

# **Fisheries Release Mortality: Identifying, Prioritizing, and Resolving Data Gaps**

L. R. Benaka, L. Sharpe, L. Anderson, K. Brennan, J. E. Budrick,  
C. Lunsford, E. Meredith, M. S. Mohr, and C. Villafana



U.S. Department of Commerce  
National Oceanic and Atmospheric Administration  
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-142  
July 2014



# **Fisheries Release Mortality: Identifying, Prioritizing, and Resolving Data Gaps**

L. R. Benaka, L. Sharpe, L. Anderson, K. Brennan, J. E. Budrick,  
C. Lunsford, E. Meredith, M. S. Mohr, and C. Villafana

**NOAA Technical Memorandum NMFS-F/SPO-142  
July 2014**



U.S. Department of Commerce  
Penny S. Pritzker, Secretary

National Oceanic and Atmospheric Administration  
Kathryn D. Sullivan, Administrator

National Marine Fisheries Service  
Eileen Sobeck, Assistant Administrator for Fisheries

**Recommended citation:**

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. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/SPO-142, 84 p.

**Copies of this report may be obtained from:**

National Marine Fisheries Service  
National Oceanic and Atmospheric Administration  
National Observer Program (attn. Lee Benaka)  
1315 East-West Highway, 12<sup>th</sup> Floor  
Silver Spring, MD 20910

**Or online at:**

<http://spo.nmfs.noaa.gov/tm/>

## Table of Contents

Dedication.....	v
Executive Summary .....	vi
1. Introduction.....	1
2. Background.....	3
3. NMFS-Funded Release Mortality Research by Region.....	4
3.1 Northeast.....	4
3.2 Southeast.....	11
3.3 West Coast .....	23
3.4 Alaska .....	27
3.5 Pacific Islands .....	29
4. How Release Mortality Assumptions Are Incorporated into Stock Assessments .....	30
5. Approaches to Developing Revised Release Mortality Assumptions .....	32
5.1 Delphi Technique.....	32
5.2 Model-Based Approach .....	33
6. Identification and Prioritization of Data Gaps .....	36
7. Identification and Prioritization of Species-Specific Research Needs .....	39
7.1 West Coast Examples .....	40
7.2 Southeast Examples .....	42
7.3 Northeast Examples .....	43
8. Best Practices and Techniques for Release Mortality Research.....	45
8.1 Outreach.....	45
8.2 Tagging .....	46
8.3 Arrays.....	47
8.4 Estimating Mortality Rates Using Chamber Studies, Cage Studies, and Acoustic Tagging .....	47
8.5 Application of Mortality Rates in Management .....	48
9. Identifying Components of a National Release Mortality Science Strategy .....	50
10. Conclusion: Next Steps for Addressing Broader Release Mortality Issues.....	52
11. References.....	53

Appendix A Release Mortality Workshop Attendees (September 25-26, 2013).....	56
Appendix B Summary of NMFS-Funded Release Mortality Research by Region .....	57
Appendix C Compilation of Release Mortality Estimates Used by NMFS.....	66

### **Dedication**

The authors would like to dedicate this report to the memory of Karen M. Burns. Beginning in the 1990s, Dr. Burns conducted numerous helpful and influential studies of release mortality in Southeast reef fishes. She was missed during the development of this report, but her work continues to inspire release mortality research.

## Executive Summary

Recreational and commercial fisheries face continued effort restrictions due to high fishing mortality and slow stock rebuilding processes. Regional fishery management councils have implemented short fishing seasons, closed areas, species-specific non-retention measures, and size limits in response to overfished declarations. Under these restrictive management systems, release mortality and barotrauma can occur, which impedes the rebuilding of overfished stocks. Some fishermen believe that the use of fishing practices and technologies designed to minimize barotrauma and post-release mortality should reduce overall fisheries mortality and in turn lead to increased fishing opportunities.

This report describes research projects addressing release mortality that were funded by NOAA's National Marine Fisheries Service (NMFS) from 1999 to 2013. The projects highlighted in this section are not a complete accounting of all NMFS-funded release mortality research during this timeframe, but these projects do reflect the large majority of projects funded and research areas. The number of NMFS-funded research projects varies by region: Northeast (17), Southeast (24), West Coast (8), Alaska (4), and Pacific Islands (1).

This report focuses on various approaches to incorporating release mortality assumptions into stock assessments, as well as techniques that have been used in the Northeast (Delphi Technique) and the West Coast (model-based approach) to develop revised release mortality estimates.

In September 2013, scientists from within and outside of NMFS attended a workshop to help NMFS identify and prioritize data gaps related to discard mortality estimates and related stock assessment issues. Workshop attendees identified and prioritized several important release mortality data gaps, including:

- Development of baseline discard mortality information, including an understanding of underlying factors and their interactions.
- Measurement of release mortality in fishery, as opposed to lab, conditions.
- Development of reliable and robust proxies for mortality (both short- and long-term).
- Examination of unaccounted escapement mortality.
- Identification of optimal sampling designs for accuracy and precision of discard mortality estimates.
- Communication of how discard mortality estimates are calculated and used, and how they affect stock assessments, annual catch limits, and management.

Workshop participants agreed on a list of seven high-priority criteria that should help direct scientists and managers in focusing release mortality resources on particular species. This report discusses several species in terms of these high-priority criteria. This report also discusses best practices and techniques related to release mortality research, especially effective outreach efforts related to release mortality research, as well as tagging and the related issue of acoustic arrays. Finally, this report identifies some components of a national release mortality science strategy and describes next steps for addressing broader release mortality issues.



## 1. Introduction

Recreational and commercial fisheries face continued effort restrictions due to high fishing mortality and slow stock rebuilding processes. The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) is committed to rebuilding overfished fish stocks. The [NMFS Status of Stocks 2012 Report](#) identified several important recreational and commercial fish stocks as overfished, including: Atlantic cod; Northeast winter and yellowtail flounder stocks; various Atlantic marlin, tuna, and sharks; red snapper in the South Atlantic and Gulf of Mexico; and some Pacific rockfish stocks. Regional fishery management councils have implemented short fishing seasons, closed areas, species-specific non-retention measures, and size limits in response to overfished declarations. Under these restrictive management systems, barotrauma and release mortality can occur, which impedes the rebuilding of overfished stocks and can limit fishing opportunity.

The term "release mortality" refers to the incidence of mortality after a fish has been discarded. ("Discard mortality" is often an interchangeable term.) A variety of factors can increase release mortality, including how the fish is handled and whether it is exposed to air, is injured during the fishing process, or experiences thermal shock during ascent. Release mortality can occur soon after discarding, due to severe injury or immediate post-release predation, or it can be prolonged; for example, if a fish's internal organs have been damaged prior to release, mortality caused by starvation can take a week or longer. In addition, the concept of release mortality encompasses "boarding mortality," which occurs when a fish is dead or near-dead when it is brought on board and then subsequently discarded.

"Barotrauma" results from a change in pressure as some deep-water fish, especially fish with physoclistous gas bladders, are rapidly brought to the surface. The symptoms of barotrauma, including stomach eversion and bulging eyes, have been described extensively in literature, especially for Pacific rockfish (for example, Jarvis and Lowe 2008, Hannah et al. 2012). Fishermen around the country have adopted various fishing practices, including venting and descending devices, which are designed to minimize the effects of barotraumas. These methods have only been tested for success or ease of use for a handful of species to date.

Where they have been tested, descending devices have been shown to substantially reduce mortality due to barotrauma or predation and thus aggregate release mortality (Jarvis and Lowe 2008, Hannah et al. 2012, PFMC 2012, PFMC 2013, PFMC 2014). This reduction in mortality has been quantified for three species of West Coast rockfish, and these mortality rates will be incorporated into recreational fisheries management systems in Washington, Oregon, and California for 2013 and beyond (PFMC 2014). Further research may lead to accounting for reduced mortality in additional species and deeper depths when a descending device is used.

The recreational fishing community has raised the issue of barotrauma and recreational release mortality as a concern over the past few years. Fishermen and managers have developed and promulgated best practices designed to reduce post-release mortality (e.g., through the FishSmart website [www.fishsmart.org](http://www.fishsmart.org)). Barotrauma and release mortality also are concerns in commercial fisheries. Some fishermen believe that the use of fishing practices and technologies designed to

minimize barotrauma and post-release mortality should reduce overall fisheries mortality and in turn lead to increased fishing opportunities.

Fisheries release mortality is a concern not only in the United States, but also in Europe. In response to a request from the European Commission, the International Council for the Exploration of the Sea established a Workshop on Methods for Estimating Discard Survival in January 2014. This Workshop was tasked to, among other things, (1) develop guidelines and, where possible, identify best practices for undertaking discard survival studies; (2) identify approaches for measuring and reducing, or accounting for, the uncertainty associated with mortality estimates; and (3) critically review current estimates of discard mortality (ICES 2014).

Fishermen and managers are asking what changes in management, especially related to quota-setting and fishery restrictions, should occur if best practices and technologies are being used to reduce post-release mortality and the effects of barotrauma. If more fish released or discarded in recreational and commercial fisheries are likely to survive, then long-standing release mortality assumptions used for fisheries management and stock assessments may need to be re-examined. Ultimately, fishermen expect that they should be allowed increased access to fish if their fishing practices lead to an improvement in survival rates for discarded or released fish. Alternatively, reduced mortality will help rebuild stocks faster than otherwise, although using estimated conservation benefits for stock rebuilding or increasing fishing opportunities for healthy stocks that co-occur with overfished species is a policy decision for each regional fishery management council.

The intent of this paper is to review release mortality initiatives by region; identify, prioritize, and try to resolve data gaps; and identify components of a national post-release mortality science strategy. This paper also includes a discussion of best practices and techniques for release mortality research.

## 2. Background

NMFS has been increasingly focused on best fishing practices to reduce release mortality and barotrauma since the late 2000s. In June 2008, NMFS and the Gulf of Mexico Fishery Management Council implemented Amendment 27 to the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico. This amendment required the use of non-stainless-steel circle hooks when using natural baits to fish for Gulf of Mexico reef fish, and it required the use of venting tools and dehooking devices for fishermen participating in the commercial and recreational reef fish fishery.

Outreach and education efforts regarding the use of descending devices to mitigate mortality of discarded West Coast rockfish started in 2007. Since then, more than 50,000 copies of the [“Bring That Rockfish Down”](#) brochure, and hundreds of descending devices, have been distributed to anglers, tackle shops, and fishing clubs throughout California by the California Department of Fish and Wildlife, in collaboration with California Sea Grant and fishing clubs. Similar outreach was conducted soon after in Oregon and Washington, and efforts in all three states are expected to continue to educate the fishing public and increase documented rates of descending device use.

In September 2009, NMFS initiated a Recreational Fisheries Initiative to strengthen its partnership with the saltwater recreational fishing community. This initiative led to an April 2010 Recreational Saltwater Fishing Summit and an October 2010 Recreational Saltwater Fisheries Action Agenda. The Action Agenda included five “signature issues,” one of which focused on cooperative research and monitoring, including the engagement of the recreational community in addressing barotrauma issues through a joint NMFS–stakeholder workshop.

Beginning in 2011, NMFS funded an initiative called FishSmart—a sportfishing-driven program focused on communication with anglers, researchers, and partners. In March 2011, FishSmart held a National FishSmart Workshop on Improving the Survival of Angler-Caught and Released Fish, which focused on barotrauma. FishSmart subsequently held three regional workshops on improving survival of angler-caught and released fish in recreational fisheries for the Gulf of Mexico/South Atlantic (April 2012), Pacific (May 2012), and Mid-Atlantic/New England (March 2013).

In March 2013, the NMFS National Policy Advisor for Recreational Fishing provided resources to the NMFS Office of Science and Technology to develop this white paper. The development process for this white paper included a September 2013 workshop attended by scientists from within and outside of NMFS, which was designed to provide background information for this white paper. Appendix A lists the workshop attendees.

### 3. NMFS-Funded Release Mortality Research by Region

This section describes research projects addressing release mortality that have been funded by NMFS since the late 1990s. This section's projects are not a complete accounting of all NMFS-funded release mortality research during this timeframe, but these projects do reflect the large majority of projects funded and research areas. Appendix B summarizes these research projects in a table.

#### 3.1 Northeast

##### 3.1.1 Past Projects

###### 3.1.1.1 Discard Mortality Estimation of the Southern New England Flatfish Complex using Reflex Action Mortality Predictor (RAMP) Methods

This Cooperative Research Program project, completed in 2012, examined factors related to discard mortality for yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), and windowpane flounder (*Scophthalmus aquosus*). The Southern New England Mid-Atlantic yellowtail flounder stock has a history of substantial discards, and the current stock assessment assumes 100% discard mortality. This project used a controlled experimental trawl to test seven reflex actions from stressed and unstressed yellowtail flounder. Tow time and air exposure were tested to identify their effect on mortality. Mortality was significantly related to reflex impairment. Exposure to air was the more influential stressor in the survivability of yellowtail flounder, suggesting that the discard mortality could be reduced in the fishery by limiting the time the fish are exposed to air on deck.

For winter flounder, investigators used a controlled experimental trawl to test seven reflex actions from stressed and unstressed winter flounder. Tow time and air exposure were tested to identify their effect on mortality. Mortality was significantly related to reflex impairment, but neither air exposure nor tow time significantly affected the survivability of winter flounder. Although air exposure did not significantly affect survival, none of the experimental fish exposed to air for 15 minutes or more survived, suggesting that the discard mortality could be reduced by limiting the length of time the fish are on a dry deck.

Likewise, for windowpane flounder, investigators used a controlled experimental trawl to test seven reflex actions from stressed and unstressed windowpane flounder. Tow time and air exposure were tested to identify their effect on mortality. Mortality was not significantly related to reflex impairment, and neither air exposure nor tow time significantly affected the survivability of windowpane flounder. These results indicate that windowpane flounder are highly susceptible to the stresses of the commercial fishing process and are unlikely to survive discarding regardless of the sampling or handling method. A paper based on this research (Barkley and Cadrin 2012) applied RAMP monitoring to demonstrate a 42–73% range of yellowtail flounder discard mortality estimates from the southern New England trawl fishery.

### 3.1.1.2 Optimizing the Georges Bank Scallop Fishery by Maximizing Meat Yield and Minimizing Bycatch

This Atlantic scallop research set-aside project, completed in 2012, attempted to determine discard mortality rates for yellowtail and winter flounder in the Georges Bank scallop fishery. This project's estimates of yellowtail flounder RAMP score for the scallop fleet indicated that the estimated discard mortality rates ranged from 64 to 90%. The time series of discard mortality estimates and confidence intervals (excluding 3 months) showed a fairly stable estimate of discard mortality near 85%. Based on the RAMP results, and the possibility for additional sources of mortality not accounted for by the RAMP method, investigators agreed to assume a discard mortality of 90% for the southern New England/Mid-Atlantic yellowtail flounder stock assessment.

Investigators also tested reflex actions on 586 winter flounder. The mean RAMP score was 0.57, which correlated to a discard mortality estimate of 36%, with lower and upper confidence intervals of 16% and 60%. This estimate of discard mortality for winter flounder in the scallop fishery (36%) is lower than the currently assumed 50% for all commercial fishing. The accepted value of 50% fell within the investigators' confidence interval range, indicating that the 50% used in the stock assessments may not be an overestimate for the scallop fleet. Although the basis of the 50% discard mortality assumption is not well documented, it appears to be an approximation based on an estimate of discard mortality of yellowtail flounder off Canada. This project shows that the currently accepted value used in the winter flounder stock assessments may be an accurate representation of the true discard mortality rate for the scallop industry.

### 3.1.1.3 Evaluation of Summer Flounder Discard Mortality in the Bottom Trawl Fishery, Part II: A Study of the Offshore Winter Fishery

This Cooperative Research Program project, completed in 2012, was designed to determine summer flounder discard mortality relative to tow time, fish size, and the amount of time fish were on the deck of the vessel. Investigators conducted tows of 1, 2, and 3 hours in duration. Investigators culled fish both immediately (from 0 to 10 minutes on deck) and after being held on deck longer (25 to 35 minutes on deck). As soon as the fish arrived at the dock, investigators transferred live fish to a shore-side holding system and monitored them for mortality over a 21-day period. Discard mortality rates were calculated based on the live/dead fraction of fish sorted on deck as well as the mortality rate of the live fish held in the holding system over the 21-day monitoring period. The main driving factor in all analyses of live/dead fraction on deck was cull time. The fraction live is clearly impacted by the time it takes to cull the fish. At and beyond the 35 to 50 minute interval, fish begin to die off rapidly, no matter the tow time or catch weight. Jumbo-sized fish survived the best during the extended monitoring period, while small fish survived the worst. The on-deck original condition of fish was significant for mortality over 21 days. Ambient on-deck air temperature at time of capture significantly impacted mortality during the extended monitoring period. Warmer on-deck air temperatures were associated with better survival. Overall median discard mortality was calculated to be 97.65%—much higher than the current assumed rate of 80% used in the stock assessment. Overall mean discard mortality was 80.4% and was nearly identical to the value assumed in recent summer flounder

assessments. The discard mortality determined by this study should be considered a minimum mortality rate.

#### 3.1.1.4 Summer Flounder Discard Mortality in the Inshore Bottom Trawl Fishery

This Cooperative Research Program project, completed in 2011, was designed to evaluate actual trawl discard mortality of summer flounder (*Paralichthys dentatus*) within a research design for comparison to the assumed discard mortality rate currently used in the stock assessment. The study goal was to determine discard mortality relative to tow time, total catch, fish size, and the amount of time that fish were on deck. Initially, investigators conducted 10 scientific fishing trips consisting of tows of 1, 2, and 3 hours in duration. Investigators culled fish at consistent time intervals into live and dead on deck. Additionally, a sub-sample of live fish from the immediate cull and the delayed cull were held in an on-board live system and then transferred to an extended mortality monitoring net pen system.

The overall summed discard mortality as determined by this project had a mean of 64.6% and a median of 78.7%. The mean discard mortality in the 1-hour tows was 58%, in the 2-hour tows 61%, and in the 3-hour tows 77%. When comparing the parameter values of tow time, cull time, and total catch as determined by this study, it is apparent that shorter tows, faster culling, and improved handling practices, while reducing per-tow total catch, can reduce summer flounder discard mortality.

#### 3.1.1.5 The Design, Development, and Field Testing of an Innovative Circular Net Pen to be Used to Assess Bycatch Mortality of Atlantic Cod at Sea

This Cooperative Research Program project, completed in 2010, involved the design and testing of an open-net system to study discard mortality at sea. The net pen was tested for a 24-hour period in September 2007. During this period, the net was deployed and retrieved 15 minutes later and then re-deployed for 24 hours before final retrieval. The pen was redeployed for 30 hours in April 2008. During this experiment, 40 trawl-caught cod were placed in the net. A video camera was inserted into the pen, and cod were actively seen swimming within the net. Moreover, it appeared that individual cod were using the net at different depths to recover from the trawling process. During the deployment times, the structural integrity of the net was maintained, even when the sea wave-height increased to 2–4 feet for an extended period of time and with the tethering vessel anchored to the sea floor.

Based on the success of the net design and the ability for cod to use the net to recover from the trawling process, the investigators concluded that the net can be deployed for any length of time under the same sea conditions to study discard mortality in a variety of fish species.

#### 3.1.1.6 Discard Mortality in the Summer Flounder Fishery: A New Approach to Evaluation

This Cooperative Research Program project, completed in 2008, was designed to determine the discard mortality, including latent mortality, for summer flounder in the otter trawl fishery in the Mid-Atlantic Bight. At the time of this study, scientists assumed 80% summer flounder discard mortality from the commercial fishery. The investigators tested the effectiveness of motion-

sensitive tags in determining discard mortality in the laboratory, estuary, and ocean. The investigators found that motion-sensitive tags could provide another means for interpreting mortality in tagged discards. Vertical movement has also shown to be potentially useful when determining mortality of a fish using acoustic telemetry over both field studies in 2009 and 2010. To test the assumption that it is possible to distinguish between live and dead tagged fish using telemetry, the investigators tracked fish in a preliminary effort in an estuary and evaluated their behavior in the laboratory.

These studies showed that dead summer flounder (carcasses) can move substantial distances, and did so in synchrony with tidal currents. Live fish were much less mobile and more directed in their movements. In order to determine the mortality of these discarded fish, both live and dead summer flounder were tagged and released in a fixed hydrophone array on September 15, 2009, at a location off Brigantine, New Jersey. Initial results from commercial fishery-length tows showed most fish in a poor to intermediate health condition. The initial on-deck mortality was 32.7%. Mobile tracking efforts were able to re-detect both initially live and dead fish during tracking, and within the array for approximately 24 hours before a northeast storm event. Fish of poor initial health re-detected after the storm were found in a relatively concentrated area about 8 km southwest of the release site, while live fish exited the array as they moved offshore as typical of the fall migration. These movement patterns provide a latent mortality estimate of 50%. The final discard mortality estimate, combining on-deck mortality and latent mortality, is 82.7%.

#### 3.1.1.7 Industry-Science Partnership Investigating the Short-Term and Long-Term Discard Mortality of Spiny Dogfish Using Hook Gear in Gulf of Maine Waters

This Cooperative Research Program project, completed in 2007, was a partnership between the Gulf of Maine Research Institute (GMRI), the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), and commercial fishermen. The primary research objective was to investigate the short-term discard mortality rate of dogfish from different commercial hook gears. Survivability was investigated through caging studies. A total of 2,418 dogfish were sampled between the two regions; of these 682 were caged by GMRI (45% males and 55% females) and 1,234 were caged by CCCHFA (27% males and 73% females). An overall regional difference in short-term discard mortality was observed; GMRI recorded significantly lower total mortality (7%) than CCCHFA (22%). Regional, averaged findings showed a sex effect with males demonstrating higher mortality (26%) than females (14%). The largest dogfish of each sex demonstrated greater resilience to mortality. Gear effects were found, with highest mortality resulting from longline gear (22%), while the different hand gear-related mortality ranged from 8–17%. The relationship between hook removal treatment and hooking severity index was significant. Because this study's long-term discard mortality assessments were aborted for logistical reasons, these findings represent the range of likely short-term discard mortality from hook gears across the region.

### 3.1.1.8 Juvenile Bycatch and Survival Assessment of Spiny Dogfish (*Squalus acanthias*) in a Western Atlantic Trawl Fishery

This 2003 Saltonstall-Kennedy (S-K) Grant Program project, completed by the New England Aquarium Corporation in 2006, found that discard mortality in dogfish fell below 50% following trawl capture in the wild. The investigators concluded that, based on the relatively low percentage of dying animals following the 72-hour period and the acid-base recovery demonstrated by survivors, spiny dogfish are able to survive at a high percentage when faced with routine trawl-capture stress. Investigators suggested that additional work should address the effects of greater fluctuations in tow times, tow weights, seasonality, air and seawater temperatures, air exposure (in the lab and the field), capture modes (e.g., gillnetting), and physical and behavioral indices as primary study parameters. Investigators also felt the apparent influence of gender on dogfish mortality also required additional investigation under more controlled settings.

### 3.1.1.9 Increasing Survival of Juvenile Atlantic Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*) in the Northwest Atlantic Demersal Longline Fishery

This S-K Grant Program project, completed in 2004 by the New England Aquarium Corporation, was designed to build upon the selectivity work already conducted and investigate how different hauling strategies might affect wound size and juvenile groundfish survivability. Longline catch is usually removed from the hook by force: the fish is held in place with a gaff braced against two parallel steel cylinders placed vertically on the gunwale, allowing the hydraulic hauler to pull the hook through the fish's flesh. This process can inflict severe injury to the fish. To minimize these injuries, an alternate protocol was investigated. A two-handed flip over the barb of circle hooks produced a single hole in the oral cavity of the fish. When this flip method was compared to the snub procedure, no difference in survival after 72 hours was observed in sublegal-sized cod bycatch. Biochemical data gathered on a similar subset of these fish suggested that the protocols chosen to judge survival may have added a level of stress that could have confounded the results.

### 3.1.1.10 Increasing Juvenile Cod Bycatch Survival in a Northwest Atlantic Longline Fishery

This S-K Grant Program project, completed in 2004 by the New England Aquarium Corporation, was designed to (1) augment the survival data already collected on juvenile cod bycatch caught by demersal longlines, (2) quantify mitigated survival of juvenile cod bycatch when treated by immersion in solutions of potassium chloride, (3) quantify the degree of physiological stress experienced by juvenile cod bycatch through the analysis of biological parameters in the blood, and (4) continue to solicit advice from longline fishermen relative to increasing the survival of groundfish discards. Longline fishing practices often remove bycatch from the hook by force: the fish is held in place with a gaff braced against two parallel steel cylinders placed vertically on the gunwale, allowing the hydraulic winch to pull the hook through the fish's flesh. This process can inflict severe injury to the fish and affect survival. In previous studies, fish dehooked by force were also found to have low serum levels of potassium ion.



In this study, the importance of the potassium ion concentration in the blood was examined. Normal seawater enriched with granular potassium chloride was tested for its mitigating effect on survival. When the survival of snubbed sub-legal sized Atlantic cod treated with potassium ion was compared to untreated fish, no difference was found after 72 hours. Biochemical data gathered on a subset of similar fish were analogous to previous studies.

#### 3.1.1.11 Selectivity and Survival of Atlantic Cod and Haddock in a Northwest Atlantic Longline Fishery

This S-K Grant Program project, completed in 1999 by the New England Aquarium Corporation, was designed to examine the selectivity of commercial hook gear to evaluate the claim that juvenile fish caught by hook have minimal stress and, consequently, better survival. Two studies were conducted. The first study compared the length frequencies of cod caught on 11/0 versus modified 15/0 circle hooks. The 15/0 circle hook was non-traditional because it was constructed of the same gauge wire as the 11/0 hook. This study found that the 15/0 circle hook retained the same number of legal cod yet caught few sub-legal cod. In the second study, juvenile cod were collected during experimental longline fishing operations during 1996 and 1997. Fish were removed from fishing gear either by a mechanical dehooking device (crucifier), or gently by hand. Survival rates were determined by placing the juvenile fish into large cages and returning them to the depth at which they were caught for a period of about 72 hours. The lowest survival figures were found for fish that were wounded by the crucifier.

The focus of the research in the second study was to assess the longline fishery and the rate of mortality of sub-legal catch after the fish were in the cages for 72 hours. The results showed high mortality associated with capture using the 11/0 circle hook when the cod had their jaws broken or torn after passing through the crucifer. Mortality increased when predation by herring gulls was considered.

#### 3.1.2 Current Projects

##### 3.1.2.1 Optimization of Gear Size and Post-Release Mortality Reduction in the New Jersey Summer Flounder Hook-and-Line Fishery

This 2013 Bycatch Reduction Engineering Program (BREP) project, to be carried out by Farleigh Dickenson University, is designed to quantitatively determine the optimal hook sizes for anglers to land legal summer flounder, reduce the number of sub-legal flounder caught (discards), and reduce the incidence of deep hooking associated with catch and release. This technological research study has been designed to directly reduce the number of flounder discards and post-release mortality through optimization of gear size for both the commercial and recreational hook and line fisheries. These “optimal” size(s) will result in fewer discards and increase stock biomass through reduction of stress and potential mortality. These data will then be used to recommend selective gear regulations to reduce future discard mortality.

### 3.1.2.2 Elucidating Post-Release Mortality and “Best Capture and Handling” Methods in Sublegal Atlantic Cod Discarded in Gulf of Maine Recreational Hook-and-Line Fisheries

This 2012 BREP grant project, being carried out by the New England Aquarium Corporation, is designed to estimate 30-day post-release mortality of Atlantic cod using ultrasonic telemetry. This project also is designed to determine and disseminate best angling and handling practices that minimize injury/stress and enhance survival in sub-legal (and barely legal) cod discarded in Gulf of Maine recreational hook and line fisheries. The work will first evaluate the condition of ~400 cod immediately following capture by recreational angling during the summer of 2013. Prior to release, acoustic transmitters equipped with depth sensors will be affixed to a subsample of 150 individuals to detect any delayed fatalities for ~30 days post-release. Through pilot work, this project’s researchers have field-tested the application of this technology to estimate mortality in cod and have found a clear disparity in acoustically transmitted depth profiles between live and dead specimens monitored over a ~2-week period.

These initial findings, coupled with the generally small-scale movements of juvenile cod, indicate that, with careful placement of an array of acoustic receivers, this technology can reliably estimate post-release mortality for this species and size class. By retrospectively evaluating the physical, biological, and other variables from the capture and handling process, this project’s researchers hope to establish a set of guidelines to reduce post-release mortality.

### 3.1.2.3 Evaluating the Condition and Discard Mortality of Skates Following Capture and Handling in the Sea Scallop Dredge Fishery

This 2012 Atlantic Scallop Research Set-Aside project is designed to investigate the species-specific immediate and post-release mortality rates for little (*Leucoraja erinacea*), winter (*Leucoraja ocellata*), and barndoor (*Dipturus laevis*) skates. Mortality rates will be quantified using the combination of mortality predictors (i.e., condition and reflex impairment) and 72-hour mortality trials in an on-deck tank system (equipped with a chilling system to mimic bottom water temperatures). Condition index values will be based on visual assessment evaluating overt physical trauma on a scale from 1 to 3. Reflex impairment will be based on five reflexes scored on a present/absent scale (0 = reflex impairment; 1 = reflex exhibited) and then calculated into a vitality score as:  $1 - (\# \text{ of reflexes exhibited} / \text{total } \# \text{ of reflexes tested})$ . In addition, this study will assess the effect of factors such as fishing conditions (e.g., season and depth) and practices (e.g., tow times, volume of catch, deck duration) on post-release mortality.

Quantitative information gathered from this study on post-release mortality can be applied to overall discard mortality estimates in the New England scallop dredge fishery, which in turn will strengthen the reliability of future management models. As of August 2013, 3,731 skates (little: 2,292; winter: 1,184; barndoor: 255) had been sampled from five separate research trips (2012–2013). Based on predictive condition and vitality (reflex-based) indexes, preliminary data suggest that a species-to-species difference exists in post-release mortality, such that barndoor skates are most vulnerable and winter skates are most resilient.

#### 3.1.2.4 Post-Release Survivability of Longline-Caught Large Coastal Sharks

This 2009 S-K Grant Program project, carried out by the University of Massachusetts, Dartmouth, was designed to increase the understanding of capture-related stress and the potential long-term effects on survival with a focus on sandbar and dusky sharks captured in the commercial demersal longline fishery. For each captured fish, blood and tissue samples would be gathered to quantify the capture-related physiological, biochemical, and molecular stress responses, with selected fish tagged to correlate stress parameters of a fish with its post-release movement patterns and long-term survival.

#### 3.1.2.5 The Immediate and Short-Term Post-Release Mortality of Species in the Northwest Atlantic Skate Complex Captured by Gillnet and Otter Trawl

This 2008 S-K Grant Program project, carried out by the New England Aquarium Corporation, aimed to quantify the species-specific at-vessel and short-term discard mortality rates from trawl and gillnet capture for skates in the Northeast Skate Complex. The analyses were designed to consider not only the impacts of fishing conditions (e.g., season, depth, and seawater and air temperature), but also fishing practices (e.g., tow/soak times, sorting durations/deck times, and handling protocols (i.e., picking versus non-picking)). In addition to generating data of great interest to management of species in the complex, this study was designed to expand the limited body of field-oriented stress investigation in elasmobranch fish.

### *3.2 Southeast*

#### 3.2.1 Past Projects

##### 3.2.1.1 Fine-Scale Behavior and Mortality in Post-Release Carcharhinid Sharks in the Florida Recreational Shark Fishery

This 2011 Cooperative Research Program project, carried out by Mote Marine Laboratory, was designed to quantify post-release mortality and behavioral effects of capture on blacktip sharks (*Carcharhinus limbatus*) caught in the Florida recreational shark fishery, and empirically test the differential impacts of circle versus J hooks on physiology and mortality. Investigators recorded capture measures (e.g., fight time, animal condition, etc.); tested blood stress indicators; and applied acceleration data loggers (ADLs) to measure fine-scale swimming behavior of blacktip sharks (N=31) caught by recreational fishermen. Mortalities (N=3, 9.7%) all took place within 2 hours (h) after release and were indicated by static depth data and the cessation of tail beat activity. Surviving sharks were monitored for 7 to 72 h ( $30 \pm 22$  h, mean  $\pm$  SD) using ADLs. ADL data were used to calculate 58 metrics of fine-scale swimming behavior and evaluate their ability to indicate a recovery period in surviving sharks. Investigators used nonlinear mixed modeling to fit a four-parameter logistic function to these metrics. Of the 58 metrics, 18 displayed a significant logistic relationship with time after release, with mean recovery periods from each metric ranging from 7.4 to 14.4 h after release ( $9.9 \pm 1.9$  h, mean  $\pm$  SD).

Overall, results show the ability of accelerometers to provide definitive information on animal outcomes and the broad applicability of these data to the study of post-release mortality and recovery in coastal sharks. Further work is needed to determine relationships between ADL-based metrics of recovery and blood biochemistry. This study did not address differences in handling practices between fishermen, such as the practice of removing the shark from the water to remove the hook or take photographs before release. However, for sharks left in the water throughout the handling process, study findings indicate low mortality for blacktip sharks caught in the recreational fishery and little effect of hook type on mortality rate or other parameters.

#### 3.2.1.2 Post-Release Survival and Habitat Utilization of Juvenile Swordfish in the Florida Straits Recreational Fishery

This 2010 Cooperative Research Program Project, carried out by Nova Southeastern University, was designed to investigate two main topics: (1) the post-release survival rates of juvenile swordfish after being released from the recreational rod and reel fishery and commercial swordfish buoy gear fishery in the Florida Straits, and (2) the habitat utilization of juvenile swordfish following release. High-resolution pop-up satellite archival tag technology was used to estimate the post-release survival of 16 individual juvenile swordfish captured with standard recreational or buoy fishing gear and techniques in the southeast Florida swordfish fishery. Five of the 14 reporting tags showed mortality within 48 hours, for a release mortality rate of 35.7%. However, no common thread could be found among the five mortalities. Results of the Release Mortality program indicated that if the true mortality rate was 35.7%, approximately 1,800 tags would need to be deployed to increase the precision of the mortality estimates to +/- 5% of the true value.

#### 3.2.1.3 Evaluating the Effect of Barotrauma on Regulatory Discards in the Red Snapper Fishery using Advanced Acoustic Telemetry and Hyperbaric Experimentation

This 2010 Marine Fisheries Initiative (MARFIN) project, carried out by Texas A&M University—Corpus Christi, was designed to: (1) examine the long term impacts of barotrauma on red snapper discards using state-of-the-art ultrasonic telemetry after single and multiple recompression events, determining the validity of mark and recapture experiments in this fishery; and (2) identify the impacts that multiple barotrauma events have on the biology of red snapper under experimental laboratory settings using hyperbaric chambers. Specifically, this study was designed to (1) compare behavior and mortality of red snapper experiencing barotrauma using acoustic telemetry; (2) determine the relationship between previous estimates of discard mortality and mortality rates derived from internally implanted acoustic telemetry tags; and (3) examine the impact of multiple decompression events on red snapper growth, mortality, reproductive potential, and behavior under laboratory settings.

#### 3.2.1.4 Collaborative Research to Quantify and Reduce Bycatch Mortality of Blacknose Sharks in Shrimp Trawls

During this 2010 Cooperative Research Program project, University of Georgia Marine Extension Service staff worked with Georgia Department of Natural Resources biologists and commercial shrimpers to (1) understand commercial trawler interactions with blacknose sharks

using trained observers to collect data and (2) quantify the shark bycatch reduction potential of the newly certified Big Boy turtle excluder device (TED) with narrow 2” bar spacing compared to a Double Cover TED with standard 3.5” bar spacing (the industry standard), with fisheyes removed from both nets. This project was designed to involve commercial shrimpers throughout all stages of the project. Results indicate that the Big Boy TED with 2” bar spacing significantly reduces shark bycatch without affecting shrimp retention.

Data collected on commercial shrimp trawlers indicate that blacknose sharks do not represent a large component of total shark bycatch in Georgia. The most common shark species captured were Atlantic sharpnose, bonnetheads, and scalloped hammerheads. On the commercial vessel with the most complete observer coverage (F/V *Sundown*, with 294 observed 2-hour trawls over a period of 2 years), the encounter rate for blacknose sharks was 11.9%. This vessel was fishing four nets simultaneously. The catch per unit effort was less than one blacknose shark per day (0.8). A total of 92 blacknose sharks were captured by this vessel in 2012–2013. Blacknose sharks were encountered primarily in May and June when Georgia state waters are newly opened to commercial shrimping (0-3 miles); this is the time of year when blacknose occur near shore within the small size range that makes them vulnerable to trawl gear.

#### 3.2.1.5 Release Mortality of Gulf of Mexico Greater Amberjack from Commercial and Recreational Hand-Line Fisheries

This 2009 MARFIN project, carried out by the University of Florida, yielded several results. During this study, greater amberjack were discovered to have a “self-venting” mechanism unheard of in other physoclistous reef fishes. Venting does appear to assist greater amberjack when captured from deeper depths, usually deeper than 150 ft. Amberjack may be good candidates for venting because their swim bladders are tough and are buttressed by their ribs. Overall, greater amberjack seem to survive capture and release much more easily than most other reef fishes. This may be because they are really semi-pelagic, and although they aggregate around structure, similar to reef fish, they also use the water column from the surface to great depths in a matter of minutes. This project indicated a high acute survival rate for greater amberjack for some handline fisheries, and initially depth of capture and decompression do not appear to be major factors in release or discard mortality.

There are several possible explanations as to why acute barotrauma may not be high in amberjack. First, greater amberjack cannot be brought up as quickly to the surface as other fish, such as gag grouper or red snapper, because they energetically resist being brought up (hence their attribute of being great fighting fish). This may give the fish time to re-absorb oxygen from the swim bladder into the blood stream. Second, the membrane of the swim bladder is very thick in amberjack and is internally baffled, which would provide greater structural support. Finally, the self-venting mechanism is the main contributor to off-gassing of the excess gases expanding in the swim bladder.

### 3.2.1.6 Characterization of Recreational Discard Composition and Mortality Rates for Gray Snapper and Other Estuarine-Dependent Reef Fishes within a Gulf Coast Estuary and Nearshore Florida Waters

This 2009 Cooperative Research Program project, carried out by the Florida Fish and Wildlife Conservation Commission, was designed to characterize recreational discard mortality rates for gray snapper captured within a gulf coast estuary and nearshore Florida waters and to develop sampling methods to more effectively collect detailed recreational catch, effort, and disposition data for gray snapper and other estuarine-dependent reef fishes. Discard mortality experiments indicated that mortality rates for gray snapper (*Lutjanus griseus*) in the lower Tampa Bay estuary (inshore) and neighboring Gulf of Mexico waters (nearshore;  $\leq 20$  nm from shore) were relatively low. A total of 247 gray snapper were caught over nine inshore and nearshore experiments; 17 of these fish died within 48 hours, for an overall mortality rate of 6.9%. The inshore mortality rate (1.4%) was lower than the nearshore mortality rate (14.4%) and was probably related to depth of capture.

Hook position and increasing depth significantly influenced the probability of mortality. Gag (*Mycteroperca microlepis*) were also retained during inshore mortality experiments; a total of 111 gag were caught over four experiments, and eight of these fish died within 48 hours leading to an overall mortality rate of 7.2%. Hook position and decreasing size of the individual significantly influenced the probability of gag mortality. For both species, individuals hooked in the lip were most likely to survive the catch and release event, while gray snapper hooked in the esophagus or gag hooked in the gills were the least likely to survive. The short-term mortality rates calculated during this study are relatively low and are conservative estimates due to responsible handling practices; these rates may increase depending on depth captured, fish size, and the position of the hook in each fish.

Directed hook and line sampling was conducted each month in inshore and nearshore Tampa Bay waters from July 2009 to July 2011. The use of circle hooks during our study resulted in a high percentage of reef fish being hooked in shallow anatomical locations such as the lip or inside the mouth (94.6%). A large proportion (95.7%) of all fish caught was reported to be released in good condition.

### 3.2.1.7 Survival of Discarded Reef Fish Species in the Recreational Fishery Using At-Sea Observer Surveys and Mark-Recapture Methods off the Florida Coast in the Gulf of Mexico

This 2009 Cooperative Research Program project, carried out by the Florida Fish and Wildlife Conservation Commission, was designed to evaluate survival of discarded reef fish from recreational for-hire headboats operating in the Gulf of Mexico. Based on behavioral observations at the surface immediately upon release, the majority of reef fish discarded in this study were able to break the surface and swim out of sight immediately (good condition) or relatively quickly after some minor disorientation (fair condition). More than 90% of discarded gag and red grouper and more than 80% of scamp were released in good condition. Compared to grouper species, a higher percentage of red snapper and vermilion snapper were visibly struggling at the surface and were often unable to submerge (poor condition), or were unresponsive and presumed dead (dead condition) upon release. Red snapper caught on circle

hooks are 1.3 times more likely to be lip-hooked when caught on circle hooks compared to other hook types.

The results from this study indicate several key differences between regions and among trip types should be accounted for when applying discard mortality rates to the reef fish fishery as a whole. Regional differences in accessibility to deep water and the relative proportion of trips that take place at varied depths within each region should be considered when applying depth-dependent discard mortality rates. The numbers of recaptured fish at the time this report was written were insufficient to evaluate relative survival of fish caught and released under variable conditions in the recreational hook-and-line fishery. Reports of recaptured fish were low during the peak fishing season in 2010 due to the large areal fishing closures in the Gulf of Mexico following the Deepwater Horizon incident.

### 3.2.1.8 Minimizing Discards in the Gulf of Mexico Recreational Red Snapper Fishery: Hook Selectivity and the Efficacy of a First Fish Rule

This 2009 Cooperative Research Program project, carried out by the University of West Florida, was designed to examine several aspects of the northern Gulf of Mexico charterboat reef fish fishery to identify possible measures to mitigate discarding. Two extensive hook selectivity experiments were conducted in which anglers fished with a range of circle hook sizes onboard boats to test the effect of circle hook size on reef fish catch rates and selectivity. Reef sites were video sampled with a micro remotely operated vehicle equipped with a red laser scaler to estimate fish community and size structure prior to fishing reefs with different sized circle hooks.

In the first experiment ( $n = 69$ ), three circle hook sizes (9/0, 12/0, and 15/0) were fished, while five hook sizes (adding 2/0 and 4/0 hooks) were examined in the second experiment ( $n = 52$ ). Red snapper constituted 25.3 and 22.9% of fishery species individuals observed among reefs during experiments 1 and 2, respectively. However, red snapper constituted no less than 61% and as much as 89% of fish captured while fishing. Increasing hook size decreased catch rates among all fishes captured, and decreased estimated catchability for red snapper.

Results indicate that increasing hook size does affect catchability and selectivity in the reef fish fishery, but potential conservation benefits of using larger hooks may be confounded by unintended effects given that the largest hooks used in the current study caught red snapper almost exclusively. Results from scientific observation of normal charterboat fishing activities during open and closed red snapper seasons indicate charterboat captains are able to avoid red snapper somewhat during closed seasons as the mean proportion of red snapper captured during closed season observer trips was 23.8% versus 88.6% during open seasons. Furthermore, mean number of red snapper discards was actually higher for open (19.8) versus closed (14.9) season trips. Observer data were collected on relatively few ( $n = 25$ ) trips aboard only four Gulf of Mexico charterboats.

### 3.2.1.9 Discard Mortality of Red Snapper in the Northeastern Gulf of Mexico Recreational Fishery

This 2009 MARFIN project, carried out by Patzig Marine Services, Inc., was designed to examine discard mortality in the recreational red snapper industry. Red snapper were caught using either a standard recreational 3-to-5 hook rig using #8/0 circle hooks with dead bait or a 1-hook rig using #9 circle hooks with live bait. All fish were vented with a venting tool made from a 10 mL syringe with a 14 gauge hypodermic needle. Fish were initially held in a recirculating live well until 20 to 25 individuals were caught. While fish were in the live well, they were visually monitored for stress by the NMFS Field Biologist and the principal investigator. When 20 to 25 fish were caught, they were dipped out of the live well with a net and placed in a 6-foot diameter by 12-foot length wire mesh holding pen deployed into the water. After a holding period of 2 to 3 hours, the cage was lifted to the surface and all dead fish removed and annotated by tag number as non-survivors. There were 1,486 red snapper sampled. An additional 11 fish were recaptures. Overall 204 (14%) of the total samples died in the cage and/or live well, and 1,282 (86%) survived to be released.

### 3.2.1.10 A Directed Study of the Recreational Red Snapper Fisheries in the Gulf of Mexico along the West Florida Shelf

This 2009 Cooperative Research Program project, carried out by the Florida Fish and Wildlife Conservation Commission, found several key differences between regions and among trip types that should be accounted for when applying discard mortality rates to the reef fish fishery as a whole. First, regional differences in accessibility to deep water and the relative proportion of trips that take place at varied depths within each region should be considered when applying depth-dependent discard mortality rates. Exposure studies indicate that depth-dependent mortality for various reef fishes is low at shallow depths (<20m), increases to between 20% - 40% (depending on the species) at capture depths below a threshold between 30 or 40 meters, and mortality exponentially increases beyond the threshold at deeper depths. Consequently, understanding where and how recreational fisheries operate is critical when assessing catch-and-release mortality. If this information is known, depth-dependent discard mortality relationships described by studies such as this one may be applied to other recreational hook-and-line fisheries for which it is less feasible to measure discard mortality directly, such as the private boat fishery.

Variable effects of circle hooks and release methods (venting versus releasing without venting) also demonstrate the importance of monitoring within a fishery, both for quantifying discard mortalities and changes in fishing behaviors in response to regulations. For species with high discard rates, even low percentage reductions for discards that suffer mortality can have a significant impact on total fishery removals. Except for a brief closure February-March during the years of this study, red grouper was open to recreational harvest year-round, and it is clear from the size distribution of discards that the majority of grouper that are vulnerable to capture are under the legal harvest size. Even small percentage reductions in mortality attributed to the use of circle hooks for species with high rates of discarding, such as red grouper, can equate to substantial reductions in total removals attributed to the fishery. Red snapper were discarded during the years of this study at lower rates compared to red grouper, but discards are still a substantial portion of total removals, and this species appears to be more vulnerable to hook



injuries. Therefore, this species may particularly benefit from larger reductions in discard mortality through the use of circle hooks. Results from this study also indicate that fish that can re-submerge on their own have a higher rate of survival if they are not vented, but may benefit from venting when it helps them re-submerge.

#### 3.2.1.11 Determination of Alternate Fishing Practices to Reduce Mortality of Prohibited Dusky Shark in Commercial Longline Fisheries

This study aimed to understand the effects of longline hooking on dusky shark mortality, and to observe the effects of certain factors on longline mortality. Although other studies have found a correlation between soak time and mortality in dusky sharks (Romine et al 2009), this study was able to correlate time-on-hook and mortality in dusky sharks. This study showed that median mortality is reached after 6 hours on the hook, and 90% mortality is reached after 15 hours. This median mortality is shorter than that when soak time is used as a measure of mortality rates, when median mortality occurs after 13 hours.

This study found that consideration of time-on-hook and mortality can lead to more effective management measures related to the restriction of soak time. Overall, this study's results supported predictions that dusky sharks experience high levels of hooking mortality, and that time-on-hook is a more accurate measurement of mortality associated with bottom longline gear than soak time. This study also found water temperature to be an insignificant factor affecting mortality.

#### 3.2.1.12 Examining the Efficiency of Modified Circle Hooks in Reducing the Bycatch of Undersized Lutjanid and Serranid Fishes

To examine the potential for reduction of post-release mortality of undersized snapper and groupers caught with circle hooks, the NMFS Southeast Fisheries Science Center tested the efficacy of modified circle hooks in further reducing incidences of gut hooking. The modified circle hook, or AP circle hook, incorporates a 40-mm wire extension (also referred to as an appendage) from the hook's eye, thereby increasing the diameter of the hook while negligibly affecting its effective size and weight. As of the end of 2011, 1,286 fishes had been captured, representing 21 genera and at least 27 species. Black sea bass, red snapper, and vermilion snapper dominated the catch, constituting 48.5, 24.0, and 9.5% of landings, respectively. There was no evidence of size-related selectivity or reduced efficiency (50.04% captured with circle hooks and 49.96% captured on AP circle hooks for all fishes collected) between the two hook types, regardless of species. Of the captured fishes, 97% were lip hooked regardless of hook type. When comparing hooking location by hook type, over 95% of all fishes captured were hooked in the jaw; however, 98.75% of fishes captured on appendaged hooks were hooked in the jaw, compared to 95.79% of fishes captured on circle hooks. Of the 17 fishes hooked in the throat or alimentary canal, only one of these occurrences was on an appendaged hook.

### 3.2.1.13 Reducing Discard Mortality in Red Snapper Recreational Fisheries using Descender Hooks and Rapid Recompression

This 2007 Cooperative Research Program project, carried out by Texas Tech University, compared the survival of fish released at the surface, both vented and unvented, with fish released at the bottom using a device invented by a fisherman—the Shelton Fish Descender (SFD hook). To test the hook, investigators used two types of mark and recapture methods: passive tags returned by fishermen (with tag returns as a proxy for relative survival), and acoustic tags that recorded acceleration and depth of the fish for at least 4 days after release. Overall survival was substantially lower under warm, stratified water conditions (summer) than cooler, mixed water conditions (spring/fall/winter). With both methods, investigators found no significant differences in relative survival rates by release method (treatment), season, or fish condition at release within years or overall years combined, although depth, year, fish length, and the interaction of year and fish length were all significant. Results were confounded by changes in red snapper management that shortened the fishing season from 6 months to 6–8 weeks, thus reducing the likelihood of tag recapture, and by significant increases in the sizes of fish from an average of ~340 mm in 2007 to 579 mm in 2011.

Trends in tag returns indicated that unvented surface-released fish had higher relative survival under mixed water conditions, while either vented or unvented surface-released fish had higher relative survival under summer water conditions. These results were supported by the acoustic tag study, which also showed higher survival in unvented surface-released fish in winter and vented surface-released fish in summer. The only condition under which bottom-released fish showed improved survival over surface-release methods was when dolphin predators were avidly foraging on discarded fish, although predation may have been underestimated for bottom-released fish. These results suggest that different release methods may be appropriate under different temperature and predator conditions to increase survival of released fish, although more research is needed.

### 3.2.1.14 Size and Age Structure and Catch and Release Mortality Estimates of Sub-Adult and Adult Red Drum in the Tampa Bay Estuary and Nearshore Gulf of Mexico Waters

This 2005 MARFIN project, carried out by the Florida Fish and Wildlife Conservation Commission, was designed to, among other things, determine the catch-and-release mortality and the sizes of released red drum captured in Tampa Bay. A total of 251 red drum were collected during nine different experiments, of which 14 individuals died within 48 hours for a mortality rate of 5.6%. Logistic regression analyses indicated that both temperature and hook position significantly influenced the probability of mortality, with mortality rates increasing significantly with higher temperatures and among individuals hooked in the throat. No direct evidence of higher mortality using J-hooks was detected, although a higher proportion of individuals caught using J-hooks experienced deeper hooking. Results from this study will not significantly alter results from the existing Florida red drum assessment (as of 2009), which assumed a 5% post-release mortality rate.

### 3.2.1.15 Cooperative Hook and Line Discard Mortality Study of Vermilion Snapper in the Northeastern Gulf of Mexico Commercial Fishery

This 2005 Cooperative Research Program project, carried out by Patzig Marine Services, was designed to collect information pertaining to the discard mortality of vermilion snapper using three common methods of air bladder puncture when fish were brought up rapidly from depth. Fish were tagged, measured, and placed in a holding pen, where underwater cameras filmed them for a minimum of 3 hours. Investigators released survivors back into the Gulf. Predation of discarded fish was also documented. A total of 30 trips were made, providing 1,912 samples. Overall, 34% of the samples captured died in the cage and 66% survived to be released. Results showed that survival of vermilion snappers was greater when swim bladders are punctured with a hypodermic needle and that no venting was only slightly worse (1%) than using a fillet knife for venting. The investigator found that predation from porpoises, sharks, and other species was a significant factor in the mortality of discarded vermilion snappers. Through observations and some photographic evidence, the added effects of predation by sharks, porpoises, wahoo, king mackerel, and greater amberjack on discard mortality may be far greater than shown by this study's recorded data.

### 3.2.1.16 The Capture Depth, Time, and Hooked Survival Rate for Bottom Longline-Caught Large Coastal Sharks

This 2005 Cooperative Research Program project, carried out by the University of Florida, used bottom longline gear, hook timers, and time depth recorders to collect data pertaining to the relationship between soak time (the time longline gear is actively fishing) and capture depth on fishing mortality and catch per unit effort (CPUE) of individual shark species and shark species aggregates. Analyses showed that the majority (93.4%) of animals were caught while the longline was fishing on the bottom, two-thirds of the tripped timers had animals attached to the hook, and the majority of sharks were caught within the first 6 hours of a longline set. The catch consisted primarily of nurse (*Ginglymostoma cirratum*) (25.7% shark catch and 23.8% total catch), sandbar (22.4% shark catch and 20.7% total catch), blacktip (14.1% shark catch and 13% total catch) and Atlantic sharpnose (*Rhizoprionodon terraenovae*) (10.5% shark catch and 9.7% total catch) sharks. The bycatch species most commonly encountered were red grouper (*Ephinephelus morio*) (44.3% bycatch catch and 3.3% total catch). The mortality rates for the Atlantic sharpnose (100%) and nurse (0%) sharks were not dependent on the amount of time spent on a hook. The sandbar shark mortality rate increased when time on hook increased, and the blacktip shark suffered its highest mortality after being on a hook for 4 hours or longer. Data analysis suggested that the majority of shark species bit the hook within the first 6 hours of the set. Mortality rates for several species of shark increased with the amount of time animals were hooked on the longline, and the majority of shark species were caught in water deeper than 100 ft.

### 3.2.1.17 Decompression and Delayed Mortality: Effects of Barotrauma on Red Snapper (*Lutjanus campechanus*)

This 2004 MARFIN project, carried out by Texas Tech University, was designed to (1) evaluate the effects of barotrauma in a controlled setting using a hyperbaric chamber to simulate capture

from a variety of depths, (2) assess the effects of barotrauma on internal organs and establish correlations between tissue damage and release mortality, (3) test the visual acuity of red snapper and relate any changes in vision caused by decompression to survival, and (4) create a condition index that would allow observers to easily associate external signs of stress with delayed mortality.

The investigators demonstrated that as the level of the stressors applied increased, the number of barotraumas experienced increased, reflex response capabilities decreased, circulating plasma cortisol increased, and swimming performance decreased. These observations suggested that the stress associated with rapid thermal change and decompression causes a significant decline in the ability of red snapper to recognize, react, and evade potential threats upon release.

#### 3.2.1.18 Estimates of Catch-and-Release Mortality for Red Drum, *Sciaenops ocellatus*, in the Recreational Fishery of South Carolina

This 2003 Cooperative Research Program project, carried out by the South Carolina Department of Natural Resources, employed the most popular hook (J-hooks, non-offset circle hooks, and offset circle hooks) and natural bait types in two fishery-independent hooking studies representing the major targets (sub-adults and adults) of the South Carolina red drum fishery. Findings were compared to a fishery-dependent logbook study using fishing guides as well as a long-term dataset for adult red drum maintained by South Carolina Department of Natural Resources. Fishing in shallow habitats revealed that the smallest proportion of sub-adult red drum died when fishing with non-offset circle hooks. The largest number of sub-adult red drum were deep hooked (gills or gut) when J-hooks were used. The largest proportion of sub-adult fish died as a result of being deep hooked on offset circle hooks. A bottom longline study for adult red drum found fewer fish died when caught on non-offset circle hooks than on J-hooks. The large hook study also indicated that long-term impacts of catch and release may exist for reproductively active adults. The investigators concluded that non-offset circle hooks of the appropriate size should be used to maintain the lowest level of catch and release mortality for both sub-adult and adult red drum fisheries.

#### 3.2.1.19 Removing Gas from the Distended Swim Bladder of Reef Fish: Does It Really Increase Post-Release Survival?

This S-K Grant Program project, completed by the South Carolina Department of Natural Resources in 1999, was designed to determine whether puncturing the distended swim bladder of reef fish in the southeastern United States would increase post-release survival. The benefits of deflating reef fish swim bladders were investigated by capturing fish by hook and line, deflating 203 fishes using a 16 gauge hypodermic needle, deflating 223 fishes with a 3 mm steel canula, and not deflating 227 fishes acting as control subjects. Benefit was measured by survival over the first 24 hours after release. This study found that black sea bass benefited significantly from deflation and that vermilion snapper also benefitted, but not to the same extent as black sea bass. Survival of fish deflated by the hypodermic needle and the 3 mm canula was approximately equal. The largest increase in survival was in black sea bass caught at 43–55 meter depth and deflated with the hypodermic needle. Control specimens exhibited a 61% survival rate while

100% of the specimens deflated by needle survived. Therefore, study results indicated that released black sea bass should be deflated.

### 3.2.2 Current Projects

#### 3.2.2.1 Testing an Alternative Method for the Safe Release of Reef Fishes Caught on Hook-and-Line Gear in the Recreational Fishery in the Gulf of Mexico

This 2013 BREP project, being carried out by the Florida Fish and Wildlife Conservation Commission, is designed to: (1) assess whether rapid recompression for reef fishes in the Gulf of Mexico is a viable alternative to surface release when fish require venting and/or when venting is deemed unnecessary, (2) determine an optimum depth range for recompression and reduced predation, and 3) quantify potential reductions in post-release mortalities if new release methods are prescribed. Principal investigators will work cooperatively with the recreational for-hire industry to assess the practical application of recompression in the recreational fishery. Experimental treatments will compare the current practice—where fish are vented at the discretion of anglers and released at the surface—to an alternative method where fish are returned rapidly to depth and recompressed without the need for venting. The primary species of interest are red snapper, gag, and red grouper. Experiments will be conducted from recreational for-hire vessels in northern and central portions of the west coast of Florida from June through September—the period of highest stress and vulnerability for discarded reef fish. Experiments will be conducted in depths between 30 and 60 meters where recreational fishing takes place and barotrauma is a concern. Fish will be tagged and recapture rates among treatment groups will be compared to assess relative survival rates.

#### 3.2.2.2 Evaluation of the Effects of Recreational Catch-and-Release Angling on the Survival of Gag Grouper (*Mycteroperca microlepis*)

This 2013 project, funded by MARFIN, is being carried out by the Florida Fish and Wildlife Conservation Commission. The project is designed to identify the effects of catch and release angling (i.e., regulatory discards) on the survival and behavior of gag grouper across a range of depths and to evaluate the effectiveness of gear and tactics used to return fish to depth. Acoustic telemetry will be used to assess survival of gag grouper after recreational angling and release, as well as the efficacy of strategies employed to reduce pressure-related fishing trauma. Gag grouper will be caught during all seasons of the year over a range of depths (5–50 m) using standard reef fish recreational fishing tactics. Fish will be fitted with pressure-sensitive acoustic tags so their position within the water column may be monitored after release. Fish will be evaluated for signs of barotrauma and then returned to depth via venting or, alternatively, through submersion using a weighted crate or dropline.

Permanently deployed acoustic receivers will continuously monitor sites and record fish presence and position within the water column, quantifying immediate, short-term (days–weeks) survival and fine-scale behavioral patterns after a catch and release event. Permanently deployed receivers allow for the collection of data over extended periods, and can provide information regarding long-term (months–years) survival, behavior patterns, and residence times of acoustically tagged gag grouper. Movement and behavioral data collected after fish release will

not only allow for a realistic indication of acute fish survival after an angling event, but can also provide an evaluation of the effectiveness of traditional and alternative methods used to return fish to depth.

### 3.2.2.3 Discard Mortality of Carcharhinid Sharks in the Florida Commercial Shark Fishery

This 2013 Cooperative Research Program project is being carried out by Mote Marine Laboratory. The project is designed to quantify post-release mortality and behavioral aspects of capture on sandbar (*Carcharhinus plumbeus*) and blacktip sharks (*C. limbatus*) caught in the Florida commercial shark fishery. This work will be accomplished by working with Florida commercial shark fishermen to tag animals with acceleration data loggers (ADLs), which record animal movements and body posture at sub-second intervals and therefore provide high-resolution information about mortality, swimming abnormalities, and recovery time. ADL data will be compared to capture indices and blood-based stress indicators and used with hook timers to quantify the effect of hooked time on physiology and post-release swimming behavior in these two species.

### 3.2.2.4 To Vent or Descend? Evaluating Seasonal Release Mortality of Gag and Red Grouper in Recreational Fisheries of the Eastern Gulf of Mexico

This 2012 project, funded by MARFIN, is being carried out by the University of Florida. The project is designed to compare the acute, short- and long-term release mortality of gag and red grouper (*Epinephelus morio*) caught in recreational hook and line fisheries in the eastern Gulf of Mexico that have been released either after venting or by using descenders during winter and summer. The investigators plan to determine seasonal (winter versus summer) acute and short-term release mortality rates for gag and red grouper caught in recreational fisheries and released after venting or through use of a descender device, using both surface and underwater observations and short-term caging experiments. The investigators also plan to compare surface and underwater observations of released gag and red grouper for behavioral and motor deficits based on either being vented or returned to depth using a descender device. In addition, the investigators plan to model the effect of season as a potential factor contributing to release mortality in gag and red grouper through integration with other factors previously known to contribute to release mortality, such as capture depth and time on deck.

### 3.2.2.5 Examining Hook Selectivity in the Northern Gulf of Mexico Recreational Reef Fish Fishery

This 2012 Cooperative Research Program project is being carried out by the University of South Alabama. It is designed to collect fishery observer data onboard northern Gulf of Mexico charterboats and conduct offshore hook selectivity experiments in spring and summer 2013. Two observer trips were made in fall 2012, during which 93 reef fish were sampled. The size distribution for red snapper discards reflected the fact that the red snapper recreational season was closed. The mode of the age distribution of red snapper discards was 5 years, although a third of the discards were 3 years old or younger.

### 3.2.2.6 An Evaluation of the Effects of Catch and Release Angling on Survival and Behavior of Goliath Grouper (*Epinephelus itajara*)

This 2010 MARFIN project, carried out by the Florida Fish and Wildlife Conservation Commission, was designed to identify the effects of catch and release angling on the survival and behavior of goliath grouper across a range of depths and to provide information on the abundance, size distribution, and residency of goliath grouper at specific sites within a defined region of the central eastern Gulf of Mexico. The investigators plan to use acoustic telemetry to assess immediate effects of catch and release angling for this species via both manual and passive tracking of animal movements. Diver surveys at sampling sites directly following fish release will allow initial confirmation of fish survival and condition as well as a description of the abundance and size distribution of other goliath grouper present. Manual tracking immediately following fish tagging will provide information regarding short-term survival and fine-scale movement patterns after a catch and release event. Long-term behavioral data will be collected via passive acoustic telemetry and will provide data regarding the long-term survival, behavior, and residence of fish at specific sites.

## *3.3 West Coast*

### 3.3.1 Past Projects

#### 3.3.1.1 The Effects of Decompression and the Efficacy of Recompression as a Bycatch Mortality Reduction Tool for Rockfish

This 2008 S-K Grant Program project, completed by Oregon State University, evaluated the efficacy of using recompression to reduce bycatch mortality in rockfish species. The investigators evaluated the response of six species of Pacific rockfish to forced decompression at the histological level (heart ventricle, rete mirabile, head kidney, liver, gill, and eye) and macroscopic level to determine if differences in the macroscopic barotrauma response between species also extended to tissues. In addition, they investigated whether “baseline” levels (i.e., shortly after capture) of plasma cortisol differed between species. Tissue injuries as a result of forced decompression included emphysema in the heart ventricle, emboli in the vessels of the rete mirabile, and emboli in the vessels of the head kidney. No injury was observed at the histologic level in the liver, gill or eye due to barotrauma. Baseline cortisol levels ranged between 0 to 54.1 ng/ml and showed no differences among species. The investigators also induced barotrauma in adult black rockfish (*Sebastes melanops*) from a simulated depth of 35 m, followed by recompression. Blood and selected tissues (eye, heart ventricle, head kidney, liver, rete mirabile, and gonad) were sampled at days 3, 15, and 31 post-barotrauma to evaluate the tissue-level response during recovery. No mortality from barotrauma occurred during the experiments. The majority of both treatment and control fish resumed feeding by day 31. The only macroscopic injuries observed in treatment fish were the presence of a ruptured swimbladder and/or a ruptured tunica externa (outer layer of swimbladder). Organ histology showed injury in the rete mirabile of 7% of treatment fish. Plasma analyses indicated no strong effects due to barotrauma, suggesting overall handling stress outweighed any effects from barotrauma.

### 3.3.1.2 Reducing Post-Release Mortality for Common Thresher Sharks Captured in the Southern California Recreational Fishery

The common thresher shark (*Alopias vulpinus*) is the focus of a popular southern California recreational fishery that typically captures individuals by hooking them in the caudal fin. This technique reduces the ability for forward locomotion and the capacity for ram ventilation. This multi-year BREP project used pop-up satellite archival tags (PSAT tags) to assess the post-capture survivorship of tail-hooked adult and sub-adult common thresher sharks using. Survivorship estimates were based on 19 common thresher sharks captured in southern California from 2007 to 2009 using recreational stand-up tackle. Five mortalities were observed over the course of the study, resulting in an overall post-release mortality estimate of 26% (Heberer et al 2010). All mortalities occurred in large individuals with fight times of  $\geq 85$  min.

The study indicated that large tail-hooked common thresher sharks with prolonged fight times exhibit a heightened stress response that may contribute to an increased mortality rate. These results suggest that for larger individuals, caudal-based capture methods used in the California recreational fishery may not be suitable for an effective catch and release-based strategy. Subsequent studies funded by NMFS identified several techniques that may result in higher survival rates for mouth-hooked individuals, including the use of non-offset circle hooks, dead drifting, drop-back troll techniques, and drifting with artificial lures.

### 3.3.1.3 Incidental Take and Post-Release Mortality of Blue Sharks in the U.S. West Coast Drift Gillnet and Longline Fisheries for Swordfish

The California drift gillnet (CADGN) fishery targets swordfish in the California Current. With the exception of ocean sunfish, blue sharks are caught in greater numbers than any other fish species taken in this fishery. Nearly all blue shark are discarded at sea due to lack of market value. A 2009 analysis of the 1990–2008 observer data revealed that 32% of blue sharks captured were released alive, and an additional 5% were discarded with their disposition unknown. The remaining 63% were discarded dead. In 2007, the NMFS Southwest Fisheries Science Center and Southwest Regional Office began deploying PSAT tags on sharks released from the CADGN fishery to assess survivorship in order to determine more accurate estimates of fishery mortality for use in a blue shark stock assessment. As a part of the study, a set of criteria was developed to document the condition of all live blue sharks released: released: good, fair, or poor. Prior to the 2011–2012 season, 12 blue sharks (100–200 cm fork length (FL), median 149 cm) had been tagged by fishery observers. Three of the 12 sharks were released in good condition, while the remaining 9 were released in fair condition.

Satellite tag records suggest that all animals survived the acute effects of capture in the CADGN fishery. During the 2011–2012 season, fishery observers deployed three survivorship Pop-up Archival Transmitting (sPAT) tags—new, more economical tags that record daily minimum and maximum depths and temperatures and are programmed to pop off if the tag exceeds a certain depth or remains at a constant depth for several days. These tags are effective for determining the fate of tagged fish. Of the three sharks tagged (two females of 134 and 162 cm FL, and one 161 cm FL male), two were in poor condition when released and one was considered in fair



condition. Two of the three sharks died immediately and the third \ died after 8 days. These results, combined with the results from the prior years, suggest that sharks that are released in good condition are likely to survive, whereas those released in poor condition are likely to die. Science Center scientists are compiling the data on the condition of all sharks released to more accurately apply the survivorship estimates to the discarded population.

#### 3.3.1.4 Ability of Southern California Deepwater Rockfish to Survive Barotrauma Following in-situ Recompression

This 2011–2012 BREP project examined the long-term survival rate of deep-water rockfish species captured from depths of 80 to 180 m and subsequently recompressed and released using a weighted cage or other commercially available recompression device. Rockfish survival and behavior were monitored for up to 4 months following release using newly developed accelerometer and pressure-sensitive acoustic transmitters that were attached to each fish upon capture. Fifty tags were deployed on five different species, and of the fish that remained within detection range, 92.9 percent survived in the short term (up to 2 days), with 76.7 percent surviving long-term. The two deep-dwelling depleted species tagged in this project, bocaccio (*Sebastes paucispinis*) and cowcod (*S. levis*), both showed high long-term survival following recompression and release (90.0% and 100% respectively).

Several types of commercially available “recompression” or “descending” devices can be used by recreational and commercial fishermen to release rockfish bycatch. A long-term survival rate of over 75 percent suggests that these devices should be considered in future management decisions as options to reduce bycatch mortality. Further studies are now needed to test the relative feasibility of the use and the success of different device types in the various fisheries that encounter rockfishes as bycatch.

This study showed that rockfish caught deeper than 125 m should be recompressed to a minimum depth of 40 to 45 m. Such details are crucial in developing the future technology and protocols needed to properly implement recompression practices on a large scale. The results of this work were used to inform long-term mortality estimates for all depths and aggregate mortality estimates in depths greater than 50 fathoms. These estimates along with data from other West Coast research efforts were used by the Groundfish Management Team of the Pacific Fishery Management Council to derive mortality rates reflecting the use of descending devices.

#### 3.3.1.5 Post-Release Mortality in the Central California Ocean Recreational Salmon Fisheries

Assessments for West Coast ocean recreational salmon fisheries assume a post-release mortality rate of 14%, except in the case of the Central California fisheries (Salmon Technical Team 2000). Beginning in the early 1990s, a light tackle method of fishing known as “California-style drift mooching” became popular in Central California. This method results in a much higher proportion of gut-hooked fish than the standard method of trolling, and thereby a significantly higher post-release mortality rate of sublegal-size fish.

To assess the post-release mortality rate for these fisheries, the California Department of Fish and Wildlife, supported and assisted by the NMFS Southwest Regional Office and Southwest

Fisheries Science Center, held 276 drift-mooch caught Chinook salmon at sea in large onboard holding tanks for 96 hours (Grover et al. 2002). The control-adjusted 4-day mortality rates were found to depend strongly on hook wound location, ranging from 4% for maxillary-hooked fish to 85% for gut-hooked fish. These wound location-specific mortality rates were weighted by the distribution of hook wound locations for drift-mooch caught fish determined by fishery onboard observers to obtain an overall post-release mortality rate of 42% for drift-mooch caught and released fish. For the fishery as a whole, a weighted average of the 14% troll-caught and 42% drift-mooch-caught rates is assessed based on the prevalence of these two methods in the fishery, which varies by area and month, but typically has yielded an overall post-release mortality rate for the Central California salmon fisheries in the range of 20 to 25%.

Although the required use of barbless circle hooks for drift-mooch fishing beginning in the late 1990s has reduced the post-release mortality rate in this fishery by reducing the fraction of gut-hooked fish, the mortality rate is still relatively high. If other modifications to the drift-mooch technique or angler education is successful in further reducing the fraction of gut-hooked fish, the overall post-release mortality rate for these fisheries could be readily reassessed using the methods outlined above.

#### 3.3.1.6 A Device for Greatly Reducing Fishing Mortality for Protected Giant Seabass (*Stereolepis gigas*) and Jewfish (*Epinephelus itajara*)

This S-K Grant Program project, completed in 2002 by the Pfleger Institute of Environmental Research, addressed release mortality of California's giant sea bass and Florida's goliath grouper (formerly referred to as jewfish), which are both very large protected species that are incidentally caught by recreational and commercial hook and line anglers. When these fish are brought to the surface, the air in their swim bladders expands greatly, making the fish so buoyant that they cannot swim back to the bottom when released. A release device was designed and manufactured to allow commercial and recreational anglers a means of safely releasing large bottom fish with swim bladders. A prototype was built from which changes were made before a final product was produced. The final product was tested in the field on giant seabass and goliath grouper. Fish captured and released with this device were shown to survive through the use of acoustic tagging and tracking. Twenty-five of these devices were manufactured for distribution to commercial and party boats that routinely encounter these large protected species.

### 3.3.2 Current Projects

#### 3.3.2.1 Field Validation of the RAMP Approach for Determining Crab Bycatch Mortality

This 2012 BREP grant project, which was ongoing as of mid-2013, is designed to determine mortality rates for bycaught Dungeness crab (*Cancer magister*) in Oregon's commercial and recreational crab pot fisheries and indirectly in commercial bottom trawling. (Only male crab over a set size may be retained in pot fisheries, and no crab may be retained by trawling.) These mortality rates will be accomplished using a tag-return study and the Reflex Action Mortality Predictor (RAMP) approach, which relates reflex impairment of discarded crab to a probability of mortality. The combination of these two methods should allow for an evaluation of both immediate and longer-term mortality rates, and will allow for the identification of variables that

can be adjusted to reduce these rates. Investigators tagged and released crab from October 2012 to April 2014. The investigators will offer rewards for tag returns until August 2014. Fishermen have been and will continue to be encouraged to report recaptured crab through extensive outreach efforts. Data will be analyzed in the summer of 2014, and results will be submitted in a final report to BREP in October 2014 and then disseminated to the fishing community through flyers and a workshop.

### 3.3.2.2 Examining Environmental Effects of Rockfish Catch-and-Release Survival: Does Low Oxygen Contribute to Mortality Following Barotrauma?

This 2013 BREP project, to be carried out by the University of California, San Diego, is designed to determine the effects of low levels of dissolved oxygen on rockfish recovery from barotrauma following catch and release. Specifically this will include: (1) determination of oxygen concentrations typically experienced by rockfish in the wild using oxygen-sensing acoustic transmitters, (2) determination of rockfish voluntary movements in relation to changing oxygen concentrations using acoustic transmitters and a three-dimensional positioning system, (3) determination of rockfish resting metabolic rates and the critical oxygen concentration at which aerobic demands cannot be met both prior to and while recovering from barotrauma, and, (4) examination of rockfish survival and recovery at varying dissolved oxygen levels following barotrauma. Field and laboratory studies will be implemented to understand the effects of low levels of dissolved oxygen on rockfish recovery from barotrauma. Fieldwork will involve a tagging study to examine rockfish sensitivity and movements in relation to dissolved oxygen in vivo. Laboratory studies will include determination of rockfish oxygen demands and the critical oxygen concentration causing stress following simulated capture using a hyperbaric chamber.

## *3.4 Alaska*

### 3.4.1 Past Projects

#### 3.4.1.1 Mortality Rates for Crab Bycatch in Trawls

In 2009, scientists from the NMFS Alaska Fisheries Science Center collected data to estimate the mortality rates of red king crab (*Paralithodes camtsactus*) after passage under the groundgear of commercial bottom trawls. This followed the methods of similar research on Tanner and snow crabs in 2008. Crabs were recaptured after passing under the central and side sections of a trawl footrope, as well as after contacting the sweeps ahead of the trawl. Crabs were also assessed after capture by a similar net fished ahead of the trawl, to estimate and account for the effect of capture and handling. The scientists also evaluated the effectiveness of modifications to sweeps and footrope that were expected to reduce crab mortality. More than 3,700 crabs from 73 trawl hauls were assessed for reflex impairments, while more than 738 were assessed and then held in onboard tanks to establish the association between these impairments and the probability of mortality. Estimates of crab mortality rates after trawl encounters were generated for all major Bering Sea crab species. Sweep modification reduced all of those rates.

### 3.4.1.2 Trawl Codend Mesh Size and Shape Investigations to Reduce Catch and Discard of Undersized Pollock

This S-K Grant Program project, completed by the Alaska Fisheries Development Foundation in 2000, was designed to test the survival of small pollock that escape through codend and intermediate trawl meshes. At-sea experiments were conducted in the Gulf of Alaska by replacing top panels of the trawl codend and extensions with escape panels for selectivity and escape mortality trials. Escapees from the meshes were herded via a specially designed top panel cover into a specially designed caging system and recaptured. Collection units were towed to a cage-staging site and secured to the bottom. Captured pollock were monitored daily by divers over 14 days to determine mortality. Results indicated that most of the mortality took place during the first four post-escape days. Thereafter, mortality was low but continued until the experiment was terminated.

Mortality was clearly related to fish size, with large fish more likely to survive the trawling and escape process. Results suggested lower mortalities for fish escaping meshes in the extension than fish escaping through the codend. Fourteen-day mortality caused by escapement and the caging/holding processes ranged from 46–84% for pollock that escaped through the codend meshes and from 47–63% for fish that escaped through intermediate meshes.

### 3.4.1.3 Practical Application of Fishing and Handling Techniques in Estimating the Mortality of Discarded Trawl-Caught Halibut

This S-K Grant Program project, completed by the Alaska Fisheries Development Foundation in 1998, was designed to evaluate the practical application of two estimates of mortality for discarded trawl-caught halibut. Halibut bycatch mortality was estimated via two models: the International Pacific Halibut Commission (IPHC) model, which relates halibut condition to halibut mortality; and the University of Washington (UW) model, which considers mortality as a function of fishing and handling practices. The results indicate that trawl-caught halibut mortality can be reduced through modified fishing and handling practices, and that current observer sampling practices lead to overestimates of mortality when the IPHC method is employed.

## 3.4.2 Current Projects

### 3.4.2.1 Use of Digital Imaging Technology to Reduce Released Halibut Mortality in Alaska's Recreational Fishery

This 2013 BREP project, to be carried out by the Alaska Charter Association, is designed to develop digital imaging technology for the recreational fishery to measure halibut lengths. This project will test the use of digital imaging technology, which should reduce handling times and physical injury to fish, thereby reducing release mortality. This project's planned development of an at-sea means to validate trophy-sized halibut also should reduce halibut mortality by encouraging the release of more halibut. Specifically, this project will (1) determine the relationship between morphometric features on the head of a halibut to its fork length and (2)

develop and field test a Smartphone digital imaging application that will display length and weight of halibut after capturing an image of a halibut's head.

### *3.5 Pacific Islands*

#### 3.5.1 Current Projects

##### 3.5.1.1 Estimating Post-Release Mortality in Istiophorid Billfish

This BREP-funded project, which began in 2010 and is ongoing, is using PSATs to estimate the post-release survival of large Pacific blue marlin (*Makaira nigricans*) and striped marlin (*Kajikia audax*) released from pelagic longline gear. These data will provide important information about post-release survival of marlin bycatch in the Hawaii-based tuna longline fishery. This study also plans to establish biochemical predictors of morbidity and mortality from tissue plugs and blood. This approach conducts comprehensive pathophysiological analyses of large numbers of fish (including tagged fish) to diagnose primary factors that account for the fish condition, as well as secondary factors that might change dramatically but have little impact on survivability. Integration of PSATs and pathophysiological analyses generates predictive power. The primary benefit expected from this project is to generate robust estimates of post-release survival of striped and blue marlin released from longline fishing gear that targets tuna.

#### **4. How Release Mortality Assumptions Are Incorporated into Stock Assessments**

In most cases, stock assessment models rely on the most accurate estimates possible of total removals from a population. In addition to harvest, total removals must include mortality associated with discarded individuals. Incorporating the rate of release mortality into stock assessments is possible, but has proven difficult because accurate estimates of release mortality are often unavailable. Numerous factors affect mortality following release, but estimates of mortality rates are often unavailable. Further, incorporating estimates derived from controlled studies into stock assessments may be overly simplistic due to the complex influences affecting release mortality.

When mortality rates are undetermined, some stock assessments take a conservative approach and assume a 100% release mortality rate. Thus, all released fish, along with the harvest by the fishery, are assumed to represent the total removals by the fishery. Applying a constant mortality rate to all discards simplifies the estimation of total removals because it occurs outside of the assessment model. However, applying constant mortality rates as a proxy may be inappropriate because of the range of factors and interactions that affect the true discard mortality. Although constant discard mortality rates may be appropriate for some stocks, it is likely that adopting proxy values for these estimates may be misrepresentative in many cases, and use of a constant discard mortality rate may be unrealistic. Stock assessments that include some data about mortality rates are sometimes able to apply gear-specific mortality rates.

To effectively account for varying release mortality rates within a stock, absolute estimates of mortality rates should be available for all factors that may influence the release mortality, such as fish size, gear type, or environmental factors. When absolute rates are unavailable for all factors, innovative approaches must be employed, and buffers for uncertainty may be invoked to ensure that mortality rates are not underestimated when attempting to account for mortality rates estimated to be less than 100%. Alternative approaches to mortality rates include:

1. **Constant rate:** Commonly used in stock assessment, this method applies a constant mortality rate, which could be 100% or a lesser number, to all discards.
2. **Modified Delphi method:** An iterative decision-making process designed to come to agreement on divergent or disparate opinions or data and often assumes a constant rate, but one that may be less than 100%. This approach strives to reach consensus agreement, but its results may be no more accurate than existing prior assumptions regarding discard mortality rates.
3. **Mortality assessment predictor:** A viability ranking system is developed and applied at the stock assessment level to estimate mortality among major factors. This approach applies a viability technique, as opposed to directly sampling fish, at the stock assessment level (e.g., making proxy estimates for different sources of mortality such as estimates for fish caught in trawls versus pots).
4. **Mortality models:** Bayesian or other methods incorporate the best available data to create plausible mortality curves that can be applied in the stock assessment model.
5. **Viability assessment:** Detailed viability indices are developed and recorded for a sub-sample of the total discards. This approach involves actually sub-sampling fish and applying a viability predictor for the sample and then extrapolating it to the whole

population (e.g., using viability estimates derived from fisheries observers to estimate mortality rates for separate gear types).

The appropriate approach for estimating mortality following release will depend on the variability in release mortality rates, as well as the data and resources available to inform the assessment model. The impact of discard mortality on assessments can range widely depending on the size of the discard component relative to the overall removals, as well as the mortality rate(s) used.

Methods for estimating discard mortality rates and accounting for total mortalities in assessments are not always complementary. For example, the total number of fish caught in recreational fisheries is estimated by the [Marine Recreational Information Program](#) (MRIP). The MRIP classifies fish into three categories:

1. Retained for harvest
2. Dead but not brought to dock (i.e., used as bait or released dead)
3. Released alive

In stock assessments, total numbers of dead removals include fish that are harvested or released dead (not brought to dock). Constant discard mortality rates, which are determined in separate studies, are applied to the number of live releases. However, these discard mortality studies often include both mortality of live releases plus fish that died immediately. Unless immediate mortalities can be separated out of an estimate of discard mortality rate, a fish that died immediately may get counted twice: once as a dead fish in the MRIP survey, and then again as a discard mortality rate applied to live releases.

## 5. Approaches to Developing Revised Post-Release Mortality Assumptions

Developing appropriate release mortality assumptions is a complicated task, often fraught with uncertainties arising from lack of reliable information on various capture and release scenarios as well as variability among the factors affecting release mortality. The task is further complicated by the fact that post-release mortality does not always occur immediately, when fishermen or observers can observe it. Due to injury, physiological stress from the capture and handling experience, increased predation risk, and various other (often subtle) sub-lethal impacts, mortality can result shortly after a fish is discarded, or in the longer term, days to even months after the initial capture event. Finally, mortality also may differ significantly among species; the type of fishery (e.g., trawl vs. non trawl methods, commercial vs. recreational methods); how the fish are handled (e.g., time on deck, expertise of handlers, whether any re-acclimation efforts are made); the habitat from which the fish are caught (e.g., water temperature and depth); the characteristics of the fish themselves (e.g., sex, size); and as a function of several other factors. Complicating matters, many of these factors are compounding or interactive. For the broadest possible application, the design and interpretation of release mortality investigations should therefore account for the broadest possible conditions relevant to that species and/or fishery.

Although much work is being done to study the impact of these factors on release mortality estimates, most often those who develop mortality rate estimates have limited information to work with. The information limitations can be grouped into two broad categories. First, for many species there is either no information available, or only anecdotal information along with expert opinion. Second, when peer-reviewed studies of release mortality are available, they often do not fully characterize the release mortality experienced in the fishery. For example, a study may employ experimental conditions that do not accurately reflect actual fishing behavior, or the study design may not address longer-term mortality, or it may evaluate only a subset of the fishing methods used in the fishery. Because of the variability in methodologies and the lack of information available for robust discard mortality estimates in the literature, stock assessment scientists often must adopt alternative approaches for identifying mortality discard estimates applicable to individual stocks. In New England the Delphi Technique has been used. On the West Coast a three-step, model-based approach is being employed.

These alternative approaches do not always yield more robust estimates of discard mortality. In addition, managers should consider using a precautionary approach to account for uncertainty when applying such estimates.

### *5.1 Delphi Technique*

The Delphi Technique is a decision-making process that brings together a group of experts and aims to reach a consensus through an iterative process of anonymous questionnaires and discussions of the questionnaire results.

In New England, the Gulf of Maine Research Institute conducted an anonymous online questionnaire that invited industry members, scientists, and fishermen to provide their opinions on the percentage of discarded Atlantic cod that die during commercial otter trawl, commercial gill net, commercial hook and line/longline, and recreational hook and line activities. After the



online questionnaire was completed, a workshop was held that brought together scientists, fishermen, fisheries managers, and others. Workshop participants discussed the questionnaire results, worked through available discard information, and heard input from industry members. Participants then completed a second anonymous questionnaire and had a final discussion reviewing questionnaire results and reaching consensus on the assumed mortality rates for the different fishing activities.

During the course of the workshop, industry representatives and scientists shifted their opinions based on the discussions and the information presented. Although the results of the initial questionnaire showed large differences in the rates thought to be appropriate by the two groups of participants, by the end of the workshop the group was in agreement about the rates they would recommend adopting in future cod stock assessments.

The Delphi Technique has a number of strengths. Stakeholders are comfortable with the process, the process itself results in more informed participants, and its participatory nature means that stakeholder knowledge, which is rarely codified in the scientific literature, can be used to inform the decision. Perhaps most importantly, it provides a way to arrive at agreed-upon values for the assumed mortality rate.

But the Delphi Technique also has weaknesses. It takes a significant amount of time and resources to properly conduct the exercise, and even more time and resources are needed if the exercise must be conducted separately for each species. In addition, it is unclear how the various issues under discussion during the process actually ended up influencing the agreed-upon assumed rates, which can make it difficult for those not involved in the process to understand how the final decisions were reached. In addition, it can be unclear whether the final agreed discard mortality rates are a better approximation of the true discard mortality compared to the status quo. That is, the technique does not yield formal estimates of the mortality rate with known statistical properties, including measures of statistical bias and uncertainty. Rather, it yields values agreed upon by those who took part in the exercise, but the relationship of these values to the truth is unknown and unquantifiable.

## *5.2 Model-Based Approach*

The Groundfish Management Team (GMT) of the Pacific Fishery Management Council (PFMC) developed methods for estimating mortality of groundfish species discarded at the surface (PFMC 2008), as well as methods for estimating mortality that reflect release with descending devices for a sub-set of rockfish species (PFMC 2012, PFMC 2013, PFMC 2014). Estimates of groundfish mortality that were based on accounting for three types of discard mortality: (1) “surface” mortality that is observed during the catch, handling, and release of the fish; (2) short-term, below-surface mortality that has been observed in research trials; and 3) longer-term, below-surface mortality for which little or no information is available.

Estimates of surface mortality were created by developing a generalized linear model of the proportion of fish released dead by depth and by species based on information from observer program data (PFMC 2008). For those species for which a species-specific model could not be developed due to an insufficient amount of observer data, a guild-based method was used to base

the mortality rate by depth on species with similar depth distribution and vertical orientation in the water column. The surface mortality estimates were then treated as baseline mortality rates. To account for the short-term, below-surface mortality, those initial rates were increased by a different amount depending on whether the species was shallow- or deep-dwelling, according to research by Albin and Karpov (1996). The GMT used its expert judgment to apply an additional 5% mortality per 10 fathoms of depth to account for a lack of data regarding longer-term, below-surface mortality. Future revisions may utilize more recent data regarding long-term mortality rates from acoustic tagging studies (Wegner et al. in prep) to better inform long-term mortality estimates in future iterations of surface release mortality estimation.

The GMT subsequently estimated mortality rates reflecting release with descending devices for cowcod, canary, and yelloweye rockfish management. These rates accounted for reduced mortality as a result of being rapidly returned to depth, which mitigated barotrauma, sun exposure, and surface predation-related mortality. The mortality estimation method incorporated short-term mortality rates from cage studies (Jarvis and Lowe 2008, Hannah et al. 2012) and long-term mortality rates from acoustic tagging studies (Wegner et al. in prep). The mortality estimates and associated confidence intervals in each depth bin were estimated using a Bayesian Hierarchical Method, which accounted for variation between species and the sample size of each species using data from the latitude of the focal species (PFMC 2012, PFMC 2013, PFMC 2014).

The assumptions, biases, and uncertainties associated with the estimates were fully vetted, discussed, and addressed to the extent possible given available data. Proxy species were used to bolster the sample size in each depth bin because the focal species were uncommon in some depth bins. The PFMC adopted buffers for uncertainty based on the upper 90% confidence interval estimate of short-term mortality given the sample size in each 10-fathom depth bin. The proposed mortality estimates were reviewed and approved by the PFMC Scientific and Statistical Committee (SSC) and adopted by the PFMC for use in management with retrospective application in 2013 and in the years to come. Future research to increase the sample size of focal species, evaluate seasonal fluctuations in mortality rates, determine mortality rates in depths greater than 100 fathoms, and provide a generalized or proxy estimate of mortality for application to other rockfish species would improve estimates and allow application of mortality rates reflecting use of descending devices to a broader suite of species.

This model-based approach has many strengths. It specifically takes into account immediate, short-term, and longer-term mortality, allowing for explicit consideration of the different types of damage that can be inflicted when a fish is captured. There are clear explanations for how each aspect of the mortality estimate is produced. Finally, this method can produce estimates for multiple species. Stakeholders with valuable insights and information had the opportunity to participate in review of the methods within the PFMC process over two years of development, but were not directly involved in determining the rates themselves, removing subjectivity.

However, there are a few weaknesses associated with this type of process as well. The method employs some data from sources that have not been peer-reviewed, although methods were reviewed and approved by the SSC. Scientific expert opinions were used to fill in gaps in long-term mortality for surface mortality estimates where there was little scientific information

available. When estimating mortality reflecting use of descending devices, proxy data from other species and estimates for the same species in deeper depth bins were used when data for the focal species were unavailable or sparse.

## 6. Identification and Prioritization of Data Gaps

In September 2013, a workshop attended by scientists from within and outside of NMFS was held to help NMFS identify and prioritize data gaps related to discard mortality estimates and related stock assessment issues. (Appendix A lists the workshop attendees.) The workshop attendees identified four data gap categories:

1. Understanding the factors affecting discard mortality estimates
2. Developing discard mortality estimates
3. Improving and refining existing discard mortality estimates
4. Enhancing outreach regarding discard mortality estimates

For each data gap category, workshop participants listed specific data gaps and then identified the data gaps they felt were most important. Each person was limited to three “votes.” Each of the listed gaps was important to at least one workshop attendee, by virtue of its eligibility for votes, but some gaps were more important than others. Listed below are data gaps by category, with number of votes received indicated in parenthesis.

### *Understanding the Factors Affecting Discard Mortality Estimates*

1. Collect spatially explicit discard data (4).
2. Understand the impact of best versus actual practices on mortality (3).
3. Understand the relationship of initial to long-term mortality (3).
4. Consider mortality estimate impacts on long-term management and rebuilding goals (3).
5. Quantify impacts and efficiency of best practices (1).
6. Increase commercial and recreational discard observations (1).
7. Identify when mortality estimates can be generalized and when a species or fishery needs to be looked at individually (1).
8. Identify factors that have a strong impact on survival (1).
9. Conduct laboratory experiments on best-practice efficacy (0).
10. Understand how shifts in mortality rates impact stock assessments (what causes sensitivity or lack thereof) (0).
11. Capture the diversity of methods people use to catch fish, as well as the impacts these methods have on mortality (0).
12. Capture the range of individual behavior occurring in a single type of fishery (e.g., skipper behavior) (0).
13. Conduct laboratory experiments to identify and quantify factors that influence mortality (0).

### *Developing Discard Mortality Estimates*

1. Develop baseline discard mortality information, including an understanding of underlying factors and their interactions (12).
2. Measure release mortality in fishery, as opposed to lab, conditions (11).
3. Develop reliable and robust proxies for mortality (both short- and long-term) (11).
4. Conduct research on unaccounted escapement mortality (10).
5. Examine longer-term impacts of venting and descending devices (5).
6. Explore the sub-lethal effects of capture (4).
7. Determine the impacts of repeated capture (4).

8. Conduct longer-term holding studies (3).
9. Establish better controls for catch-and-release studies (2).
10. Determine more creative tagging practices and options (2).
11. Identify discarded species more accurately (2).
12. Distinguish among mortality estimates that result from different types of trauma (e.g., barotrauma vs. hooking vs. handling) (2).
13. Conduct research on the effects of fishing location (e.g., inshore, offshore) on mortality (2).
14. Conduct fish health studies (2).
15. Quantify and investigate unaccounted sources of mortality (1)
16. Conduct research on the effects of temperature on mortality (1).
17. Identify species-specific mortality rates (0).
18. Identify depth(s) to which fish should be returned (0).
19. Identify fish behavior changes post-capture (0).
20. Conduct research on ghost gear mortality (0).
21. Conduct submergence studies (i.e., studies focusing on the ability or inability of a released fish to submerge) (0).
22. Conduct research on the effects of fishing depth on mortality (0).

*Improving and Refining Existing Discard Mortality Estimates*

1. Identify optimal sampling designs for accuracy and precision of discard mortality estimates (7).
2. Collect a wider range of recreational data including hook type, depth, and discard condition (5).
3. Use sensitivity analyses to identify which discard mortality rates need to be more accurate and/or precise (4)
4. Validate volunteer and self-reported discard data (2)
5. Examine how mortality estimates are currently used in stock assessment models (e.g., are estimates developed before the stock assessment process or as part of the process?) and whether this usage can be improved (1).
6. Identify mortality estimates based on insufficient information (0).
7. Conduct laboratory experiments that more accurately reflect fishery conditions (0).
8. Determine if discard mortality rates vary based on whether the discarded species is a target species or not (0).

*Enhancing Outreach regarding Discard Mortality Estimates*

1. Communicate how discard mortality estimates are created, used, and impact stock assessments, annual catch limits, and management (6).
2. Identify behaviors that fishermen would consider changing, as well as the barriers to change (1).
3. Quantify how often best practices are used in various fisheries (1).
4. Incentivize best behaviors and high-quality reporting back (0).
5. Identify to what extent best practices are able to be employed (0).
6. Identify mortality factors that fishers can control (0).
7. Quantify compliance with regulations and enforcement (0).

The following data gaps from the four identified categories received at least three votes and could be considered the most important data gaps identified at the workshop:

- Develop baseline discard mortality information, including an understanding of underlying factors and their interactions (12).
- Measure release mortality in fishery, as opposed to lab, conditions (11).
- Develop reliable and robust proxies for mortality (both short- and long-term) (11).
- Conduct research on unaccounted escapement mortality (10).
- Identify optimal sampling designs for accuracy and precision of discard mortality estimates (7).
- Communicate how discard mortality estimates are created, used, and impact stock assessments, annual catch limits, and management (6).
- Examine longer-term impacts of venting and descending devices (5).
- Collect a wider range of recreational data including hook type, depth, and discard condition (5).
- Explore the sub-lethal effects of capture (4).
- Determine the impacts of repeated capture (4).
- Use sensitivity analyses to identify which discard mortality rates need to be more accurate and/or precise (4)
- Collect spatially explicit discard data (4).
- Understand the impact of best versus actual practices on mortality (3).
- Understand the relationship of initial to long-term mortality (3).
- Consider mortality estimate impacts on long-term management and rebuilding goals (3).
- Conduct longer-term holding studies (3).

Although workshop participants identified a large number of data gaps, some of the above gaps could be lumped together (e.g., by focusing on all effects of capture, as opposed to sub-lethal effects or repeated-capture effects). Likewise, some of the gaps identified above are very specific gaps that could be nested within other more generally described gaps.

Development of reliable and robust proxies for mortality is especially important because of the high cost of release mortality studies and the need to increase the power of studies. In addition, workshop participants identified the need for well-designed baseline studies using robust methodologies that can be applied to multiple scenarios, with an emphasis on long-term studies that accurately depict a fish's mortality in the wild. Such long-term studies could include creative tagging options, dual-frequency identification sonar, and other methods.

Providing effective outreach regarding discard mortality is also important because fishermen need to appreciate and understand the relevant science when science-based management measures require them to change their practices. Outreach requires an understanding of where fishermen receive information about their fisheries and willingness to devote substantial effort to change fishermen's attitudes.

## 7. Identification and Prioritization of Species-Specific Research Needs

At the September 2013 workshop, scientists from within and outside of NMFS identified and prioritized criteria related to species-specific research needs. However, when prioritizing research, one should always ask whether the research is likely to yield significant gains. For example, in some fisheries 100% of discards are presumed to be dead. Additional costly research may result in this estimate being revised downward somewhat, but perhaps not to a large degree. In that case, scarce resources might be better spent on species where research is likely to have a larger impact, that is, where the anticipated delta between status quo and anticipated revised estimates is large.

In addition, some species may require extensive study; for example, multiple studies may be needed to address the same research question so that different stakeholders can have confidence in the results. In these cases, prioritization of research needs may not be practical.

Participants at the 2013 workshop identified a list of questions (in no particular order) that managers and scientists should ask when attempting to prioritize the most important species-specific research needs:

- Is the species economically and/or ecologically valuable, both alone and in terms of its impacts on other species?
- What is the magnitude of discards as a proportion of catch and harvest of the overall stock size (that is,  $F_{\text{discards}}$  as a fraction of  $F_{\text{MSY}}$ )?
- Is the species highly restricted by managers?
- If the species is highly restricted, do these restrictions result in a large amount of discards?
- Is the species a “sentinel” species that is iconic, popular, “political,” or has a high economic value (e.g., red snapper in the Gulf of Mexico)?
- Does the fishery (recreational or commercial) that targets the species have a strong interest in sustainability or formal certification or ecolabeling (e.g., by the [Marine Stewardship Council](#))?
- How receptive and helpful are the fishery stakeholders regarding discard mortality reduction?
- Are current discard estimates (both magnitude and mortality rates) for the species highly uncertain?
- What is the species’ stock status?
- How sensitive to uncertainty is the determination of the species’ stock status benchmarks?
- What is the species’ life history characteristics (e.g., productivity) and susceptibility (e.g., catchability, habitat availability) in the context of its fishery (either single- or multi-species)?
- When subjected to a Productivity-Susceptibility Analysis (PSA) (Patrick et al. 2009), does the species receive a low productivity score and a high susceptibility score?
- Do handling practices make a significant difference in survival for the species?
- Is the species listed under the Endangered Species Act or is it otherwise rare?
- To what extent is the species being recreationally or commercially utilized?

- Has the species been subject to the stock assessment process, either through a formal data-rich process or a less formal data-poor process?
- Is the species a constraining species, that is, do discards of the species restrict the ability of fishermen to target other valuable species?
- Are scientists and/or managers able to determine that they have enough data on the species to make sound management decisions?

Workshop participants discussed these questions further and mostly agreed on a list of seven high-priority criteria that should help direct scientists and managers in focusing release mortality resources on particular species:

1. The species' status as restricted, rare, and/or iconic.
2. The species' life history and/or PSA results.
3. The species' economic impact and/or marginal value.
4. Assumed  $F_{\text{discards}}$  as a fraction of  $F_{\text{MSY}}$ .
5. The level of stakeholder engagement and/or political sensitivity regarding the species.
6. The amount of available data on the species.
7. The extent to which release mortality is an emerging concern for the species.

Workshop participants also had some general thoughts about species-specific release mortality research. One participant felt that such research should focus on a balance of short- and long-term efforts, keeping in mind the issue of “bang for the buck” and political considerations. Another participant felt it was important to not prioritize research efforts based on currently identified low release mortality rates, because those rates need to be considered in relation to the species' overall biological context. For example, even though a species' estimated release mortality rate may seem low, the species could be highly endangered and worthy of resources to further reduce the release mortality rate.

After identifying the list of seven high-priority criteria related to the identification of species-specific research needs, workshop participants discussed select important species in several regions of country in terms of the seven criteria. The following sections summarize these discussions.

### 7.1 West Coast Examples

Workshop participants identified West Coast rockfish as a type of fish with several research needs. For example, yelloweye rockfish (*Sebastes rummerimus*) is an overfished species for which harvest limits can constrain the landings of other non-overfished species. Yelloweye rockfish can live for over 100 years and have a high marginal economic value. Yelloweye rockfish must be discarded when caught, and yelloweye rockfish discard mortality alone is sufficient to limit fishing seasons and create depth restrictions for a number of co-occurring healthy stocks in mixed-stock fisheries in Washington, Oregon, and California. The fish is somewhat iconic, and fishery stakeholders are engaged in the management of yelloweye rockfish.

Although great strides have been made regarding mortality rates for yelloweye rockfish, in terms of surface release and fish released at depth with descending devices, several data gaps remain.



Short-term mortality rates reflecting surface release are well-informed (PFMC 2008), but yelloweye rockfish long-term mortality rates are less known. Additional data on long-term mortality rates would improve estimates of mortality. Currently, long-term surface release mortality rates are informed by expert knowledge, with a precautionary 5% of additional mortality per 10 fathoms of depth. This may be excessive in depths greater than 30 fathoms given recent estimates of 15% mortality for proxy species in Wegner et al. (in prep) for fish caught in 50-100 fm.

Mortality rates reflecting release at depth with a descending device are less complete (PFMC 2012, PFMC 2013, PFMC 2014). Data are available from depths of less than 50 fathoms, but little is known about mortality in deeper depths; the assumed mortality estimates used for management currently are informed by proxy data from other species. Current estimates indicate significant reduction in mortality when fish are descended back to depth (27% mortality in 30 to 50 fathoms and 57% mortality in 50 to 100 fathoms) as compared to surface release (100% mortality in greater than 30 fathoms). Yelloweye rockfish exhibit low short-term mortality when descended, as do many other species of rockfish for which data currently are available (Jarvis and Lowe 2008, Hochhalter and Reed 2011, Hannah et al. 2012, PFMC 2012, PFMC 2013, PFMC 2014, Wegner et al. in prep). Further research regarding long-term mortality and mortality in deeper depths reflecting release with a descending device would reduce uncertainty related to the estimates, increase precision, narrow confidence intervals, and reduce mortality estimates because the Pacific Fishery Management Council decided to adopt rates based on upper 90% confidence interval estimates to provide a buffer against management uncertainty.

Pacific salmon are iconic fish, and their life history is well-known. However, researchers know little regarding salmon release mortality rates across various types of gears. Bycatch of certain salmon species can constrain commercially important non-overfished fisheries. Because of these potential economic impacts, release mortality studies should focus on the type of salmon encountered in these fisheries as bycatch. Fishery stakeholder engagement regarding salmon management and research is high, as evidenced by the fishing industry's pursuit of Marine Stewardship Council certification for salmon. This stakeholder engagement could improve fishing practices.

Pacific halibut (*Hippoglossus stenolepis*) is a well-studied groundfish that encounters a variety of gear types. Managers are concerned with halibut release mortality from trawl fisheries, and observer programs are collecting data on halibut release condition. Release mortality rates seem to be highly influenced by the amount of time taken to get halibut back into the water. Non-trawl release mortality rates for halibut can be low, but for trawls the rate is almost 100%. Related to this high mortality rate, one workshop participant mentioned that it is important to focus on immediate mortality as well as longer-term release mortality. Halibut excluder devices have the potential to reduce these mortality rates. Pacific halibut are iconic, and Pacific halibut bycatch can constrain directed fisheries for other species. Species abundance for Pacific halibut has been dropping in recent years, but bycatch levels have not. Bycatch mortality represents approximately 20% of Pacific halibut removals.

## 7.2 Southeast Examples

The federal waters of the Southeast United States are inhabited by numerous commercially and recreationally important species. Chief among these are members of the snapper-grouper complex, a group of physoclistous fishes that inhabit deep-water areas and are subject to considerable pressure trauma after being pulled from reef habitats. These species include red snapper (*Lutjanus campechanus*), vermilion snapper (*Rhomboplites aurorubens*), black sea bass (*Centropristis striata*), gag grouper (*Mycteroperca microlepis*), and red grouper (*Epinephelus morio*). Discard estimates for these species have been derived from numerous studies. The snapper-grouper complex also includes other managed reef fishes, such as red porgy (*Pagrus pagrus*), gray triggerfish (*Balistes capriscus*), and white grunt (*Haemulon plumieri*), for which estimates of discard mortality are either imprecise or non-existent.

Workshop participants identified vermilion snapper as a species relevant to the seven high-priority criteria. Landings of vermilion snapper are not restricted. The species is neither rare nor iconic, although it is often mistaken for red snapper. The vermilion snapper stock has been rebuilt in recent years and is not undergoing overfishing. Vermilion snapper has a resilient life history, maturing early and spawning frequently. Vermilion snapper is not a particularly data-rich species, but scientists have identified regional differences between vermilion snapper from the Gulf of Mexico and the South Atlantic. Stakeholders are generally not particularly attentive to vermilion snapper issues unless the stock becomes overfished. This species has been studied to determine rates of post-release survival after both venting and non-venting treatments over a wide range of depths off the U.S. Southeast coast (Collins et al. 1999).

In comparison to the less-studied vermilion snapper, the iconic and overfished red snapper is characterized by much study and a large amount of available data. However, managers are challenged to focus the data so they can be used to make helpful management decisions. Red snapper management is highly dynamic, and managers do not always know precisely where the fishery will operate. Red snapper seasons are very short and are characterized by high levels of discards. Estimated release mortality rates also are highly variable and depend on capture depth and other factors. As the red snapper stock rebuilds, they are appearing in shallow areas and other areas where they have not been observed previously. Workshop participants felt that range and effort information are key data gaps. In addition, workshop participants felt that future research should refine the existing variability in release mortality rate estimates. Workshop participants also felt that baseline research related to release mortality may be adequate, but a larger region-wide study is needed to align red snapper research results to stock assessment needs, building on smaller projects that have already been completed (see Appendix B).

Workshop participants also discussed the deep-water snapper-grouper complex, a well-known group of fish that includes snowy grouper (*Epinephelus niveatus*), Warsaw grouper (*Epinephelus nigritus*), speckled hind (*Epinephelus drummondhayi*), and golden tilefish (*Lopholatilus chamaelonticeps*). These species are generally long-lived and slow-maturing. These species also can be constraining for other directed fisheries in some instances. Stock assessments for these species assume a 100% release mortality rate, although recent use of decompression devices suggests this assumption should be reexamined. Stakeholder engagement is not high, but it could be increased with the promise of increased angler access to these species or,

conversely, as managers examine the use of marine protected areas to help ensure the sustainability of these species by eliminating bycatch mortality over a portion of the range of each of these deep-water species. Engagement of stakeholders as research partners during the testing of descending devices also could increase stakeholder engagement.

Black sea bass, like vermilion snapper, are not iconic, restricted, or rare. This species recently has been studied to determine rates of post-release survival after capture using traps and hook and line gear. That research project established a group of true control fish by tagging fish on the sea bottom so that pressure trauma could be accurately accounted for in estimating rates of discard mortality for fish caught over a variety of depths and conditions (Rudershausen et al. 2014). Black sea bass is of some interest to stakeholders because the population is increasing. Black sea bass are not overfished. Discard percentages for this species can be quite high when commercial and recreational seasons close due to annual catch quotas being reached, which forces fishermen to discard black sea bass. Spatially explicit release mortality research is needed for black sea bass, because its geographical range may be expanding. Scientists have been able to provide some basic advice to fishermen regarding venting black sea bass. Venting does not appear necessary to increase post-release survival of this species over the wide range of depths where it is commonly encountered in this region (Rudershausen et al. 2014). Tagging projects are appropriate for black sea bass because the fish do not move a great deal and get recaptured frequently, often from the same location (Rudershausen et al. 2014). Additional research on black sea bass would be helpful in determining where black sea bass are being discarded. If black sea bass are being caught and released in shallow water, barotrauma is not a large issue, but if black sea bass are being caught and released in deeper water, then barotrauma is a factor. Even though the accepted barotrauma rate for this fish is relatively low, the large number of released fish (millions per year) could result in a large number of dead discards. In addition, black sea bass could serve as a vehicle for learning about release mortality characteristics that could be applied to other, similar species, such as gag grouper and red grouper.

### 7.3 Northeast Examples

Workshop participants considered skates (as a species group) in relation to the seven high-priority criteria. Managers had assumed that skates exhibit a large variety of reactions to capture, and short-term scientific studies have confirmed this. Longer-term studies may yield different results. One of the skate species, thorny skate (*Amblyraja radiata*), is of conservation concern because its biomass is at a historically low level. Studies have shown that thorny skates experience low levels of short-term release mortality. However, researchers suspect that long-term mortality rates for thorny skates may be much higher. The thorny skate and the other skate species are not iconic, and fishery stakeholders are not highly involved with skate research. Skate bycatch does not constrain fisheries, and skate management is a challenge because data collection efforts do not always differentiate among the various species. The fraction of  $F_{\text{discards}}$  to  $F_{\text{MSY}}$  is unknown.

Workshop participants also discussed striped bass (*Morone saxatilis*) in terms of the high-priority criteria. Striped bass are iconic in New England, and striped bass populations can be found in the waters of several states. Striped bass fisheries have large economic impacts on states where they are fished. Discard rates are high due to large catch and release fisheries.

Stakeholder engagement is substantial in some states. Release mortality research has been limited and has occurred mostly in impoundments and reservoirs. Striped bass are exposed to the air when caught because anglers like to photograph them. Fishing methods can impact striped bass release mortality. In addition, striped bass life stage can have an important impact on release mortality rates.

## **8. Best Practices and Techniques for Release Mortality Research**

Participants at the September 2013 release mortality workshop spent some time discussing best practices and techniques related to release mortality research, especially effective outreach efforts related to release mortality research, as well as tagging and the related issue of acoustic arrays. Workshop participants felt that knowing the pros and cons of various techniques can help scientists and management agencies write better research proposals. Knowing the pros and cons of various research techniques also can help scientists new to the field of release mortality research develop high-quality research proposals.

### *8.1 Outreach*

Workshop attendees felt that outreach efforts should carefully consider the needs of the audience. For example, release mortality experts who create videos should try to ensure the videos are high-quality and even high-definition, because many fishermen watch such videos on their phones. Attendees felt that underwater video camera footage is especially meaningful to fishermen when they consider modifying their fishing practices. Although workshop attendees felt that brevity was important to video outreach (e.g., a 3-minute video is usually more effective than a 9-minute video), workshop attendees also thought that longer-format versions can be effective in certain situations. For example, fishermen might be able to watch a 15-minute video at home on their personal computers, or a commercial boat's crew could watch a 15-minute video on safe-release practices while on a fishing trip. Shorter videos may be more effective on party boats where cabins can be cramped and anglers are busy setting up gear and identifying fishing sites. Additional video content could be made available for passengers with special interest beyond the initial shorter video message. Short videos available online for viewing on smartphones may be more engaging than videos shown on a TV on a crowded boat.

Attendees cited several different methods to communicate best practices to fishermen. Agencies that have contact information can reach out directly to fishermen. This outreach can be more successful when local fishing clubs are involved in the dissemination of information. Some fishing clubs have even provided descending devices to their members. Fishing clubs also can post videos on their websites. Workshop attendees thought that sport fishing talk shows are a good outlet for messages regarding fishing practices and fisherman behavior. Trade shows also represent a good opportunity to provide information regarding best fishing practices and techniques through trade show booths staffed by experts as well as presentations provided by experts to trade show attendees. Workshop attendees felt that studies to determine whether these communication efforts really change practices are important.

It is important to note differences in communication approaches for commercial versus recreational fishermen. In commercial fisheries, individual contact information is available as part of fishing license records, and this can facilitate direct contact with fishermen. Recreational fisheries sometimes are less centrally managed and require broader, mass communication techniques.

One workshop participant commented that the typical annual research funding process is not conducive to conducting sustained, long-term outreach efforts, which usually are most effective. Another participant mentioned a study he helped conduct of recreational salmon angler preferences for receiving information (Nguyen et al. 2012). The study grouped anglers into three categories in terms of receiving information on responsible fishing:

1. Traditional anglers, who obtain most of their information informally through other anglers or through their fishing network.
2. Investigative anglers, who independently and actively seek out information from a wide variety of sources.
3. Networking anglers, who obtain most of their information from tackle shops and by reading brochures.

The study concluded that fisheries managers will need a mix of outreach approaches to effectively reach all anglers.

Finally, outreach can be crucial to the effectiveness of tag studies. Outreach can help ensure that people who encounter tagged fish know how to report the required information, which is important to studies of long-term mortality.

## *8.2 Tagging*

Tagging allows researchers to establish a group of control fish with which the discard survival of fish in various conditions can be compared (Heuter et al. 2006; Pollock and Pine 2007).

Workshop attendees spent a great deal of time discussing tagging, beginning with the question of whether tags are worth their expense. Tagging can encompass conventional “mark-recapture” tagging as well as more sophisticated electronic tagging methods. Deploying enough tags to obtain a large sample size can be expensive. Workshop attendees generally felt tags were worth the expense, especially when compared to the cost of not having the type of information that can be derived from tagging. One attendee suggested negotiating with tag manufacturers when considering a large purchase, in order to avoid paying face value for electronic tags.

Workshop attendees were concerned with issues related to the tagging process and retention of tags on fish, such as establishing a control population and identify normal behavior for a fish after it has been caught, handled, and tagged during the course of a research project. Tagging fish in situ could help address this issue, although not all workshop attendees felt that tagging processes resulted in adverse impacts to fish. Another attendee expressed interest in geomagnetic tags, which could be effective when deployed on bottom-dwelling fish species.

Another attendee pointed out that some fish naturally digest and/or absorb and then expel transmitters. For example, fish tagging at an Oregon aquarium has demonstrated that external tags can eventually be extruded by fish after 6 to 8 months. Researchers would not be able to notice such phenomena if they monitored fish for only 2 to 3 months. Using a “relative risk” type of approach to estimate discard mortality of fish in various categories (Heuter et al. 2006) can address this problem by assuming that fish across all treatments experience similar rates of tag-shedding.

Other fish shed transmitters when they encounter hazards in the water. One attendee stated that he uses external wire tags for halibut tagging studies involving trawl gear and hook and line gear, and he has experienced an approximate 20% loss rate for these tags. Another attendee has placed tagged fish in a tank with hazards to try to determine a tag-shedding rate. In addition, workshop attendees felt that a combination of laboratory and field studies could examine the physical effects of sutures and tag attachment on fish. Researchers need to ensure variability between tagging trips, even if they are deploying tags over multiple trips. Among-trip variability in accounting for the influences of tagging in studies of post-release mortality can be addressed by incorporating abiotic data (e.g., water temperature, deck time) into models estimating discard mortality.

### *8.3 Arrays*

Workshop attendees felt that acoustic and/or passive tags can be useful, but these tags create challenges when fish move out of the acoustic array field and the tags fail to report. In addition, some attendees felt that maintaining arrays is costly and labor-intensive. Researchers have trouble determining whether a tag stopped reporting due to movement from an array, or due to fish mortality. Researchers need to estimate these types of failure rates and incorporate them into uncertainty estimates for research projects.

Carefully planning a tagging study to ensure the array can detect emigrants relative to a fish being removed is important here (Bacheler et al. 2009). Kerns et al. (2012) describe a study that estimates instantaneous catch-and-release mortality using high-reward conventional tags and acoustic tags. It is assumed that a fisherman will call in to report the high-reward tag and let the researcher know whether the fish was kept or not. This allows the researcher to determine whether a fish was a harvest mortality or, if released and found to stop moving soon after a capture event, a discard mortality.

Some attendees felt that scientists have difficulty establishing the extent of array fields for some fish when the scientists are unsure of the target fish's home range. In addition, mortality estimates may become inflated if live fish leave an array field while dead fish remain in the array field. To overcome obstacles related to arrays, researchers should share tag data so that other arrays can pick up fish tag data once a fish leaves its original array field. Underwater gliders and autonomous underwater vehicles sometimes have sensors attached that can be used to listen for fish that have left their original array fields. In addition, scientists could pick up fish tag signals by integrating acoustic sensors into submarines that service oil platforms in the Gulf of Mexico.

### *8.4 Estimating Mortality Rates using Chamber Studies, Cage Studies, and Acoustic Tagging*

Barometric chamber studies, acoustic tagging, and cage studies provide a means of approximating mortality rates for fish released using a descending device. Although barometric chamber studies provide insight into the effects of barotrauma on survival and condition (Parker 2006, Smiley and Drawbridge 2006, Rogers et al 2011, Pribyl et al. 2012), cage studies and acoustic tagging may provide more representative estimates of discard mortality reflecting the use of descending devices. The degree of thermocline, time on deck, air temperature, handling, and hook location may affect survival (Jarvis and Lowe 2008, Hannah et al. 2012), but these

factors are not reflected in barometric chamber studies. Cage and barometric chamber studies do not account for sub-surface predation after release (i.e., lingcod on rockfish and dolphins on red snapper), although acoustic tagging would account for such mortality (Wegner et al. in prep). In instances where post-release predation rates are expected to contribute significantly to overall discard mortality, acoustic tagging may provide more accurate estimates of mortality, or it can be used to help determine the rate of predation to be added to the results of cage studies, through which a greater number of samples can be collected at less cost.

Note that the duration of observation pertinent to mortality rate estimates can be determined using acoustic tagging, to set the minimum duration of a cage study. Cage studies can be conducted at a lower cost, increasing sample sizes needed to analyze variation due to treatments or environmental correlates. Cage studies may also be viewed as being subject to less uncertainty than acoustic tagging studies because the fate of individuals that leave the array is often unknown, and the fate of those in the array can be difficult to determine definitively without controls and visual confirmation.

Each of these three methods can provide estimates subject to varying biases, assumptions, and uncertainties. Buffers can be invoked to ensure the estimates do not underestimate mortality rates, but these buffers should be within reason so as not to negate the perceived benefit from use of descending devices. The Groundfish Management Team of the Pacific Fishery Management Council provided a detailed analysis of such considerations in estimating mortality rates reflecting the use of descending devices on cowcod, canary, and yelloweye rockfish, as well as buffers for uncertainty (PFMC 2012, PFMC 2013, PFMC 2014).

#### *8.5. Application of Mortality Rates in Management*

Although estimating mortality rates that accurately reflect mortality of discarded fish presents a formidable task, the application of these rates can present further difficulties given the limitations of data currently available from fishery sampling programs. Mortality rates are likely to be gear specific, so separate estimates may be needed for different sectors, although mortality rates derived for the recreational fishery may act as a proxy for rod and reel commercial fisheries. If mortality estimates are depth dependent, sampling programs may need to collect additional data on depth of capture and intensify sampling to provide a suitable sample size informing the proportion of catch by depth in each depth bin. For species that are rarely encountered due to depletion or restrictions intended to minimize encounters, proportions of catch by depth may be estimated with a relatively low sample size unless sampling is intensified or data is pooled over time to increase the sample size used in each estimate.

In accounting for the use of descending devices, estimates of total mortality from a given fishery sector require determination of the proportion of fish released at the surface or with a descending device. To obtain data necessary to apply mortality rates reflecting the use of descending devices, samplers must inquire as to the disposition of discarded fish in the field, that is, determine whether fish are released with or without a device and the fate of fish released on the surface. This determination takes time from other data collection priorities and must be weighed in light of the importance of this information to possible additional fishing opportunities and/or more accurate stock assessments. Therefore, additional sampling or data elements may be



required to collect the data needed to apply depth-dependent mortality rates reflecting surface release or release using descending devices. Efficacy of descending devices in returning fish to the bottom may vary. Mortality rates assume successful descent of fish, and questions regarding fish disposition must be phrased to elicit a response indicating whether descent was successful. Application of buffers for uncertainty may be warranted to prevent underestimation of mortality, which may have adverse effects on fish stocks over time if additional fishing opportunities are allowed as a result of decreased mortality estimates.

## **9. Identifying Components of a National Release Mortality Science Strategy**

Although post-release mortality studies have been funded by NMFS since the late 1990s, and although such research has expanded outside of NMFS in recent years, post-release mortality studies have lacked an overarching strategy or framework. This paper identifies several post-release mortality science data gaps, and these gaps can serve as components of a national post-release mortality science strategy.

A national post-release mortality science strategy could include several major components, as suggested by scientists and managers who gathered at the September 2013 NMFS release mortality workshop. One major component would be to develop baseline discard mortality information, including an understanding of underlying factors and their interactions. Managers and scientists have difficulty determining whether alternative gear and fishing practices truly reduce post-release mortality without a full understanding of how a variety of factors—including air exposure, gear type, and temperature—affect different fish species. Gathering baseline data related to post-release mortality for different fish species could be labor-intensive in the short term, but it could create long-term research efficiencies and more effective solutions.

Measuring post-release mortality in fishery conditions, as opposed to laboratory conditions, could be another major component of a national post-release science strategy. Conducting such research in the field can present logistical challenges and can be expensive, but field research can also reduce bias and account for important fishery factors such as post-release predation.

Developing reliable and robust proxies for short- and long-term post-release mortality could be another major component. Conducting research on every fish species to develop post-release mortality estimates is resource-intensive and inefficient. If scientists and managers focus on certain species that are part of a complex or otherwise have similar traits to several other species, then limited research resources could have a larger impact.

Because post-release mortality research has been largely uncoordinated in recent years, identification of optimal sampling designs for accuracy and precision of post-release mortality estimates would be an important component of a national science strategy. As shown in Section 8.0 of this paper, scientists from the United States and Canada already have a good sense of what does and does not work in the area of post-release mortality outreach and research. If scientists and managers can reach a consensus on the most effective sampling designs, as well as outreach practices, then precision and communication of post-release mortality estimates can be optimized.

Any national post-release mortality science strategy must involve a communication and outreach component, because partnerships with recreational and commercial fishing communities are critical to the reduction of post-release mortality. A national science strategy should focus on communication of how post-release mortality estimates are created and used, as well as how such estimates impact stock assessments and catch limits or quotas. Effective communication ultimately could provide managers and scientists with a better understanding of the impacts of best practices versus actual practices on post-release mortality.

Finally, a national post-release mortality science strategy should focus on a variety of emerging technical aspects of post-release mortality, including the collection of a wider range of recreational data regarding hook types, capture and release depths, seasonal effects, and discard condition. Other technical aspects that could be a component of a national science strategy include determination of sub-lethal effects of capture and the effects of repeated capture, as well as the collection of more spatially explicit discard data. The expanded use of sensitivity analyses in stock assessments also could help identify which post-release mortality rates need to be more accurate and precise.

As with any interesting and challenging scientific problem, there is no shortage of data gaps or directions for additional research. Although this section identifies some major components of a possible national post-release mortality science strategy, Section 6 of this paper includes many other data gaps identified by at the September 2013 workshop that could be folded into a national strategy.

## 10.0 Conclusion: Next Steps for Addressing Broader Release Mortality Issues

NMFS, through its various research programs and its Recreational Fisheries Initiative, is committed to understanding post-release mortality, determining post-release mortality rates, developing best fishing practices to reduce those rates, and incorporating those rates into stock assessment and other processes that determine fishing quotas for recreational and commercial fishers. In addition, NMFS has funded, and continues to fund, research projects (see Section 3.0 and Appendix B) around the United States to examine and reduce post-release mortality rates. Results of those projects are incorporated into the stock assessment process in different ways, as shown in Sections 4.0 and 5.0.

Although these efforts have been productive and have helped scientists and managers understand and identify the importance of post-release mortality—and in some cases resulted in reduced post-release mortality estimates—NMFS should consider a more coordinated, national approach to post-release mortality science to make the most effective use of limited resources. NMFS could allocate resources in a variety of ways, including the use of a matrix approach. Table 1 presents a simplified way to think about resource allocation by focusing on some of the specific high-priority criteria listed in Section 7.0.

**Table 1. Matrix for prioritizing release mortality research resources.**

	<b>Mortality well-studied</b>	<b>Mortality not well-studied</b>
<b>Sufficient discard data</b>	Low	Medium
<b>Insufficient discard data</b>	Medium	High

Using this approach, species for which there are high-quality mortality studies, and for which sufficient discard data are available, would be prioritized lower than species that have not been the subject of high-quality mortality studies and that lack sufficient discard data. Using this system, high-priority species might require some research to improve fishery discard data before focusing on discard mortality studies. On the other hand, if discard data are sufficient, then the applied power of mortality estimates would be maximized. Therefore, perhaps release mortality studies involving species or fisheries with high-resolution discard data *should* be prioritized.

Moving forward effectively will require the right partners as well. These partners include states where post-release mortality issues are important. Partnerships with the eight regional fishery management councils and three marine fishery commissions, including their technical staff and committees such as scientific and statistical committees and SouthEast Data, Assessment, and Review (SEDAR), also will be critical. Other important partners include analytical end-users (e.g., stock assessment scientists), as well as post-release mortality technical experts with study design expertise.

In addition, and perhaps most importantly, partnerships with fishery stakeholders including anglers, commercial fishermen, and members of non-governmental organizations—especially those involved in science processes—will be critical partners. Finally, outreach and communication specialists must be embedded within this endeavor to ensure that solutions to post-release mortality challenges are used by those who can make the greatest difference.

## 11.0 References

- Albin, D. and K. A. Karpov. 1996. Mortality of lingcod, *Ophiodon elongatus*, related to capture by hook and line. *Marine Fisheries Review* 60(3):29-34.
- Bacheler, N. M., J. A. Buckel, J. E. Hightower, L. M. Paramore, and K. H. Pollock. 2009. A combined telemetry-tag return approach to estimate fishing and natural mortality rates of an estuarine fish. *Canadian Journal of Fisheries and Aquatic Sciences* 66:1230-1244.
- Barkley, A. S., and S. X. Cadrin. 2012. Discard mortality estimation of yellowtail flounder using reflex action mortality predictors. *Transactions of the American Fisheries Society* 141(3):638-644.
- Collins, M. R., J. C. McGovern, G. Sedberry, H. S. Meister, and R. Pardieck. 1999. Swim bladder deflation in black sea bass and vermilion snapper: potential for increasing postrelease survival. *North American Journal of Fisheries Management* 19:828-832.
- Grover, A. M., M. S. Mohr, and M. L. Palmer-Zwahlen. 2002. Hook-and-release mortality of Chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. Pages 39-56 in J. A. Lucy and A. L. Studholme, editors. *Catch and release in marine recreational fisheries*. American Fisheries Society, Symposium 30, Bethesda, Maryland.
- 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(1):46-56.
- Heberer, C., S. A. Aalbers, D. Bernal, S. Kohin, B. DiFiore, and C. A. Sepulveda. 2010. Insights into catch-and-release survivorship and stress-induced blood biochemistry of common thresher sharks (*Alopias vulpinus*) captured in the southern California recreational fishery. *Fisheries Research* 106:495-500.
- Heuter, R. E., C. A. Manire, J. P. Tyminski, J. M. Hoenig, and D. A. Hepworth. 2006. Assessing mortality of released or discarded fish using a logistic model of relative survival derived from tagging data. *Transactions of the American Fisheries Society* 135:500-508
- 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(5):852-860.
- ICES (International Council for the Exploration of the Sea). 2014. Report of the workshop on methods for estimating discard survival (WKMEDS), 17-21 February 2014, ICES HQ, Copenhagen, Denmark. ICES CM 2014/ACOM:51. 114 pp.

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.

Kerns, J. A., M. S. Allen, and J. E. Harris. 2012. Importance of assessing population-impact of catch-and-release mortality. *Fisheries* 37:11:502-503.

Nguyen, V. M., M. A. Rudd, S. G. Hinch, and S. J. Cooke. 2012. Differences in information use and preferences among recreational salmon anglers: implications for management initiatives to promote responsible fishing. *Human Dimensions of Wildlife* 17:248-256.

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.

Patrick, W. S., P. Spencer, O. Ormseth, J. Cope, J. Field, D. Kobayashi, T. Gedamke, E. Cortés, K. Bigelow, W. Overholtz, J. Link, and P. Lawson. 2009. Use of productivity and susceptibility indices to determine stock vulnerability, with example applications to six U.S. fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-101, 90 p.

PFMC (Pacific Fishery Management Council). 2008. Final environmental impact statement for the proposed acceptable biological catch and optimum yield specifications and management measures for the 2009-2010 Pacific Coast groundfish fishery. Pacific Fishery Management Council, Portland, OR, Chapter 4: 276-290. [http://www.pcouncil.org/wp-content/uploads/chp4\\_0910.pdf](http://www.pcouncil.org/wp-content/uploads/chp4_0910.pdf)

PFMC (Pacific Fishery Management Council). 2012. Groundfish Management Team progress report on developing mortality rates for rockfish released using descending devices. Pacific Fishery Management Council, Portland, OR. November Council Meeting, Agenda Item I.3. [http://www.pcouncil.org/wp-content/uploads/I3b\\_GMT\\_NOV2012BB.pdf](http://www.pcouncil.org/wp-content/uploads/I3b_GMT_NOV2012BB.pdf)

PFMC (Pacific Fishery Management Council). 2013. Groundfish Management Team report on proposed discard mortality for cowcod, canary rockfish, and yelloweye rockfish released using descending devices in the recreational fishery. Pacific Fishery Management Council, Portland, OR. April Council Meeting, Agenda Item D.5, [http://www.pcouncil.org/wp-content/uploads/D5b\\_GMT\\_APR2013BB.pdf](http://www.pcouncil.org/wp-content/uploads/D5b_GMT_APR2013BB.pdf)

PFMC (Pacific Fishery Management Council). 2014. Groundfish Management Team report on proposed discard mortality for cowcod, canary rockfish, and yelloweye rockfish released using descending devices in the recreational fishery. Pacific Fishery Management Council, Portland, OR. March Council Meeting, [Agenda Item D.3](#), [http://www.pcouncil.org/wp-content/uploads/D3b\\_SUP\\_GMT\\_RPT2\\_MAR2014BB.pdf](http://www.pcouncil.org/wp-content/uploads/D3b_SUP_GMT_RPT2_MAR2014BB.pdf)

Pollock, K. H., and W. E. Pine III. 2007. The design and analysis of field studies to estimate catch-and-release mortality. *Fisheries Management and Ecology* 14:123-130.

Pribyl, A. L., C. B. Schreck, M. L. Kent, M. Kelley, and S. J. Parker. 2012. Recovery potential of black rockfish, *Sebastes melanops* Girard, recompressed following barotrauma. *Journal of Fish Diseases* 35(4):275-286.

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(1-2):1-7.

Romine, J. G., J. A. Musick, and G. H. Burgess. 2009. Demographic analyses of the dusky shark, *Carcharinus obscurus*, in the Northwest Atlantic incorporating hooking mortality estimates and revised reproductive parameters. *Environmental Biology of Fishes* 84:277-289.

Rudershausen, P. J., J. A. Buckel, and J. E. Hightower. 2014. Estimating reef fish discard mortality using surface and bottom tagging: effects of hook injury and barotrauma. *Canadian Journal of Fisheries and Aquatic Sciences* 71(4):514-520.

Smiley, J. E. and M. 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.

STT (Salmon Technical Team). 2000. STT recommendations for hooking mortality rates in 2000 recreational ocean Chinook and coho fisheries. March supplemental report B2. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon.

**Appendix A. Release Mortality Workshop Attendees (September 25-26, 2013)**

<i>Attendee</i>	<i>Affiliation</i>
Leif Anderson	NMFS Northwest Fisheries Science Center
Lee Benaka	NMFS Office of Science and Technology
Hugues Benoit	Fisheries and Oceans Canada
Ken Brennan	NMFS Southeast Fisheries Science Center
Jeff Buckel	North Carolina State University
John Budrick	California Department of Fish and Wildlife
Patrick Campfield	Atlantic States Marine Fisheries Commission
Paul Caruso	Massachusetts Division of Marine Fisheries
Chip Collier	North Carolina Department of Environment and Natural Resources
Steven Cooke	Carleton University, Ontario, Canada
Andy Danylchuk	University of Massachusetts Amherst
Robert Hannah	Oregon Department of Fish and Wildlife
Erica Jarvis	Orange County (California) Sanitation District
Chris Lunsford	NMFS Alaska Fisheries Science Center
John Mandelman	New England Aquarium
Earl Meredith	NMFS Northeast Fisheries Science Center
Michael Mohr	NMFS Southwest Fisheries Science Center
Michael Palmer	NMFS Northeast Fisheries Science Center
Terrance Quinn	University of Alaska Fairbanks
Danielle Rioux	NMFS Office of Sustainable Fisheries
Paul Rudershausen	North Carolina State University
Beverly Sauls	Florida Fish and Wildlife Commission
Leah Sharpe	NMFS Office of Science and Technology
Greg Stunz	Harte Research Institute at Texas A&M University-Corpus Christi
Charles Villafana	NMFS West Coast Regional Office
Gregg Williams	International Pacific Halibut Commission
Dan Wolford	Coastside Fishing Club



**Appendix B. Summary of NMFS-Funded Release Mortality Research by Region (NE = Northeast, SE = Southeast, WC = West Coast, AK = Alaska, PI = Pacific Islands**

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
NE	2013	Farleigh Dickinson University	Optimization of Gear Size and Post-Release Mortality Reduction in the New Jersey Summer Flounder Hook-and-Line Fishery	122,911	BREP	Ongoing	Summer flounder	
NE	2012	New England Aquarium Corporation	Elucidating Post-Release Mortality and “Best Capture and Handling” Methods in Sublegal Atlantic Cod Discarded in Gulf of Maine Recreational Hook-and-Line Fisheries	248,659	BREP	Ongoing	Atlantic cod	
NE	2012	VA Institute of Marine Science	Evaluating the Condition and Discard Mortality of Skates Following Capture and Handling in the Sea Scallop Dredge Fishery	1,092,642	Scallop RSA	Ongoing	Skates	
NE	2009	University of MA, Dartmouth	Post-Release Survivability of Longline-Caught Large Coastal Sharks	362,294	S-K	Ongoing	Sandbar sharks, dusky sharks	
NE	2008	New England Aquarium Corporation	The Immediate and Short-Term Post-Release Mortality of Species in the Northwest Atlantic Skate Complex Captured by Gillnet and Otter Trawl	222,618	S-K	Ongoing	Skates	
NE	2011	Coonamessett Farm	Optimizing the Georges Bank Scallop Fishery by Maximizing Meat Yield and Minimizing Bycatch	1,847,700 ***	NE CRP	Complete	Yellowtail, winter flounder	Investigators concluded an assumed discard mortality rate of 90% for the southern NE/Mid-Atlantic yellowtail flounder stock assessment; confirmed that a discard mortality estimate of 50% for winter flounder may be accurate for the scallop fishery.

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
NE	2009	Cornell Cooperative Extension	Evaluation of Summer Flounder Discard Mortality in the Bottom Trawl Fishery, Part II: A Study of the Offshore Winter Fishery	376,650	Mid-Atlantic RSA	Complete	Summer flounder	Overall median discard mortality was calculated to be 98%, much higher than the 80% rate used in the stock assessment at the time. Overall mean discard mortality rate was calculate to be 80.4%, nearly identical to the rate used for stock assessments.
NE	2008	National Fisheries Institute	Discard Mortality in the Summer Flounder Fishery: A New Approach to Evaluation	148,719	Mid-Atlantic RSA	Complete	Summer flounder	Project's discard mortality estimate, combining on-deck and latent mortality, was 82.7%
NE	2008	University of MA, Dartmouth	Discard Mortality Estimation of the Southern New England Flatfish Complex using Reflex Action Mortality Predictor (RAMP) Methods	75,529	NE CRP	Complete	Yellowtail, winter, windowpane flounder	A paper based on this research applied RAMP methods to demonstrate a 42-73% range of yellowtail flounder discard mortality estimates from the southern New England trawl fishery.
NE	2007	Cornell Cooperative Extension	Summer Flounder Discard Mortality in the Inshore Bottom Trawl Fishery	284,800	Mid-Atlantic RSA	Complete	Summer flounder	Mean discard mortality was 64.6%; median mortality rate was 78.7%. Tow time and cull time were important factors.
NE	2006	University of New England	The Design, Development, and Field Testing of an Innovative Circular Net Pen to be Used to Assess Bycatch Mortality of Atlantic Cod at Sea	\$25,000	NE CRP	Complete	Atlantic cod	

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
NE	2005	Gulf of Maine Research Institute	Industry-Science Partnership Investigating the Short-Term and Long-Term Discard Mortality of Spiny Dogfish Using Hook Gear in Gulf of Maine Waters	78,807	NE CRP	Complete	Spiny dogfish	Gear effects were found, with highest mortality resulting from longline gear (22%), while different hand gear mortality ranged from 8 to 17%.
NE	2004	New England Aquarium Corporation	Increasing Survival of Juvenile Atlantic Cod and Haddock in the Northwest Atlantic Demersal Longline Fishery	163,244	S-K	Complete	Atlantic cod, haddock	
NE	2004	New England Aquarium Corporation	Increasing Juvenile Cod Bycatch Survival in a Northwest Atlantic Longline Fishery	99,457	S-K	Complete	Atlantic cod	
NE	2004	New England Aquarium Corporation	Selectivity and Survival of Atlantic Cod and Haddock in a Northwest Atlantic Longline Fishery	200,000	S-K	Complete	Atlantic cod, haddock	
NE	2003	New England Aquarium Corporation	Juvenile Bycatch and Survival Assessment of Spiny Dogfish in a Western Atlantic Trawl Fishery	169,580	S-K	Complete	Spiny dogfish	Less than 50% mortality following trawl capture in the wild.
SE	2013	FL Fish and Wildlife Conservation Commission	Testing an Alternative Method for the Safe Release of Reef Fishes Caught on Hook-and-Line Gear in the Recreational Fishery in the Gulf of Mexico	185,843	BREP	Ongoing	Reef fish	
SE	2013	FL Fish and Wildlife Conservation Commission	Evaluation of the Effects of Recreational Catch-and-Release Angling on the Survival of Gag Grouper	113,749	MARFIN	Ongoing	Gag grouper	
SE	2013	Mote Marine Laboratory	Discard Mortality of Carcharhinid Sharks in the Florida Commercial Shark Fishery	235,847	SE CRP	Ongoing	Atlantic sharks	
SE	2012	University of FL	To Vent or Descend? Evaluating Seasonal Release Mortality of Gag and Red Grouper in Recreational Fisheries of the Eastern Gulf of Mexico	113,537	MARFIN	Ongoing	Gag grouper, red grouper	

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
SE	2012	University of South Alabama	Examining Hook Selectivity in the Northern Gulf of Mexico Recreational Reef Fish Fishery	202,636	SE CRP	Ongoing	Reef fish	
SE	2010	FL Fish and Wildlife Conservation Commission	An Evaluation of the Effects of Catch and Release Angling on Survival and Behavior of Goliath Grouper	100,000	MARFIN	Ongoing	Goliath grouper	
SE	2011	Mote Marine Laboratory	Fine-Scale Behavior and Mortality in Post-Release Carcharhinid Sharks in the Florida Recreational Shark Fishery	192,325	SE CRP	Complete	Blacktip sharks	Mortalities (N=3, 9.7%) all took place within 2 h after release and were indicated by static depth data and the cessation of tail beat activity.
SE	2011	NMFS SEFSC	Examining the Efficiency of Modified Circle Hooks in Reducing the Bycatch of Undersized Lutjanid and Serranid Fishes	37,000	BREP	Complete	Snappers, groupers	
SE	2010	Texas A&M University—Corpus Christi	Evaluating the Effect of Barotrauma on Regulatory Discards in the Red Snapper Fishery using Advanced Acoustic Telemetry and Hyperbaric Experimentation	135,000	MARFIN	Complete	Red snapper	
SE	2010	University of GA Research Foundation	Collaborative Research to Quantify and Reduce Bycatch Mortality of Blacknose Sharks in Shrimp Trawls	59,330	SE CRP	Complete	Blacknose sharks	The Big Boy turtle excluder device with 2" bar spacing significantly reduced shark bycatch without affecting shrimp retention. Data indicates that blacknose sharks do not represent a large component of total shark bycatch in Georgia.

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
SE	2010	Nova Southeastern University	Post-Release Survival and Habitat Utilization of Juvenile Swordfish in the Florida Straits Recreational Fishery	183,768	SE CRP	Complete	Atlantic swordfish	Limited tagging resulted in an estimated release mortality rate of 35.7%.
SE	2010	NMFS SEFSC	Determination of Alternate Fishing Practices to Reduce Mortality of Prohibited Dusky Shark in Commercial Longline Fisheries	39,357	BREP	Complete	Dusky shark	90% mortality after 15 hours on-hook.
SE	2009	Patzig Marine Services, Inc.	Discard Mortality of Red Snapper in the Northeastern Gulf of Mexico Recreational Fishery	148,150	MARFIN	Complete	Red snapper	14% mortality rate.
SE	2009	University of FL	Release Mortality of Gulf of Mexico Greater Amberjack from Commercial and Recreational Hand-Line Fisheries	244,867	MARFIN	Complete	Greater amberjack	This project indicated a high acute survival rate for greater amberjack for some handline fisheries, and initially depth of capture and decompression do not appear to be a major factors in release or discard mortality.
SE	2009	University of West FL	Minimizing Discards in the Gulf of Mexico Recreational Red Snapper Fishery: Hook Selectivity and the Efficacy of a First Fish Rule	268,545	SE CRP	Complete	Red snapper	
SE	2009	FL Fish and Wildlife Commission	Survival of Discarded Reef Fish Species in the Recreational Fishery using At-Sea Observer Surveys and Mark –Recapture Methods off the Florida Coast in the Gulf of Mexico	185,427	SE CRP	Complete	Reef fish	

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
SE	2009	FL Fish and Wildlife Conservation Commission	Characterization of Recreational Discard Composition and Mortality Rates for Gray Snapper and Other Estuarine-Dependent Reef Fishes within a Gulf Coast Estuary and Nearshore Florida Waters	222,495	SE CRP	Complete	Gray snapper	Overall mortality rate of 6.9% estimated for gray snapper; overall mortality rate of 7.2% estimated for gag.
SE	2009	FL Fish and Wildlife Conservation Commission	A Directed Study of the Recreational Red Snapper Fisheries in the Gulf of Mexico along the West Florida Shelf	999,000	SE CRP	Complete	Red snapper	Red snapper may particularly benefit from larger reductions in discard mortality through the use of circle hooks; fish that can re-submerge on their own have a higher rate of survival if they are not vented, but may benefit from venting when it helps them re-submerge.
SE	2007	TX Tech University	Reducing Discard Mortality in Red Snapper Recreational Fisheries using Descender Hooks and Rapid Recompression	262,369	SE CRP	Complete	Red snapper	
SE	2005	FL Fish and Wildlife Conservation Commission	Size and Age Structure and Catch and Release Mortality Estimates of Sub-Adult and Adult Red Drum in the Tampa Bay	132,059	MARFIN	Complete	Red drum	5.6% mortality rate (compared to 5% used in 2009 FL red drum assessment).
SE	2005	Patzig Marine Services, Inc.	Cooperative Hook and Line Discard Mortality Study of Vermillion Snapper in the Northeastern Gulf of Mexico Commercial Fishery	114,072	SE CRP	Complete	Vermillion snapper	34% mortality rate within ~3 hours.
SE	2005	University of Florida	The Capture Depth, Time, and Hooked Survival Rate for Bottom Longline-Caught Large Coastal Sharks	144,264	SE CRP	Complete	Nurse, sandbar, blacktip, and Atlantic sharpnose sharks	

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
SE	2004	TX Tech University	Decompression and Delayed Mortality: Effects of Barotrauma on Red Snapper	100,184	MARFIN	Complete	Red snapper	
SE	2003	SC Department of Marine Resources	Estimates of Catch-and-Release Mortality for Red Drum in the Recreational Fishery of South Carolina	90,000	SE CRP	Complete	Red drum	
SE	1999	SC Department of Marine Resources	Removing Gas from the Distended Swim Bladder of Reef Fish: Does It Really Increase Post-Release Survival?	38,196	S-K	Complete	Reef fish	100% of 223 fishes deflated with a needle survived over first 24 hours after release, compared to 61% survival rate for controls.
WC	2013	University of CA, San Diego	Examining Environmental Effects of Rockfish Catch-and-Release Survival: Does Low Oxygen Contribute to Mortality Following Barotrauma?	183,997	BREP	Ongoing	Rockfish	
WC	2012	Oregon State University	Field Validation of the RAMP Approach for Determining Crab Bycatch Mortality	68,289	BREP	Ongoing	Dungeness crab	
WC	2011	NMFS SWFSC	Ability of Southern California Deepwater Rockfish to Survive Barotrauma Following in-situ Recompression	104,290	BREP	Complete	Pacific rockfish	90% of bocaccio, and 100% of cowcod, survived long-term. 93% of 5 different species survived in the short-term (up to 2 days)
WC	2008-2011	NMFS SWFSC and SWRO	Reducing Post-Release Mortality for Common Thresher Sharks Captured in the Southern California Recreational Fishery	229,265	BREP	Complete	Thresher shark	26% mortality rate.
WC	2009	NMFS SWFSC	Incidental Take and Post-Release Mortality of Blue Sharks in the U.S. West Coast Drift Gillnet and Longline Fisheries for Swordfish	46,615	BREP	Complete	Blue shark	
WC	2008	Oregon State University	The Effects of Decompression and the Efficacy of Recompression as a Bycatch Mortality Reduction Tool for Rockfish	61,374	S-K	Complete	Rockfish	

Region	Year	Recipient	Title	Funding (\$)	Funding Source*	Complete or Ongoing?	Target Species	Results
WC	1996	CA Department of Fish and Wildlife	Post-Release Mortality in the Central California Ocean Recreational Salmon Fisheries	40,000	NMFS Southwest Regional Office	Complete	Chinook salmon	4% mortality rate for maxillary-hooked fish and 84% for gut-hooked fish; 42% mortality rate for drift-mooch caught-and-released fish; 14% mortality rate for troll-caught fish. Overall mortality rate for CA salmon fisheries of 20-25%.
WC	2002	Pfleger Institute of Environmental Research	A Device for Greatly Reducing Fishing Mortality for Protected Giant Seabass and Jewfish	19,211	S-K	Complete	California giant sea bass and goliath grouper	
AK	2013	AK Charter Association	Use of Digital Imaging Technology to Reduce Released Halibut Mortality in Alaska's Recreational Fishery	186,725	BREP	Ongoing	Halibut	
AK	2009	NMFS AFSC	Mortality Rates for Crab Bycatch in Trawls	159,642**	BREP	Complete	Red king crab	Estimates of crab mortality rates after trawl encounters were generated for all major Bering Sea crab species.
AK	2000	AK Fisheries Development Foundation	Trawl Codend Mesh Size and Shape Investigations to Reduce Catch and Discard of Undersized Pollock	675,000	S-K	Complete	Pollock	14-day mortality caused by escapement and the caging/holding processes ranged from 46-84% for pollock that escaped through codend meshes and 47-63% for fish that escaped through intermediate meshes.
AK	1998	AK Fisheries Development Foundation	Practical Application of Fishing and Handling Techniques in Estimating the Mortality of Discarded Trawl-Caught Halibut	154,452	S-K	Complete	Halibut	



<b>Region</b>	<b>Year</b>	<b>Recipient</b>	<b>Title</b>	<b>Funding (\$)</b>	<b>Funding Source*</b>	<b>Complete or Ongoing?</b>	<b>Target Species</b>	<b>Results</b>
PI	2010-2012	NMFS PIFSC and Queen's University (Ontario, Canada)	Estimating Post-Release Mortality in Istiophorid Billfish	385,039	BREP	Ongoing	Pacific blue marlin, Pacific striped marlin	

\*BREP = Bycatch Reduction Engineering Program; S-K = Saltonstall-Kennedy Grant Program; RSA = Research Set-Aside Program; CRP = Cooperative Research Program; MARFIN = Marine Fisheries Initiative

\*\*Only a portion of the indicated funding was used for release mortality research.

\*\*\*BREP funding constitutes a small portion of overall project funding; additional funds came from other NMFS sources.

### Appendix C. Compilation of Release Mortality Estimates Used by NMFS

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
New England	Cod (Gulf of Maine)	multiple estimates based on type of fishery	unclear	Large-mesh otter trawl: 75%; Small-mesh otter trawl: 75%; Large-mesh gillnet: 80%; Extra-large-mesh gillnet: 80%; Longline: 33%; Shrimp trawl: 75%; Recreational: 30%	none
New England	Cod (Georges Bank)	multiple estimates based on type of fishery	unclear	Large-mesh otter trawl: 75%; Small-mesh otter trawl: 75%; Large-mesh gillnet: 80%; Longline: 33%; Scallop dredge: 100%; Recreational: 30%	none
New England	Haddock (Gulf of Maine)	multiple estimates based on type of fishery	unclear	Commercial gear: 100%; Recreational: 0%	none
New England	Haddock (Georges Bank)	assumption of 100% mortality	unclear		none
New England	Winter Flounder (Georges Bank)	assumption of 100% mortality	unclear		none
New England	Winter Flounder (Southern New England)	multiple estimates based on type of fishery	single study	Large-mesh otter trawl: 50%; Scallop dredge: 50%; Recreational: 15%	Durso and Iswanowicz 1983
New England	Winter Flounder (Gulf of Maine)	assumption of 100% mortality	unclear		none

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
New England	Yellowtail Flounder (Georges Bank)	assumption of 100% mortality	unclear		none
New England	Yellowtail Flounder (Southern New England)	assumption of 90% mortality	unclear		none
New England	Windowpane Flounder (northern and southern)	assumption of 100% mortality	unclear		none
New England	Pollock	assumption of 100% mortality	single study plus precautionary principle	100%	Clay et al. 1989
New England	American Plaice	assumption of 100% mortality	unclear		none
New England	Witch Flounder	assumption of 100% mortality	unclear		none
New England	Atlantic Halibut	assumption of 100% mortality	unclear		none
New England	White hake	assumption of 100% mortality	unclear		none
New England	Redfish	assumption of 100% mortality	unclear		none
New England	Ocean pout	assumption of 100% mortality	unclear		none
Mid Atlantic	Summer Flounder	one estimate	multiple studies	10%	Lucy and Holton 1998, Malchoff and Lucy 1998, Malchoff et al. 2001
Mid Atlantic	Black Sea Bass*	one estimate	single study plus Delphi analysis	25%	Bugley and Shepherd 1991
Mid Atlantic	Scup	one estimate	single study plus additional unpublished work	15%	Howell and Simpson 1985, Terceiro 2011

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
Mid Atlantic	Bluefish	one estimate	single study modified by a Council technical committee	15%	Malchoff 1995
Mid Atlantic	Spiny Dogfish	one estimate	unclear	25%	none
South Atlantic	Black Sea Bass*	one estimate	multiple studies	15%	Low 1981, Vaughn et al. 1995, Collins et al. 1999
South Atlantic	Red Snapper*	multiple estimates based on type of fishery	multiple studies	Private recreational: 39%, For-hire recreational: 41%, Commercial: 48%	Burns et al. 2004
South Atlantic	Vermillion Snapper*	one estimate	unpublished data	25%	none
South Atlantic	Mutton Snapper	one estimate	studies on other species	15%	none
South Atlantic	Goliath Grouper	incorporated into the overall model	unclear	n/a	none
South Atlantic	Red Grouper*	one estimate	multiple studies (one of which is the same one used for the Gulf of Mexico estimate)	20%	none
South Atlantic	Black Grouper	one estimate	unclear	20%	none
South Atlantic	Gag Grouper*	one estimate	multiple studies	25%	Wilson and Burns 1996, Burns et al. 2002, Overton and Zabawski 2003, McGovern et al. 2005, Rudershausen et al. 2005
South Atlantic	Red Drum*	one estimate	multiple studies plus sensitivity analysis	8%	Aguilar et al. 2002, Gearhart 2002, Murphy 2005, Vecchio and Warner 2007

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
South Atlantic	Spanish Mackerel	none	insufficient data	100%	none
South Atlantic	King Mackerel	multiple estimates based on type of fishery	single study plus observer data	Headboat fishery: 33%; Recreational fishery: 20%	Edwards 1996
South Atlantic	Greater Amberjack	one estimate	anecdotal information and sensitivity analyses	20%	none
South Atlantic	Red Porgy	one estimate	single study	8%	Collins 1996
Atlantic coast	Striped Bass	one estimate	multiple studies	8%	Diodati and Richards 1996
Atlantic coast	Red Drum*	one estimate	single study	5%	Murphy 2005
Atlantic coast	Tautog	one estimate	single study	2.50%	Simpson and Gates 1999
Atlantic coast	Weakfish	one estimate	multiple studies	10%	Murphy et al. 1995, Malchoff and Heins 1997, Swihart et al. 2000, Gearhart 2002
Atlantic coast	Atlantic Croaker	one estimate	unclear	10%	none
Gulf of Mexico	Red Snapper*	multiple estimates varying by geographic region and depth	multiple studies	East of the Mississippi/20-40m: 15%, West of the Mississippi/40m: 40%	personal communication
Gulf of Mexico	Vermilion Snapper*	multiple estimates based on type of fishery	anecdotal information and sensitivity analyses	Private recreational: 10-40%, Headboat: 40-60%, Commercial hand-line: 40-75%	none

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
Gulf of Mexico	Gag Grouper*	multiple estimates varying by geographic region and depth	multiple studies	Panhandle/10m: 11%, Panhandle/20m: 18%, Panhandle/40m: 42%, Peninsula & Keys/10m: 11%, Peninsula & Keys/30m: 29%	personal communication
Gulf of Mexico	Red Grouper*	one estimate	single study	10%	Wilson and Burns 1996
Gulf of Mexico	Greater Amberjack	one estimate	anecdotal information and sensitivity analyses	20%	none
West Coast	Black Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 11%; 11-20 fm: 20%, 21-30 fm: 29%, >30 fm: 63%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Black and Yellow Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 13%; 11-20 fm: 24%, 21-30 fm: 37%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Blue Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 18%; 11-20 fm: 30%, 21-30 fm: 43%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Bocaccio	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 19%; 11-20 fm: 32%, 21-30 fm: 46%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Brown Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 12%; 11-20 fm: 22%, 21-30 fm: 33%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Calico Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 24%; 11-20 fm: 43%, 21-30 fm: 60%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Canary Rockfish	surface release: multiple estimates varying by depth; release with descending device: multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	Surface release: multiple sources of data are combined: 1) observed discard data and GLM model to estimate surface mortality with depth; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality; Release with descending device: 1) 90% upper confidence interval estimate of short-term mortality estimates from cage studies, 2) long-term mortality estimates from an acoustic tagging study of descended fish.	Surface release: 0-10 fm: 21%; 11-20 fm: 37%, 21-30 fm: 53%, >30 fm: 100%; Release with descending device: 0-10 fm: 21%, 10-30 fm: 25%, 30-50 fm: 48%, 50-100 fm: 57%, >100 fm: 100%	surface release: Albin and Karpov 1996; PFMC 2008; release with descending device: Jarvis and Lowe 2008, Hannah et al. 2012, Wegner et al. unpublished raw data, PFMC 2012, PFMC 2013, PFMC 2014

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	China Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 13%; 11-20 fm: 24%, 21-30 fm: 37%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Copper Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 19%; 11-20 fm: 33%, 21-30 fm: 48%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Cowcod	surface release: multiple estimates varying by depth; Release with descending device: multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	Surface release: multiple sources of data are combined: 1) observed discard data from deep demersal guild proxy species and GLM model to estimate surface mortality with depth 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality; Release with descending device: 1) 90% upper confidence interval estimate of short-term mortality estimates from cage studies, 2) long-term mortality estimates from an acoustic tagging study of descended fish.	Surface release: 0-10 fm: 21%, 11-20 fm: 35%, 21-30 fm: 52%, >30 fm: 100%; Release with descending device: 0-10 fm: 21%, 10-20 fm: 35%, 20-30 fm: 52%, 30-50 fm: 57%, 50-100: 57%, >100 fm: 100%	surface release: Albin and Karpov 1996, PFMC 2008; release with descending device: Jarvis and Lowe 2008, Hannah et al. 2012, Wegner et al. unpublished raw data, PFMC 2012, PFMC 2013, PFMC 2014
West Coast	Gopher Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 19%; 11-20 fm: 34%, 21-30 fm: 49%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012



* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Grass Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 23%; 11-20 fm: 45%, 21-30 fm: 63%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Kelp Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 11%; 11-20 fm: 19%, 21-30 fm: 29%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Olive Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 34%; 11-20 fm: 45%, 21-30 fm: 57%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Quillback Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 21%; 11-20 fm: 35%, 21-30 fm: 52%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Tiger Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 20%; 11-20 fm: 35%, 21-30 fm: 51%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Treefish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 14%; 11-20 fm: 25%, 21-30 fm: 39%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Vermillion Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 20%; 11-20 fm: 34%, 21-30 fm: 50%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Widow Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 21%; 11-20 fm: 36%, 21-30 fm: 52%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Yelloweye Rockfish	surface release: multiple estimates varying by depth; release with descending device: multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	Surface release: multiple sources of data are combined: 1) observed discard data and a GLM model to estimate surface mortality with depth; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality; Release with descending device: 1) 90% upper confidence interval estimate of short-term mortality estimates from cage studies, 2) long-term mortality estimates from an acoustic tagging study of descended fish.	Surface release: 0-10 fm: 22%; 11-20 fm: 39%, 21-30 fm: 56%, >30 fm: 100%; Release with descending device: 0-10 fm: 26%, 10-30 fm: 26%, 30-50 fm: 27%, 50-100 fm: 57% , >100 fm: 100%	surface release: Albin and Karpov 1996, PFMC 2008; release with descending device: Jarvis and Lowe 2008, Hannah et al 2012, Wegner et al. unpublished raw data, PFMC 2012, PFMC 2013, PFMC 2014
West Coast	Yellowtail Rockfish	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 10%; 11-20 fm: 17%, 21-30 fm: 25%, >30 fm: 50%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Shallow Pelagic Rockfish Guild Proxy (applied to rockfishes in this guild without species specific data)	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed discard data from proxy species and guild-based GLM model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 11%; 11-20 fm: 19%, 21-30 fm: 29%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Deep Pelagic Rockfish Guild Proxy (applied to rockfishes in this guild without species specific data)	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed discard data from proxy species in the guild and guild-based GLM model to estimate surface mortality with depth; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 18%; 11-20 fm: 30%, 21-30 fm: 45%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008
West Coast	Shallow Demersal Rockfish Guild Proxy (applied to rockfishes in this guild without species specific data)	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed discard data from proxy species in the guild and guild-based GLM model to estimate surface mortality with depth; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 13%; 11-20 fm: 24%, 21-30 fm: 37%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008
West Coast	Deep Demersal Rockfish Guild Proxy (applied to rockfishes in this guild without species specific data)	multiple estimates varying by depth; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed discard data from proxy species in the guild and guild-based GLM model to estimate surface mortality with depth; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 11%; 11-20 fm: 20%, 21-30 fm: 29%, >30 fm: 100%	Albin and Karpov 1996, PFMC 2008
West Coast	Cabezon	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	California Scorpionfish	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Kelp Greenling	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Lingcod	1. one estimate; sectors include recreational, rod and reel commercial nearshore; 2. one estimate; sectors include trawl	1. single study accounting for hooking and handling mortality assessed during holding for an average of 15 days. no swim bladder thus no barotrauma or depth dependence of mortality; 2. estimated mortality from field studies.	1. 7%; 2. 50%	1. Albin and Karpov 1996, PFMC 2008; 2. Parker et al. 2003
West Coast	Pacific Cod	proxy; sectors include recreational, rod and reel commercial nearshore	multiple sources of data are combined: 1) observed data and/or a guild-based model to estimate surface mortality; 2) single study to estimate short-term, below-surface mortality; 3) expert opinion to estimate long-term, delayed mortality	0-10 fm: 5%; 11-20 fm: 32%, 21-30 fm: 53%, >30 fm: 97%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Flatfish	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Sharks	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012
West Coast	Skates	proxy; sectors include recreational, rod and reel commercial nearshore	proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality	7%	Albin and Karpov 1996, PFMC 2008, Hannah et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Spiny Dogfish	1. proxy; sectors include recreational, rod and reel commercial nearshore; 2. single value informed by multiple studies; sectors include trawl; 3. proxy; sectors include fixed gear	1. proxy for species without swim bladder based on survival of lingcod accounting for hooking and handling mortality; 2. estimated mortality from field studies; 3. proxy value for trawl applied fixed gear fishery assuming it is conservative compared to trawl	1. 7%; 2. 50%; 3. 50%	1. Albin and Karpov 1996, PFMC 2008; 2. Mandelman and Farrington 2007, Rulifson 2007; 3. Proxy of 2. above.
West Coast	Sablefish	1. single value informed by multiple studies; sectors include trawl; 2. single value informed by multiple studies; sectors include fixed gear	1. estimated mortality from field and laboratory studies; 2. estimated mortality from field and laboratory studies	1. 50%; 2. 20%	1. Erickson et al. 1997, Olla et al. 1997, Olla et al. 1998, Davis et al. 2001, Davis and Olla 2002, Davis and Parker 2004, Davis 2005, Davis and Ottmar 2006.
West Coast	Longnose Skate	single rate based on preponderance of multiple studies; sectors include trawl and fixed gear	multiple skate mortality research studies considered and conservative estimate adopted.	50%	Laptikhovsky 2004, Stobutzki et al. 2002, Benoit 2006, Benoit et al. 2010, Enever et al. 2009, Mandelman et al. 2012

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Chinook Salmon	multiple estimates by fishery and gear type	multiple studies were combined	Commercial: 26% (barbless J-hook). Recreational north of Point Arena, CA: 14% (barbless J-hook). Recreational south of Point Arena, CA: troll caught 14% (barbless J-hook), drift-mooch-caught 42% (barbless circle hook), resulting in overall rate for fishery of 20-25%. All fisheries: apply an additional "dropoff mortality rate" of 5% to account for dropoff mortality, predation loss, non-compliance, etc.	Stohr and Fraidenburg 1986, Salmon Technical Team 2000, Grover et al. 2002

* = different estimates used by different regions					
Region	Species	Type of Estimate Used	Data supporting the estimate	Estimates	Citations
West Coast	Coho Salmon	multiple estimates by fishery and gear type	multiple studies were combined	Commercial: 26% (barbless J-hook). Recreational north of Point Arena, CA: 14% (barbless J-hook). Recreational south of Point Arena, CA: troll caught 14% (barbless J-hook), drift-mooch-caught 42% (barbless circle hook), resulting in overall rate for fishery of 20-25%. All fisheries: apply an additional "dropoff mortality rate" of 5% to account for dropoff mortality, predation loss, non-compliance, etc.	Stohr and Fraidenburg 1986, Salmon Technical Team 2000, Grover et al. 2002
Alaska	Demersal Shelf Rockfish	assumption of 100% mortality	single study (additional studies are recently completed)	100%	Brylinsky et al. 2009
Alaska	Pacific Halibut	multiple estimates for different gear	single study	Circle hooks: 3.5%; "J" hooks: 10%	Meyer 2007
Alaska	Chinook Salmon	multiple estimates by size and gear type	multiple studies were combined	Commercial: legal size 21.2% and sublegal: 25.5% (barbed J-hook); legal size 18.5% and sublegal 22.0% (barbless J-hook), Recreational: >33cm 12.3% and <33cm 32.2% (barbless J-hook)	Chinook Technical Committee 1997



## References

- Aguilar, R., P. S. Rand, and G. H. Beckwith. 2002. Quantifying the catch-and-release mortality rate of adult red drum in the Neuse River estuary. North Carolina Fisheries Resource Grant Program, 01- FEG-07. Raleigh, North Carolina.
- Albin D., and K. Karpov. 1996. Northern California sport fish project lingcod hooking mortality study. California Department of Fish and Game Cruise Report.
- Benoît, H. P. 2006. Estimated discards of winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence, 1971–2004. Can. Sci. Adv. Sec. Res. Doc., 2006/002.
- Benoît H. P., T. Hurlbut, and J. Chassé. 2010. Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. Fisheries Research 106 436–447.
- Brylinsky, C., J. Stahl, D. Carlile, and M. Jaenicke. 2009. Assessment of the demersal shelf rockfish stock for 2010 in the southeast outside district of the Gulf of Alaska. Chapter 14 in Stock Assessment and Fishery Evaluation report, North Pacific Fishery Management Council.
- Bugley, K., and G. Shepherd. 1991. Effect of catch-and-release angling on the survival of black sea bass. N Am J Fish Mgmt. 11: 468-471.
- Burns, K. M., R. R. Wilson, and N. F. Parnell. 2004. Partitioning release mortality in the undersized red snapper bycatch: comparison of depth vs. hooking effects. Mote Marine Laboratory Tech. Rept. No. 932 funded by NOAA under MARFIN Grant # NA97FF0349.
- Burns, K. M., C. C. Koenig, and F. C. Coleman. 2002. Evaluation of multiple factors involved in the release mortality of undersized red grouper, gag, red snapper, and vermilion snapper. Mote Marine Laboratory Technical Report No. 790.
- Chinook Technical Committee. 1997. Incidental mortality of Chinook salmon: mortality rates applicable to Pacific Salmon Commission fisheries. Pacific Salmon Commission. Vancouver B.C. Report TCCHINOOK (97)-1. 53 p.
- Clay, D., W. T. Stobo, B. Beck, and P. C. F. Hurley. 1989. Growth of juvenile pollock (*Pollachius virens* L.) along the Atlantic coast with inferences of inshore-offshore movements. J Northwest Atl Fish Sci. 9:37-43.
- Collins, M. R. 1996. Survival estimates for demersal reef fishes released by anglers. Proceedings of the 43rd Annual Gulf and Caribbean Fisheries Institute, Nassau, Bahamas, November 1991.
- Collins, M. R., J. C. McGovern, G. R. Sedberry, H. S. Meister, and R. Pardieck. 1999. Swim bladder deflation in black sea bass and vermilion snapper: potential for increasing post release survival. N. Am. J. Fish. Manage. 19:828-832.
- Davis M. W., and B. L. Olla. 2001. Stress and delayed mortality induced in Pacific halibut *Hippoglossus stenolepis* by exposure to hooking, net towing, elevated sea water temperature and air: implications for management of bycatch. N. Am. J. Fish. Manage. 21: 725–732.
- Davis M. W., B. L. Olla, and C. B. Schreck. 2001. Stress induced by hooking, net towing, elevated sea water temperature and air in sablefish: lack of concordance between mortality and physiological measures of stress. J. Fish Biol. 58: 1–15.
- Davis, M. W., and B. L. Olla. 2002. Mortality of lingcod towed in a net is related to fish length, seawater temperature and air exposure: a laboratory bycatch study. N. Am. J. Fish. Manage. 22: 1095–1104.
- Davis, M. W., and S. J. Parker. 2004. Fish size and exposure to air: potential effects on behavioral impairment and mortality rates in discarded sablefish. N. Am. J. Fish. Manage. 24: 518-524.
- Davis, M. W. 2005. Behavior impairment in captured and released sablefish: ecological consequences and possible substitute measures for delayed discard mortality. J. Fish. Biol. 66: 254-256.
- Davis, M. W., and M. L. Ottmar. 2006. Wounding and reflex impairment may be predictors for mortality in discarded or escaped fish. Fish. Res. 82: 1-6.
- Diodati, P.J., and A.R. Richards. 1996. Mortality of striped bass hooked and released in saltwater. Transactions of the American Fisheries Society 125:300-307.
- Durso, V., and H. Iwanowicz. 1983. Hooking mortality of winter flounder *Pseudopleurocetes americanus* in coastal Massachusetts waters. MA Div. Marine Fisheries. 88p.

- Edwards, R. E. 1996. King mackerel hooking mortality assessment. National Marine Fisheries Service Report No. 92-SER-035, St. Petersburg, Florida.
- Enever, R., T. L. Catchpole, J. R. Ellis, and A. Grant. 2009. The survival of skates (Rajidae) caught by demersal trawlers fishing in UK waters. *Fisheries Research* 97: 72–76.
- Erickson D., E. Pikitch R. Methot, E. Babcock, and J. Wallace. 1997a. Survival of trawl-caught and discarded sablefish (*Anoplopoma fimbria*) during summer trials. Cruise Report 26 August - 10 September 1997.
- Erickson D., E. Pikitch, R. Methot, E. Babcock, T. Builder, J. Wallace, P. Crone, J. Brodziak, and R. Conser. 1997b. Survival of trawl caught and discarded sablefish (*Anoplopoma fimbria*) off the U.S. West Coast. 1997. ICES Annual Science Conference Theme Session: Fisheries Technology CM 1997/FF:06.
- Gearhart, J. 2002. Hooking mortality of spotted seatrout, weakfish, red drum, and southern flounder in North Carolina. Morehead City (NC): DENR Division of Marine Fisheries. Completion Report for Cooperative Agreement No. NA 87FG0367/2. Documentation and Reduction in Bycatch in North Carolina, Job 3.
- Gertseva, V. 2008. Status of the longnose skate (*Raja rhina*) off the continental US Pacific Coast in 2007. Pacific Fishery Management Council, Portland, Oregon. <http://www.pcouncil.org/groundfish/stock-assessments/by-species/longnose-skate/>
- Gertseva, V., and I. Taylor. 2012. Status of the spiny dogfish shark resource off the continental U.S. Pacific Coast in 2011. Pacific Fishery Management Council, Portland, Oregon. <http://www.pcouncil.org/groundfish/stock-assessments/by-species/spiny-dogfish/>
- Grover, A. M., M. S. Mohr, and M. Palmer-Zwahlen. 2002. Hook-and-release mortality of Chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. In J.A. Lucy and A.L. Studholme, editors, *Catch and release in marine recreational fisheries.*, Symposium 30, pp. 39-56. American Fisheries Society, Bethesda, Maryland.
- 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: Dynamics, Management and Ecosystem Science* 4:46-56.
- Howell, P. T., and D. G. Simpson. 1985. A study of marine recreational fisheries in Connecticut. March 1, 1981 - February 28, 1984. CTDEP, Fed Aid to Sport Fish Restoration F54R. Final Rep. 60 p.
- 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.
- Lapikhovskiy, V. 2004. The survival rates of rays discarded by the squid-targeting bottom trawl fishery off the Falkland Islands. *Fish. Bull.*, 102(4), 757-759.
- Low, R. A., Jr. 1981. Mortality rates and management strategies for black sea bass off the southeast coast of the United States. *N. Am. J. Fish. Manage.* 1:93-103.
- Lucy, J.A., and T. D. Holton. 1998. Release mortality in Virginia's recreational fishery for summer flounder, (*Paralichthys dentatus*) VA Mar Res Rep. 97-8. 48 p
- Malchoff, M.H., and S. W. Heins. 1997. Short-term hooking mortality of weakfish caught on single-barb hooks. *N Am J Fish Manage.* 17:477-481.
- Malchoff, M. H., and J. Lucy. 1998. Short-term hooking mortality of summer flounder in New York and Virginia. Interim report for Cornell Univ/DEC Project MOU 000024. 6 p.
- Malchoff, M., J. Gearhart, and J. Lucy. 2001. Short-term hooking mortality of summer flounder in New York, Virginia, and North Carolina (ASMFC 2001).
- Malchoff, M. H. 1995. Effects of catch and release on important northeast marine fishers: mortality factors and applications to recreational fisheries. NY Sea Grant Extension Program, Cornell Cooperative Extension Report, Riverhead, NY.
- Mandelman, J. W., and M.A. Farrington. 2007. The estimated short-term discard mortality of a trawled elasmobranch, the spiny dogfish (*Squalus acanthias*). *Fisheries Research* 83: 238–245
- Mandelman, J. W., R. A. Morrison, J. M. Cavin, and M. A. Farrington. 2012. The blood chemical status of Atlantic cod, *Gadus morhua*, following capture by jig and demersal longline with differential hook removal methods. *J. Fish Biol.* 81: 1406-1414.
- McGovern, J. C., G. R. Sedberry, H. S. Meister, T. M. Westendorff, D. M. Wyanski, and P. J. Harris. 2005. A tag and recapture study of gag, *Mycteroperca microlepis*, off the Southeastern U.S. *Bulletin of Marine Science*, 76(1): 47-59.

- Meyer, S. 2007. Halibut discard mortality in recreational fisheries in IPHC Areas 2C and 3A. Discussion paper. Alaska Department of Fish and Game Division of Sport Fish Homer, Alaska.
- Murphy, M.D., R. F. Heagey, V. H. Neugebauer, M. D. Gordon, and J. L. Hintz. 1995. Mortality of spotted seatrout released from gill-net or hook-and-line gear in Florida. *N Am J Fish Manage.* 15:745- 753.
- Murphy, M. D. 2005. A stock assessment of red drum, *Sciaenops ocellatus* in Florida: status of the stocks through 2003. Report to the Florida Fish and Wildlife Conservation Commission from the Fish and Wildlife Research Institute, St. Petersburg. FWRI In-House Report 2005-006.
- Olla, B. L., M. W. Davis, and C. B. Schreck. 1997. Effects of simulated trawling on sablefish and walleye pollock: the role of light intensity, net velocity and towing duration. *J. Fish Biol.* 50: 1181–1194.
- Olla B. L., M. W. Davis, and C. B. Schreck. 1998. Temperature magnified postcapture mortality in adult sablefish after simulated trawling. *J. Fish Biol.* 53: 743–751.
- Overton, A. S., and J. Zabawski. 2003. Release mortality of undersized fish from the snapper/grouper complex off the North Carolina coast. NC Sea Grant 03-FEG-21.
- 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. *N. Am. J. Fish. Manage.* 23: 530-542.
- PFMC (Pacific Fishery Management Council). 2008. Final environmental impact statement for the proposed acceptable biological catch and optimum yield specifications and management measures for the 2009-2010 Pacific Coast groundfish fishery. Portland, OR: Pacific Fishery Management Council. Chapter 4: 276-290. [http://www.pcouncil.org/wp-content/uploads/chp4\\_0910.pdf](http://www.pcouncil.org/wp-content/uploads/chp4_0910.pdf)
- PFMC (Pacific Fishery Management Council). 2012. Groundfish Management Team progress report on developing mortality rates for rockfish released using descending devices. Pacific Fishery Management Council, Portland, OR. November Council Meeting, Agenda Item I.3. [http://www.pcouncil.org/wp-content/uploads/I3b\\_GMT\\_NOV2012BB.pdf](http://www.pcouncil.org/wp-content/uploads/I3b_GMT_NOV2012BB.pdf)
- PFMC (Pacific Fishery Management Council). 2013. Groundfish Management Team report on proposed discard mortality for cowcod, canary rockfish, and yelloweye rockfish released using descending devices in the recreational fishery. Pacific Fishery Management Council, Portland, OR. April Council Meeting, Agenda Item D.5, [http://www.pcouncil.org/wp-content/uploads/D5b\\_GMT\\_APR2013BB.pdf](http://www.pcouncil.org/wp-content/uploads/D5b_GMT_APR2013BB.pdf)
- PFMC (Pacific Fishery Management Council). 2014. Groundfish Management Team report on proposed discard mortality for cowcod, canary rockfish, and yelloweye rockfish released using descending devices in the recreational fishery. Pacific Fishery Management Council, Portland, OR. March Council Meeting, Agenda Item D.3, [http://www.pcouncil.org/wp-content/uploads/D3b\\_SUP\\_GMT\\_RPT2\\_MAR2014BB.pdf](http://www.pcouncil.org/wp-content/uploads/D3b_SUP_GMT_RPT2_MAR2014BB.pdf)
- Rudershausen, P. J., A. Ng, and J. A. Buckel. 2005. By-catch, discard composition, and fate in the snapper/grouper commercial fishery, North Carolina. NC Sea Grant 04-FEG-08.
- Rulifson, R.A. 2007. Spiny dogfish mortality induced by gill-net and trawl capture and tag and release. *North American Journal of Fisheries Management* 27:279–285.
- Salmon Technical Team. 2000. STT recommendations for hooking mortality rates in 2000 recreational ocean Chinook and coho fisheries. STT report B.2. March 2000. Pacific Fishery Management Council, Portland, OR. 18p.
- Simpson, D. G., and M. Gates. 1999. Studies in Conservation Engineering, Job 4. In: A Study of Marine Recreational Fisheries in Connecticut. Final Report. Pp 121 – 127. CT DEP Marine Fisheries Office, Old Lyme, CT.
- Stobutzki, I. C., M. J. Miller, D. S. Heales, and D. T. Brewer. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. *Fish. Bull.* 100, 800–821.
- Stohr, A. J. M., and M. E. Fraidenburg. 1986. A Delphi estimate of chinook and coho salmon hooking mortality. State of Washington, Department of Fisheries. Technical Report No. 94. 91p.
- Swihart G. L., J. I. Galvez, L. B. Daniel, and M. L. Swihart. 2000. Evaluation of hook and release mortality from a recreational hook and line fishery on weakfish (*Cynoscion regalis*). Gloucester (MA): US Fish and Wildlife Service Office of Fishery Assistance. 4 p.

- Terceiro, M. 2011. Stock assessment of scup for 2011. NOAA National Marine Fisheries Service Northeast Fisheries Science Center Reference Document 11-21. October 2011. 104p.
- Vaughan, D. S., M. R. Collins, and D. J. Schmidt. 1995. Population characteristics of the black sea bass *Centropristis striata* from the southeastern U.S. *Bull. Mar. Sci.* 56:250-267.
- Wegner, N. C., A. L. Pribyl, and J. R. Hyde, J.R. 2012-2014. Rockfish barotrauma study. Unpublished raw data.
- Vecchio, J. L., and C. A. Wenner. 2007. Catch-and-release mortality in sub-adult and adult red drum captured with popular fishing hook types. *N. A. J. Fish. Manage.* 27:891–899.
- Wilson, Jr., R. R., and K. M. Burns. 1996. Potential survival of released groupers caught deeper than 40m based on shipboard and in-situ observations, and tag recapture data. *Bull. Mar. Sci.* 58: 234-247.