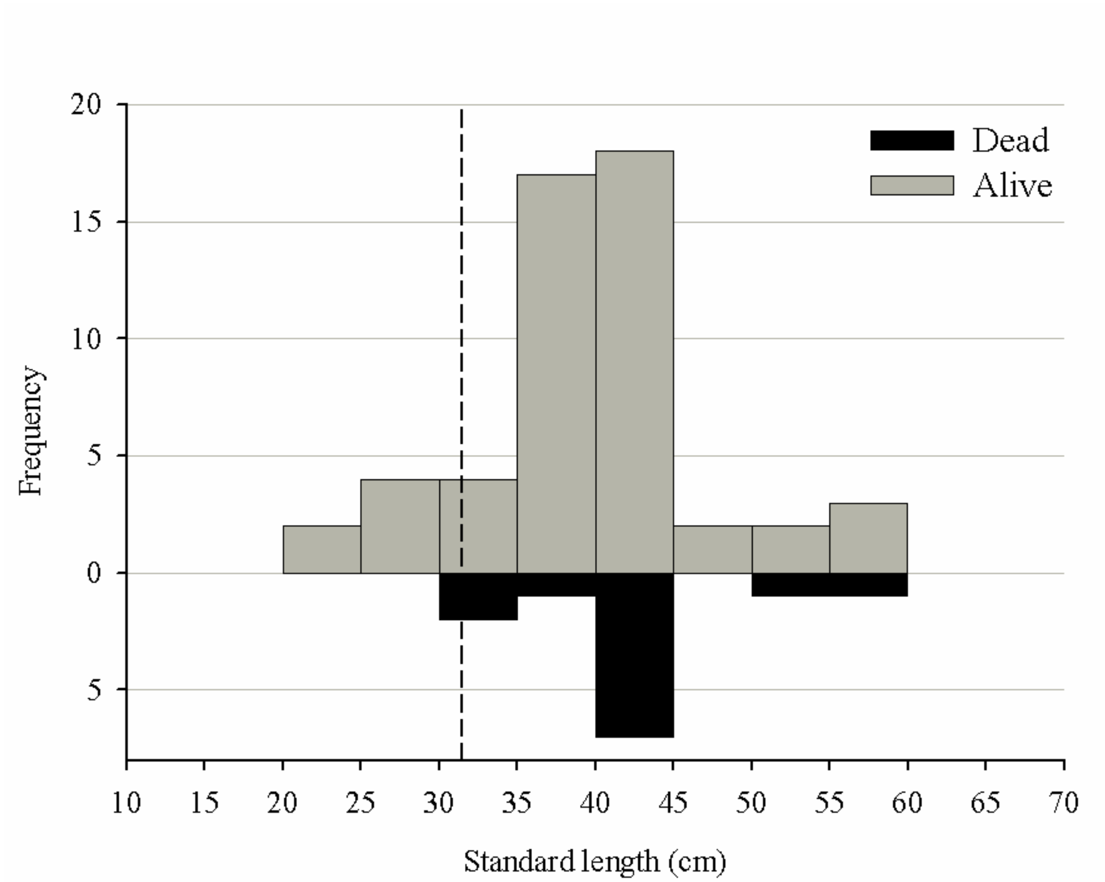

FIGURE 5. Length-frequency distribution of bocaccio captured by hook-and-line in southern California from 57 to 89 m and recompressed to original capture depth in cages (Two-Day Survival Post-Recompression Experiment, summer 2005 and 2006). Distributions are represented for fish that either survived or died within two-days following recompression. Dashed line indicates size at which 50% of juveniles become mature (Love et al., 2002).

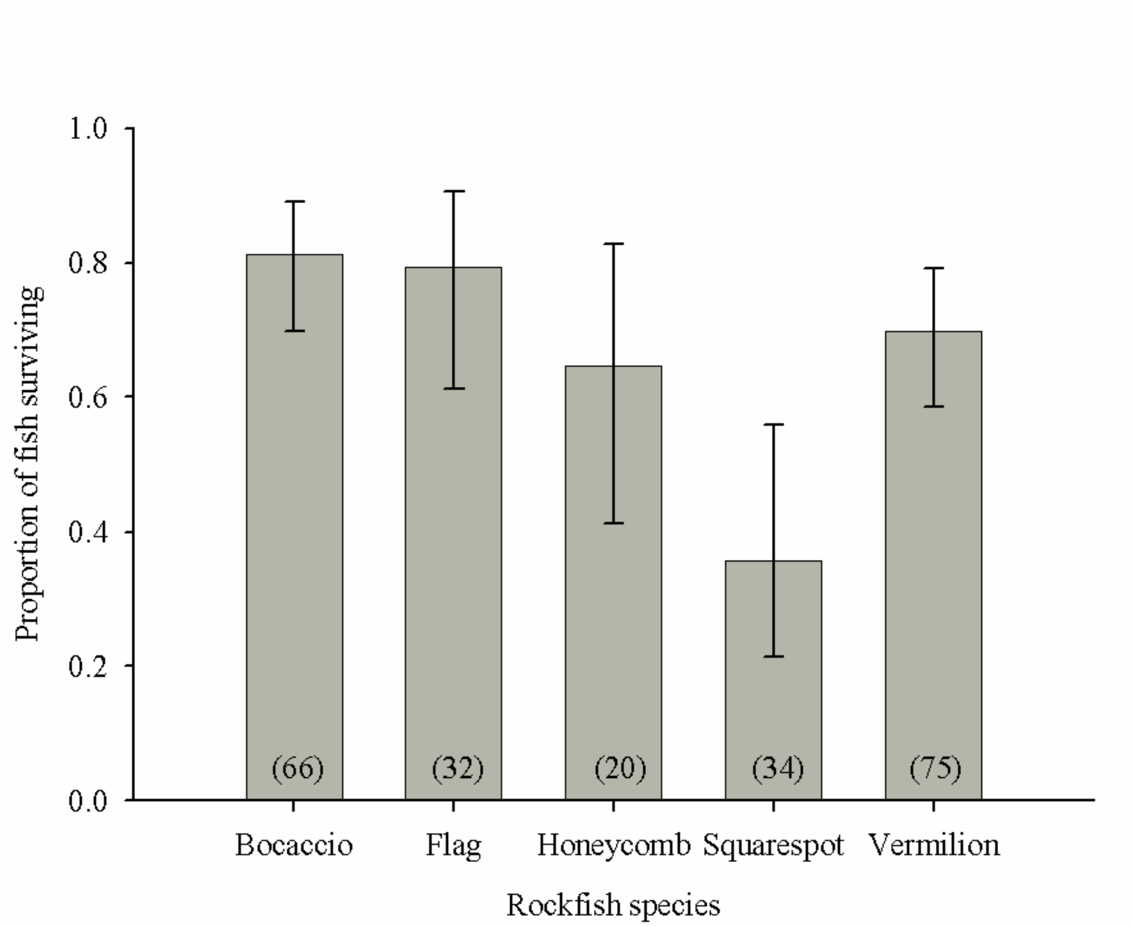

FIGURE 6. Two-day survival (± 95% binary confidence intervals) of the five most abundant species captured by hook-and-line in southern California from 55 to 89 m and recompressed to original capture depth in cages (Two-Day Survival Post-Recompression Experiment, summer 2005 and 2006). Numbers in parentheses represent samples sizes. Percent survival was significantly different among species ($X^2 = 21.6$, d.f. = 5, $p < 0.0001$).

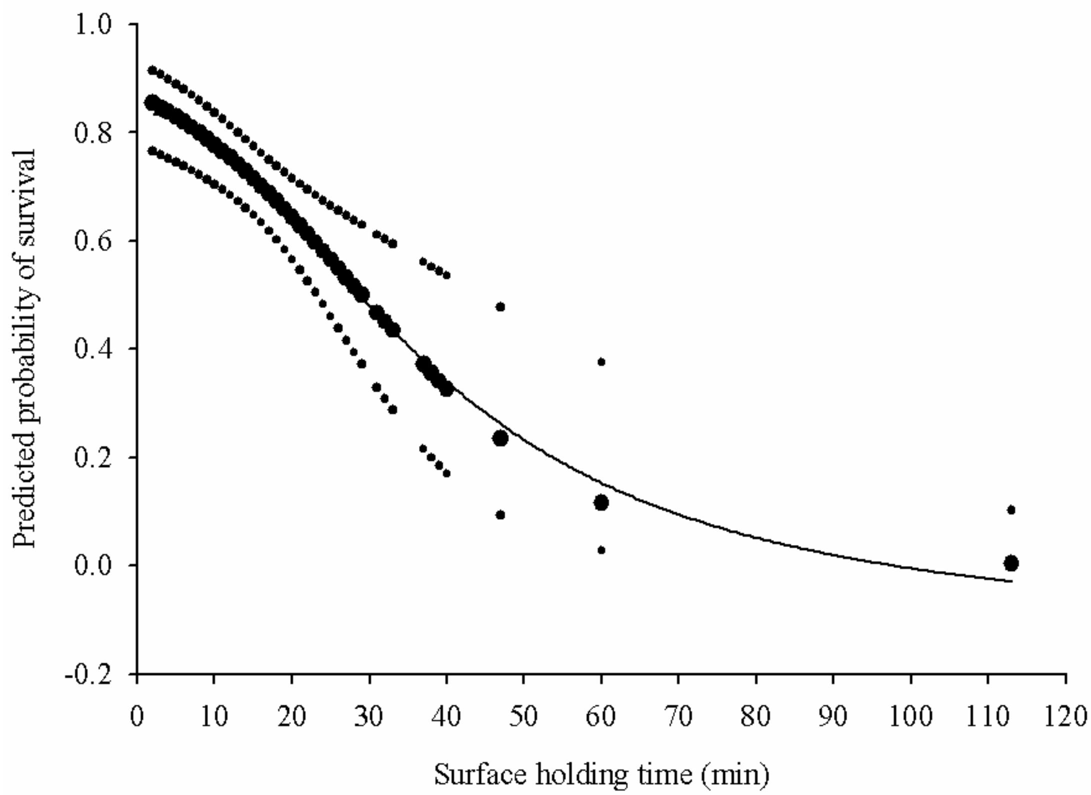

FIGURE 7. Predicted probability (± 95% C.I.) of rockfish two-day survival post-recompression as a function of surface holding time (min) (Two-Day Survival Post-Recompression Survival Experiment, summer 2005 and 2006). The probability curve is based on the five most abundant rockfishes captured during the Two-Day Cage Trials; N = 211 fish).

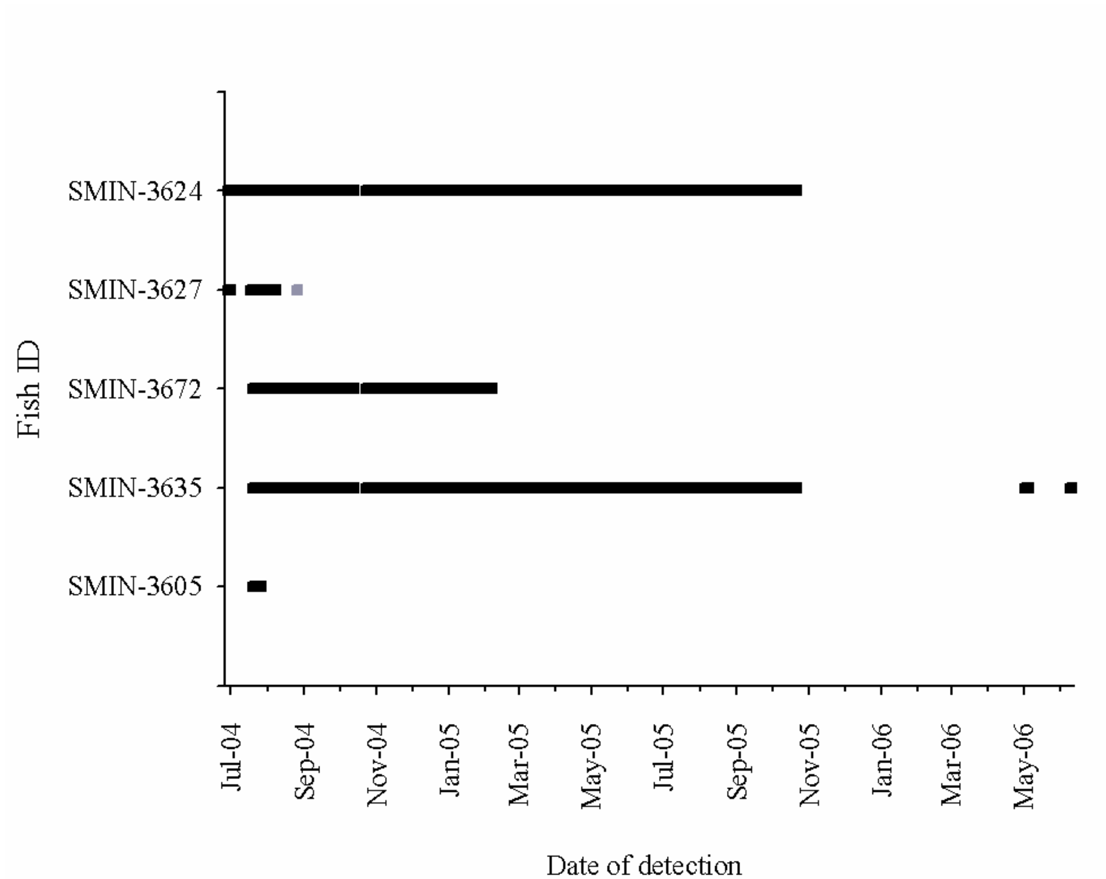

FIGURE 8. Detection plot of five vermilion rockfish acoustically tagged at Platform Gilda, recompressed in cages for a two day period, and subsequently released (Long-Term Survival Investigation, July 2004 to June 2006). Black squares represent detections at Platform Gilda and grey squares represent detections at Platform Grace. Figure modified from Lowe et al. (2007).

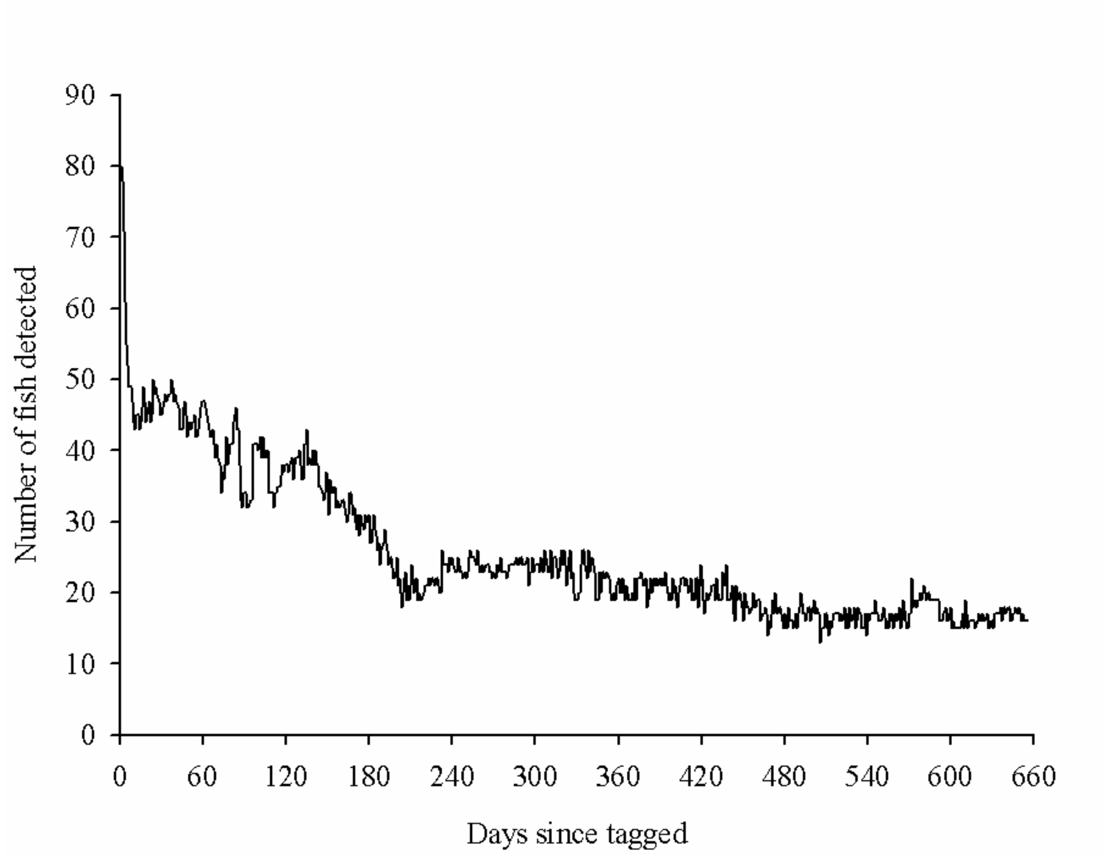

FIGURE 9. Numbers of acoustically tagged rockfish detected over a 654 day period at oil/petroleum platforms Gilda, Grace, and Gail in the Santa Barbara Channel (June 2004 to June 2006). Figure modified from Lowe et al. (2007).

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