The Snapper Saga: An Assessment of Sector Separation on the Gulf of Mexico Recreational Red Snapper Fishery

Bren School of Environmental Science & Management

A group project submitted in partial satisfaction of the degree requirements for the Master of Environmental Science and Management

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As authors of this Group Project report, we are honored to document this report on the Bren School of Environmental Science & Management's website so our results are available to the public. Our signatures signify our joint responsibility to fulfill standards set by the Bren School of Environmental Science & Management.

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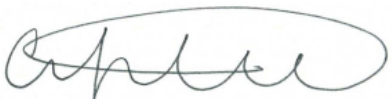
The Group Project is required of all students in the Master's of Environmental Science and Management (MESM). It is a three-quarter project in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Sarah Anderson



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Abstract

Red snapper (*Lutjanus campechanus*) is an iconic species in the Gulf of Mexico that has been historically overfished. Since implementing a rebuilding plan, both the average size of red snapper and the overall stock biomass have increased. Despite these improvements, the fishing season continues to shorten, creating discontent amongst stakeholders. Additionally, recreational anglers exceed their Total Allowable Catch (TAC). To address these issues, the Gulf of Mexico Fishery Management Council is evaluating sector separation, which would split the recreational fishery into two angler groups: for-hire (made up of charter boats and headboats) and private. Sectors would have distinct TACs and more tailored management. This project evaluates the biological and economic impacts of sector separation, while considering stakeholder knowledge and opinion. Our analysis, which assumes for-hire anglers do not exceed their TAC, suggests that sector separation will have minimal effects on the biology and that sector separation alone does not yield economic impacts. Economic changes are driven by variations in allocation and overage liability. Implementing an Individual Transferable Quota (ITQ) program in the for-hire sector could further increase welfare. ITQs could increase flexibility in fishing days, which would appease stakeholders, while also promoting stock health and the region's economy.

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List of Acronyms

CS: Consumer Surplus
EEZ: Exclusive Economic Zone
FH: For-Hire
FMP: Fisheries Management Plan
GMFMC: Gulf of Mexico Fishery Management Council
GOM: Gulf of Mexico
IFQ: Individual Fishing Quota
ITQ: Individual Transferrable Quota
MSA: Magnuson-Stevens Act
MSY: Maximum Sustainable Yield
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
OC: Ocean Conservancy
OY: Optimal Yield
SAFMC: South Atlantic Fishery Management Council
SEDAR: Southeast Data, Assessment, and Review
SFA: Sustainable Fisheries Act
SFSC: Southeast Fisheries Science Center
SPR: Spawning Potential Ratio
SQ: Status Quo
SSQ: Sums-of-Squares
TAC: Total Allowable Catch
WTP: Willingness-To-Pay

Executive Summary

I. Background

While biological improvements to the previously overfished[1] red snapper (*Lutjanus campechanus)* stock in the Gulf of Mexico (GOM) are seen on the water by anglers and in stock evaluations made by fisheries scientists, regional stakeholders are becoming increasingly dissatisfied with the management of the resource. This disparity between biological stock improvements and dissatisfied stakeholders is the cause of much friction between interest groups.

The manifestations of biological improvements in the red snapper stock include larger fish and increasing biomass. This means that the average weight of red snapper has increased over the last six years and that fishermen are increasingly successful on their fishing trips. Although these stock improvements should be good news for the fishermen, the annual Total Allowable Catch (TAC) is being caught more quickly, which is causing season length to shorten. Additionally, there are significant landings overages within the recreational sector as anglers exceed their TAC. Decreasing season length and landings overages are two issues that fisheries managers are facing in the recreational red snapper fishery.

Historically, the red snapper stock had been overfished[2] and was undergoing overfishing[3] through the 1980s. In 1996, the red snapper was placed on a Fisheries Management Plan (FMP), as mandated by the Sustainable Fisheries Act (SFA). In 2005, managers adopted a rebuilding plan for the red snapper, which entailed more restrictive management of the fishery.

Currently, the red snapper fishery is managed in two sectors: the commercial and the recreational sector. As a federally managed species, a TAC is set annually, with 51% of the TAC allocated to the commercial fishery and 49% allocated to the recreational fishery. Although the TAC is split nearly equally between the two sectors, they are managed very differently. The commercial sector is limited by the number of federal permits available and is managed using Individual Transferrable Quotas (ITQs), whereas the recreational fishery is an open access fishery. Effort in the recreational sector is limited by bag limits, minimum size limits, and season closures. Another important differing attribute between these two fisheries is that the commercial fishery does not exceed its TAC, while the recreational fishery exceeds its TAC nearly every year. Although managers anticipate overages when determining the TAC, the difficulty of monitoring recreational landings remains a challenge.

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[1] A glossary of fisheries terms presented throughout this report and their definitions can be found in

[2] Overfished is defined as a stock "whose size is sufficiently small that a change in management practices is required to achieve [either] an appropriate level and rate of rebuilding" or the minimum stock size threshold (Blackhart *et al*, 2006).

[3] Overfishing is defined as "a level of fish harvesting that is higher than that of economic efficiency; harvesting more fish than necessary to have maximum profits for the fishery" (Blackhart *et al*, 2006).

The recreational fishing sector is made up of two sectors: for-hire fishermen and private fishermen. The number of federal permits available limits for-hire fishermen. They sell offshore fishing trips to customers and operate either charter boats, which are small and can seat up to six passengers, or headboats, which are larger and can carry up to 150 passengers. Unlike for-hire anglers, private fishermen are not limited by federal permits, obtain licenses through the state governments, and use their own boats to fish offshore.

The Gulf of Mexico Fishery Management Council (GMFMC) recognizes that the current management is not meeting the needs of the regional stakeholders. Thus, the GMFMC has been exploring alternative regulations. To achieve concrete management of the recreational fishery, angler groups need to be held individually accountable for their actions, especially the landings overages. One management alternative is sector separation, which is the source of great contention. Initially proposed in 2010, sector separation would split the recreational sector into two, separately managed units: the for-hire sector (consisting of charter boats and headboats) and the private sector. With this management change, the GOM red snapper fishery would be managed as three sectors (commercial, for-hire, and private), as opposed to the current two sectors (commercial and recreational).

In 2010, the GMFMC held a working group meeting to discuss sector separation. The discussions at this workshop reflected the frustration surrounding the current management of recreational red snapper, as well as the confusion about how sector separation would be implemented in the GOM and the economic implications of executing such a program.

II. Objectives

The overarching goal of this project is to provide information that will allow stakeholders a better understanding of the implications of sector separation. Assessing the biological and economic changes that occur from implementing sector separation within the GOM recreational red snapper fishery and comparing those changes with current management schemes will allow managers and stakeholders to see what this management change could mean for the fishery and the region as a whole.

The biological changes were evaluated through comparisons of spawning biomass, landings, and the age structure of the stock at Status Quo (SQ) and under several different sector separation scenarios. The economic changes were evaluated through comparisons of profit and consumer surplus (CS) losses at SQ and under sector separation.

A secondary goal of this project is to understand the preferences and the knowledge of the sector separation discussions of the GMFMC by the regional constituents. Surveying commercial, for-hire, and private anglers in the GOM fulfilled this goal. Since recreational anglers number in the millions and are unorganized, it is often difficult to gather their opinions. The results from this opinion survey provide

useful information to aid in understanding the preferences of the stakeholders who would be affected by the proposed management changes.

By fulfilling these objectives, we aim to provide information on the implications of implementing sector separation. With a better understanding of what sector separation means for the biology of the red snapper stock and the economy of the region, managers and anglers can have more productive conversations. An additional goal of this project is to make recommendations to our client, Ocean Conservancy (OC), as well as other industry professionals. Finally, we hope that this report can be used as a reference for fisheries managers considering sector separation in other regions.

III. Approach

We constructed an age-structured biological model to explore the biological impacts of sector separation compared to the biology of the stock at SQ. The biological outputs of interest that were compared include the biomass, catch levels, and the numbers at age. The changes in numbers-at-age were inputs into our economic model and the outputs of the economic model used to compare various scenarios were CS and profits.

Before implementing sector separation in the recreational red snapper fishery, allocation of the TAC must first be determined. Since it is uncertain what these allocations are, we analyzed the biological and economic outputs using four different allocation scenarios. Furthermore, under the SQ, there is no way to tell whether private anglers or for-hire anglers are contributing to landings overages. Thus, we analyzed four different overage scenarios within our biological and economic models.

To understand the preferences and the knowledge of the regional stakeholders, we sent a survey to 1,200 anglers throughout the GOM. The survey asked respondents to rank their desired outcome from a well-managed recreational red snapper fishery. Respondents were also asked if they had previous knowledge of sector separation, what part of the industry they were involved in, and if they had any suggestions on how to best change current management practices.

IV. Results

Our biological model shows that there will be a slight increase in red snapper spawning biomass by 2032 if sector separation is implemented; therefore, sector separation would not impact the biology of the fishery in a significant way. The numbers-at-age also increase, which will further aid in the recovery of the red snapper fishery.

Our economic model shows that implementing sector separation itself will not cause economic changes, but the allocation and overage liability will impact the region's economy. CS of private anglers will decrease in all allocation and overage scenarios analyzed, except for the allocation that is based on their predicted landings for 2013.

Depending on the TAC allocation and which sector is landing the overages, the for-hire sector can see economic gains with the implementation of sector separation. The for-hire sector would see the most economic gains if the allocation is based on an average of historic landings, as compared to an allocation based on landings from a recent year.

Many stakeholders voice concerns about the uncertainty of implementing catch shares, or ITQs, which could be adopted within the recreational sector if sector separation is implemented. Evaluating an ITQ system in the for-hire sector shows that the for-hire sector could actually see profit increases under sector separation when compared to SQ. Increased profits are observed under the allocation scenario based on historic landings for all of the overages cases, except if the for-hire is contributing to all of these overages.

Survey respondents overwhelmingly desire more fishing days within the recreational red snapper fishery. Additionally, respondents were in favor of sector separation whether or not they indicated that they were familiar with the topic. The results from our survey suggest that it is possible to gain support from industry stakeholders for the adoption of sector separation within the recreational red snapper fishery.

V. Conclusions

Since the introduction of the topic in 2010, discussions of implementing sector separation in the GOM recreational red snapper fishery have been increasingly heated. Much of the controversy is due to the uncertainty of what this management alternative would produce. Although the current management is not optimal, stakeholders do not want a change to make them worse off. Additionally, the GMFMC has not been able to effectively move forward with management alternatives because they have been unable to communicate expected impacts. This report suggests that implementing sector separation could achieve economic gains for a portion of the recreational sector; these gains could be increased further with the implementation of an ITQ system. However, it is important to note that our results are dependent on the allocation and overage scenarios we chose to analyze. All management changes have tradeoffs, and the evaluation of sector separation becomes clearer when these tradeoffs are more visible. Ultimately, this report explains the impacts of implementing sector separation in the GOM recreational red snapper fishery, as well as suggestions as to what the tradeoffs would be.

Problem Statement

Fisheries managers are tasked with managing fish stocks for the greatest overall benefit to the nation. This means that they must not only act to restore depleted stocks and manage healthy stocks, but they must also prevent overfishing and take into account the importance of the resource to fishing communities and promote efficiency (MSA §301). The recreational red snapper fishery in the Gulf of Mexico (GOM) is one such fishery that is being managed on a rebuilding plan to restore the stock from its depleted levels. To rebuild the stock, effort in the fishery must be limited. This has happened through the implementation of several fishing regulations, including setting Total Allowable Catch (TAC) limits and enforcing season closures.

Recently, fishermen in the GOM have observed stock improvements. Additionally, the data collected by fisheries managers and used by fisheries scientists support these observations. In fact, in 2009, the National Oceanic and Atmospheric Administration (NOAA) announced that the red snapper in the GOM was no longer being overfished, which means that the sustainable harvest level is no longer being exceeded ("Final Regulatory Amendment to the Reef Fish Fishery Management Plan to Set Total Allowable Catch for Red Snapper", 1-98). These improvements are indications that the management regulations are succeeding in reducing effort and, ultimately, are reducing fishing mortality.

Despite these biological improvements, recreational anglers are becoming increasingly upset. One particular issue that anglers cite as a source of discontent is the season length. As a federally managed species, red snapper has a TAC for the year based on the status of the stock. Managers then make projections as to when the TAC will be reached (or caught) by anglers in order to best determine the number of days that the season can remain open. The recreational season length has decreased significantly over the last six years; in 2007, anglers were able to fish for red snapper over a 190-day season, but in 2011, the season was only 49 days (Agar and Carter, 2012). Over these six years, fishermen have seen an 86% reduction in season length.

Of all the recreational fisheries in the GOM, red snapper is one of the most targeted fish. In 2011, it was estimated that anglers took 513,564 trips (“Sector Separation Discussion Paper”, 1-24) and caught 4.603 million pounds of red snapper were (“2012 Recreational Red Snapper Quota Closure Analysis” 1-17). While these figures are staggering, they represent the efforts and catch of red snapper fishing over the short 49-day season.

Another issue within the GOM recreational red snapper fishery is that the TAC is exceeded each year. In 2011, the TAC allocated to the recreational sector was 3.52 million pounds. Thus, the 4.59 million pounds of red snapper caught that year represents an 18.8% overage (Agar and Carter, 2012). While this may seem large,

2011 was not an abnormal year, as the recreational quota has been exceeded four out of five years since 2007.[4]

The primary managing body of the GOM recreational red snapper fishery is the Gulf of Mexico Fishery Management Council (GMFMC). The GMFMC creates a Fisheries Management Plan (FMP) for all species of national interest in federal waters.[5] Red snapper has been managed under the GMFMC Reef Fish FMP since 1984. In order to change the FMP, amendments must be drafted and approved by the GMFMC. There have been 38 amendments to the GOM Reef Fish FMP, and eight of these amendments pertain to red snapper ("Final Regulatory Amendment to the Reef Fish Fishery Management Plan to Set Total Allowable Catch for Red Snapper" 1-98). In general, these amendments have done two things: increased the minimum size limit from 13 to 16 inches, and implemented a bag limit of two fish per angler per day (or per trip). Reef Fish Amendment 22, titled "To Set Red Snapper Sustainable Fisheries Act Targets and Thresholds, Set a Rebuilding Plan, and Establish Bycatch Reporting Methodologies for the Reef Fish Fishery," was the amendment responsible for setting new targets for Maximum Sustainable Yield (MSY)[6] and Optimum Yield (OY),[7] outlining steps to rebuild the red snapper stock, and creating strategies for reducing bycatch ("Final Amendment 22 to the Reef Fish Management Plan to Set Red Snapper Sustainable Fisheries Act Targets and Thresholds, Set a Rebuilding Plan, And Establish Bycatch Reporting Methodologies for the Reef Fish Fishery " 1-218).

Since the implementation of Amendment 22, the recreational red snapper fishery has begun to recover. One indication of stock improvement is the increase in the average weight of the red snapper being caught. In 2007, the average weight of red snapper was 3.2 pounds; in 2011, the average weight of a red snapper caught was 6.4 pounds ("2012 Recreational Red Snapper Quota Closure Analysis", 1-17). A second indication of the improved stock is the increased overall red snapper biomass, which has allowed fishery managers to increase the TAC since 2010.

In addition to adjusting FMPs to meet the standards set by the Magnuson-Stevens Act (MSA), a second motivation for evaluating alternative amendments is stakeholder discontent. TAC overages and diminishing season length are recognized as issues, and the GMFMC has been working on several amendments to

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[4] The only year the recreational sector did not exceed their TAC was in 2010, when the Deepwater Horizon oil spill occurred.

[5] In Texas and Florida, federal waters begin at nine miles off the coast and end at 200 miles. In Louisiana, Mississippi, and Alabama, federal waters begin at three miles off the coast and end at 200 miles.

[6] MSY is defined as "the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others" (Blackhart *et al*, 2006).

[7] OY is defined as "the harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. OY is different from MSY in that MSY considers only the biology of the species" (Blackhart *et al*, 2006).

address these issues. In 2010, the GMFMC discussed creating a new amendment that would divide the recreational red snapper fishery into two separately managed components: the for-hire sector (comprised of charter and headboats), and the private sector. Known as sector separation, this change would entail dividing the TAC allocated for the recreational community between these two sectors. This would allow the GMFMC to hold specific angler groups accountable for landings and TAC overages, which would produce more robust management of the recreational fishery.

There are several steps that must occur before an amendment is adopted into an existing FMP. These steps include scoping, a public hearing, a final action decision, and rule making. Members of the public are able to be involved in several stages of this process. Through comment letters and public testimony, stakeholders are very vocal about the proposed sector separation amendment, as the economic impacts on recreational anglers are unknown. Sector separation has become such a contentious issue that the GMFMC removed sector separation from Amendment 32 in November 2012 ("Sector Separation Discussion Paper", 1-24).

When crafting fisheries management policies, it is very important for managers to consider stakeholder opinions. The GOM recreational fishing industry is comprised of millions of stakeholders and resource users and is both economically and socially critical to the region. It is also the second largest marine recreational fishery in the United States. In the GOM, recreational fishing generates more than 84,000 full-and part-time jobs, and accounts for 41% of all United States marine recreational fishing catches ("Gulf of Mexico Regional Summary", 1-22). Every year, almost three million residents of the five GOM states (Florida, Alabama, Mississippi, Louisiana and Texas) take part in recreational fishing activities. This accounted for more than 22 million fishing trips in 2009 and approximately 147 million fish caught ("Gulf of Mexico Regional Summary", 1-22).

Currently, there is little scientific literature about the impacts of sector separation on recreational fisheries, as there are few fisheries that have implemented this strategy. Moreover, the lack of a reliable system for collecting fishing data has contributed to increased suspicion of all parties involved due to the uncertainty surrounding quota allocations under sector separation. Despite considerable effort to reform the red snapper fishery in the GOM, a thorough analysis of the possible impacts of the proposed options has not been performed. Stakeholder acceptance is crucial for the successful adoption of a management strategy. In order to move forward in discussions, it is necessary to model potential scenarios available under sector separation to understand the effects of implementation.

Natural resource management, especially fisheries management, is a tug-of-war between conserving the resource for future generations and consuming the resource for economic and personal gain. This project could help educate fisheries managers in a multitude of regions; not only will this help managers understand what sector separation is and how it works, but it may aid managers in deciding

whether to pursue sector separation in their own jurisdiction. Global fish consumption is continuing to increase, and novel management strategies are needed to cope with increased extraction to protect the ocean's supply of fish.

Project Objectives

Most recreational stakeholders in the Gulf of Mexico (GOM) agree that the current recreational red snapper management regime is suboptimal. While the red snapper stock is being rebuilt, anglers continue to be restricted. Sector separation is one proposal that is aimed at helping to increase the recreational utility. While this proposal has been discussed at Gulf of Mexico Fishery Management Council (GMFMC) meetings and workshops, there is still a lot of uncertainty about what changes sector separation would have on the fishery once implemented.

The overarching objective of this project is to provide an analysis of the biological and economic implications of sector separation to the stakeholders of the GOM recreational red snapper fishery. To do so, this analysis will provide a comparison of the biological and economic situation under current management, or "Status Quo" (SQ), and under several sector separation scenarios.

Ultimately, this report will fill an information gap surrounding sector separation. This is necessary in order to effectively evaluate alternative management options for one of the region's most important fisheries.

The objectives of this project have been achieved by the following actions:

1. Developing a biological model for the GOM red snapper fishery to reflect changes in stock biomass under sector separation
2. Developing an economic model for the recreational red snapper fishery that provides information regarding the expected impacts of sector separation and the welfare of various stakeholder groups
3. Surveying the fishing community to determine their current level of knowledge of sector separation, as well as what is valued most by fishermen

Through modeling, we are able to evaluate the potential outcomes of sector separation as an allocation tool and also provide recommendations to the GOM recreational fishing community. We intend to show our client, Ocean Conservancy (OC) and key regional stakeholders information about this proposed option to aid in the GMFMC's decision-making process, with the ultimate goal of effectively managing the red snapper stocks while still promoting the regional economy and sociopolitical desires of the stakeholders. It is critical that the broader public, especially those significantly affected by such regulations, understand any fisheries management strategy proposed.

Background

I. Fisheries Management

All fisheries in the United States must abide by the rules set forth by the Magnuson-Stevens Act (MSA), which was enacted in 1976. This remains the primary fisheries management legislation in the nation and is centered on the conservation and recovery of the nation's fisheries. In 1996, MSA was reauthorized under the Sustainable Fisheries Act (SFA). Similar to the original MSA, the SFA highlights the need to rebuild fish stocks nationwide. To ensure that fish stocks are being managed in the best way, the SFA also mandated the creation of a Fisheries Management Plan (FMP) for managers to use as a decision-making resource under different environmental scenarios.

When the FMP for GOM red snapper was established, it was the first time the commercial and recreational red snapper fisheries were allocated separate quotas. This was motivated by the rapidly decreasing stock. The FMP for recreational red snapper in the GOM was required to

> "establish separate quotas for recreational fishing (which…include charter fishing) and commercial fishing that, when reached, results in a prohibition on the retention of fish caught during recreational fishing and commercial fishing, respectively, for the remainder of the fishing year; and ensure that such quotas reflect allocations among such sectors and do not reflect any harvests in excess of such allocations" (MSA §407).

This split has continued to this day, and each sector is managed by different management regulations. Initially, this division helped ease some of the burden placed on the GOM red snapper fishery, as there is evidence that the stock has been recovering since 2005. However, as fishing pressure continues to increase, these FMPs must be updated to ensure that regulations are effectively managing stocks.

In the 1980s, it became clear that GOM red snapper was overfished and undergoing overfishing ("Stock Assessment of Red Snapper in the Gulf of Mexico", 1-224). Overfished is defined as a stock "whose size is sufficiently small that a change in management practices is required to achieve [either] an appropriate level and rate of rebuilding" or the minimum stock size threshold (Blackhart *et al*, 2006). Overfishing is defined as "a stock or stock complex [that] is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield on a continuing basis" or more than a year (Blackhart *et al*, 2006).

To alleviate the reductions in the red snapper stock, the GMFMC implemented a stock rebuilding plan in 2005. The goal was to return the stock to a 26% Spawning Potential Ratio (SPR), or "the number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an

average recruit in an unfished stock" (Blackhart *et al*, 2006). In 2009, an updated red snapper stock assessment was released by the Southeast Data, Assessment, and Review (SEDAR); this scientific advisory committee declared the red snapper stock as no longer undergoing overfishing but still overfished ("Stock Assessment of Red Snapper in the Gulf of Mexico", 1-224). However, due to a lack of reliable data and high levels of misreporting, the stock has not reached a level that allows the GMFMC to extend the recreational fishing season.

With a fishery as large as the recreational red snapper fishery in the GOM, it is beneficial to have a more localized form of management. However, managing a species that moves between jurisdictions has its complications. Each GOM state is responsible for management of recreational red snapper in the waters within its boundaries, which run from the coastline to the edge of the Exclusive Economic Zone (EEZ). In the GOM, federal waters begin at two different lengths: three nautical miles for Alabama, Louisiana, and Mississippi, and nine nautical miles for Florida and Texas. States sell licenses and permits to anglers and boaters to allow them to fish for red snapper. Depending on the state, additional gear restrictions can be imposed on top of any federal limitations. For example, each state in the GOM can apply different regulations to its own waters; specifically, Texas has historically applied its own regulations to its state waters, while the remaining GOM states use federal regulations to simplify their resource management strategy.

In addition to management at a state level, the recreational red snapper fishery is also managed by the GMFMC, as mandated in the MSA. The GMFMC meets multiple times a year to discuss changes to FMPs for the species under its jurisdiction. In 2004, the GMFMC passed Reef Fish Amendment 22, which set new targets for Maximum Sustainable Yield (MSY) and Optimum Yield (OY), created strategies for reducing bycatch, and outlined steps for rebuilding the red snapper stock in both the commercial and recreational sectors. As a result, the commercial red snapper fishery implemented an Individual Transferrable Quota (ITQ) system in 2005. This management strategy is enforceable and commercial fishermen thus stay within their Total Allowable Catch (TAC), which has led to greater revenue and higher stock levels ("Gulf of Mexico 2010 Red Snapper Individual Fishing Quota Annual Report", 1-31). The success of ITQs is attributed to "anecdotal evidence that once fishers have a financial stake in the returns from sensible investment in sustainable practices, they are more easily convinced to make sacrifices required to rebuild and sustain fisheries at high levels of economic and biological productivity" (Costello *et al*, 2008).

Several alternative management options have been proposed to help rebuild the red snapper stock and increase stakeholder approval. In 2010, the GMFMC proposed a split within the recreational sector, known as sector separation. This would separate the for-hire industry, which includes both charter and headboats, from the private anglers. Under sector separation, the differences between the for-hire industry and the private anglers allow different regulations to be applied to each

sector. If adopted by the GMFMC, sector separation would be incorporated into the recreational red snapper FMP.

Due to a lack of significant scientific and economic information on the topic, the GMFMC and its constituents are still unsure how sector separation will impact the GOM recreational red snapper fishery. With any proposed changes to the FMP, stakeholders are concerned that their economic welfare will be reduced and that the fish stocks will be negatively impacted. These concerns are only magnified by the lack of information on the impacts that sector separation could have on the region. However, if educated on the specifics of sector separation when applied to the recreational red snapper fishery, those involved could better understand how to approach this problem and how to better manage the fishery.

II. Red Snapper Biology

Comprehensive management strategies depend on an understanding of the biology of the species at hand. In addition, §303 of the MSA dictates that regional management councils must assess the conditions of the stocks within their boundaries. Because of its importance both commercially and economically, the GOM red snapper stock has undergone several biological stock assessments; there is currently a stock assessment underway, which will be released in July 2013. Understanding the biology of red snapper is crucial to the creation of the biological model used in this report. Furthermore, to achieve the goal of 26% SPR by 2032, the reproduction, life history, and harvest rates of red snapper must be accounted for.

In recent years, the GMFMC developed several rig-to-reef programs in order to enhance habitat availability and fishing grounds for red snapper. Red snapper is a demersal[8] species; in its adult stages, it is primarily found in natural and artificial reef habitats, and occasionally in sandy- and muddy-bottomed habitats. Information from the National Marine Fisheries Service (NMFS) suggests that larger and older red snapper may become more independent of structured reef habitat and reside on the open continental shelf ("Gulf of Mexico 2010 Red Snapper Individual Fishing Quota Annual Report", 1-31). In the northern GOM, natural reef habitat is scarcer than sand- and muddy-bottomed habitat; as a result, oil and gas platforms have become important artificial reef habitats that help to sustain red snapper populations (Gallaway *et al*, 2009).

Although bycatch mortality due to shrimp trawling has significantly decreased since 2003, it is likely that this industry has negatively affected red snapper stock rebuilding efforts (Gallaway *et al*, 2009). On an annual basis, the shrimp industry removes 25 to 45 million red snapper between ages zero to one, which is equivalent to between two to five million pounds of fish ("Stock Assessment Report of SEDAR 7 Gulf of Mexico Red Snapper", 1-480). Since younger red snapper prefer shallower

[8] A demersal species is a bottom-dweller (Blackhart *et al*, 2006).

areas to feed, they are at a greater risk of susceptibility to bycatch (Szedlmayer and Lee, 2004). However, once the species reach their first year (or approximately five to six inches in length), they migrate to the reef habitat, where they remain for the rest of their life.

Although the recreational fishing season for red snapper in the GOM is currently set within the spawning season, there is no evidence of adverse effects on the spawning biomass due to concentrated fishing effort, as red snapper do not exhibit spawning aggregation behaviors. The spawning season for red snapper extends from May to October, with a significant spawning peak occurring from June through mid-September (Szedlmayer and Conti, 1999). Females release several batches of eggs during this period, which increases survival chances for larvae. Furthermore, red snapper are known to have increased movement during summer months, making the stock somewhat less vulnerable to fishing effort (Moran, 1988).

Since red snapper is currently managed as one fish stock, the differences in the life history of red snapper located in the eastern and western GOM could have implications for the management of this species. According to NMFS, red snapper can live up to 57 years. The waters off of Alabama and Louisiana tend to have the larger and slower-growing individuals. Red snapper from Texas grow faster and reach a smaller maximum size than red snapper from Alabama and Louisiana, which aligns with the NMFS data (Fischer *et al*, 2004). There are also recorded differences in the age structure of the recreational fishery, with the eastern GOM showing younger individuals than the central and western GOM (Saari, 2011). Finally, there is evidence of increased growth on artificial habitats for juvenile snapper, but the size or complexity of the habitat may be an influential factor in this growth. Although mortality rates of discarded (either due to minimum size or bag limit) red snapper in the recreational fishery are significantly lower than those observed in the commercial fishery, the overall mortality caused by the recreational sector is higher than the commercial sector due to a continued increase in the number of anglers.

For a thorough stock assessment and a level of confidence in understanding the status of the fishery, information on the species life cycle is extremely important, as management decisions are based on these assessments. Once a stock is labeled as "overfished," it necessitates a rebuilding plan. By understanding the life history, the models in this report can reflect the red snapper fishery most accurately and can be used to best determine the impacts of sector separation.

III. Fishing Industry in the Gulf of Mexico

Fishing is an important socio-economic facet in the GOM and many residents make their livelihood on the water. The fishery is comprised of two sectors: commercial and recreational. The commercial sector fishes red snapper in order to sell it to wholesalers or processors for human consumption. In 2011, commercial fishermen in the GOM landed 1.75 billion pounds of fish, earning $790 million in revenue ("U.S. Commercial Landings", 1-22). Most commercial fishing occurs on small to medium

sized vessels ranging from 25 to 60 feet in length, with anglers that use bottom long-lines and hand lines (Moran, 1988).

Table 1. Commercial fishing in the Gulf of Mexico, 2011 ("U.S. Commercial Landings", 1-22)

State	Pounds Landed (thousands)	Metric Tons Landed	Revenue (thousands of dollars)
Texas	90,443	41,025	218,682
Mississippi	278,056	126,125	30,207
Florida	74,133	33,627	158,051
Alabama	426,041	11,812	50,764
Louisiana	1,285,659	583,171	332,308

The recreational sector has steadily increased in recent years, and red snapper is one of the most desired sport fish. In 2009, 2.8 million GOM residents[9] took part in recreational fishing, taking approximately 23 million trips, as seen in Figure 1 ("State of the Coast: The Gulf of Mexico At a Glance (A Second Glance)", 1-58).

Table 2. Recreational fishing in the Gulf of Mexico, 2009 ("Gulf of Mexico Regional Summary", 1-22)

State	Revenue (dollars)	Number of Jobs	Income (dollars)
Texas	$2,800,000,000	22,127	$1,400,000,000
Mississippi	$417,000,000	3,188	$162,000,000
Florida	$4,400,000,000	42,314	$2,400,000,000
Alabama	$475,000,000	4,924	$245,000,000
Louisiana	$1,800,000,000	19,688	$894,000,000

The recreational sector can further be divided into two components: the for-hire industry and private anglers. The for-hire industry is structured by charging passengers a fee to go out on a boat for a fishing trip (typically one day), with a captain who can guide passengers to popular red snapper fishing spots. Stakeholders in the for-hire industry include charter boat owners and operators, headboat (or "party boat") owners and operators, bait and tackle shop owners and operators, and the employees of these various categories. Charter boats are smaller and can fit anywhere between one to six passengers on average; these boats are aimed at a more intimate fishing experience and can have more recreational amenities (Stoll *et al*, 2002). Headboats are larger and can fit anywhere between 10 to 150 passengers on average; these boats are aimed at a more social fishing experience (Ditton *et al*, 1992). Private anglers own their own boats and go fishing alone or with friends. The fishing method is mainly hand-lines and rod-and-reels, which can be fitted with one to five baited hooks.

[9] There is also a non-resident population that benefits from the recreational fishing in the GOM.

In the commercial industry, the minimum size limit for red snapper is 13 inches and commercial anglers are managed by ITQs. Currently, recreational red snapper fishing occurs during a set season and is limited by both a bag and minimum size limit. However, even with these limitations, the recreational sector has continuously gone over their TAC. This makes managing the recreational fishery difficult for the GMFMC and is one of the motivating reasons for proposing sector separation. The daily bag limit is currently two snapper per angler, and the minimum size limit is 16 inches. In both industries, once caught, red snapper are usually gutted and stored on ice aboard the vessel until the fish changes hands. This practice has important implications for reporting catch, as red snapper can be reported in either whole weight[10] or gutted weight values.[11] Reports of gutted weights are an underestimation of the total catch, especially when dealing with the millions of pounds of red snapper that are landed. Having an accurate account of how much biomass is removed from the fishery is incredibly important for managers.

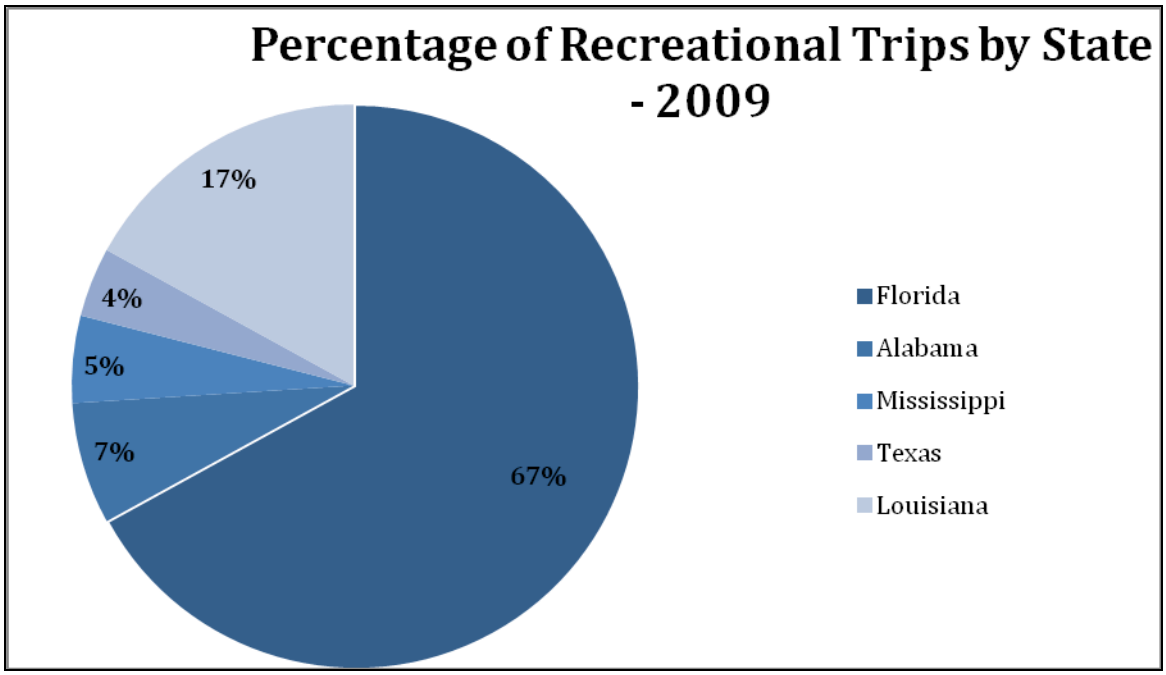

Figure 1. Percentage of recreational trips for each state within the Gulf of Mexico ("State of the Coast: The Gulf of Mexico At a Glance (A Second Glance)", 1-58)

In 2011, recreational anglers took 513,564 trips for red snapper ("Gulf of Mexico Regional Summary", 1-22). Considering the short, 49-day season, the number of recreational trips reflects how important the red snapper is for the GOM. Furthermore, recreational anglers continue to exceed their TAC, as seen in Table 3, which is a primary driver of the decreasing season length. To contrast, the commercial sector does not exceeded their TAC, as seen in Table 4.

[10] Whole weight is a measurement of the fish as caught.

[11] Gutted weight is a measurement of the fish without its gills and guts.

It is important to note that, within the recreational sector, private anglers are increasing relative to the for-hire sector. In 2011, private anglers landed approximately two times as many red snapper than the for-hire sector. This has significant implications for the management of the recreational fishery; with sector separation, each of these angler groups would have specific regulations more tailored to the landings and number of anglers within each group.

Table 3. Recreational red snapper landings and overages (in million pounds whole weight) in the Gulf of Mexico by sector ("Sector Separation Discussion Paper", 1-24)

Year	Private	Charter	Headboat	Total Landings	TAC	Overages[12]
2005	1.88	1.68	0.53	4.08	4.47	-8.6%
2006	1.78	1.67	0.58	4.02	4.47	-10.0
2007	2.29	1.66	0.49	4.44	3.16	+40.6%
2008	2.13	1.17	0.41	3.71	2.45	+51.5%
2009	2.62	1.20	0.81	4.62	2.45	+88.8%
2010	1.35	0.46	0.43	2.24	3.40	-34.2%
2011	3.02	0.95	0.63	4.59	3.87	+18.9%

Table 4. Gulf of Mexico commercial red snapper landings and overages (in pounds whole weight) ("Framework Action to Set the 2013 Red Snapper Commercial and Recreational Quotas and Modify the Recreational Bag Limit " 1-79)

Year	Total Landings (million pounds)	TAC (million pounds)	Overages
2005	4.10	4.65	-11.8%
2006	4.65	4.65	0.0%
2007	3.18	3.31	-4.1%
2008	2.48	2.55	-2.7%
2009	2.48	2.55	-2.6%
2010	3.39	3.54	-4.2%
2011	3.59	3.66	-1.9%

IV. Sector Separation

For-hire and private anglers are currently managed as one regional group. However, private and for-hire anglers behave differently, exhibit different amounts of effort on the red snapper fishery, and have varying opinions on the resource. These (and other) differences are significant enough to support a division of the recreational sector to allow for more appropriate management regulations.

One difference between for-hire and private anglers is the number of anglers permitted in each group. Currently, there is a moratorium on the number of federal recreational red snapper permits distributed to for-hire anglers. In contrast, there

[12] A "+" denotes the amount a sector goes over their TAC; a "-" denotes the amount a sector was under their TAC.

is no limit on the number of state permits and licenses distributed to private anglers. Another difference between these two angler groups is the variance in reliance on the fishery. Generally speaking, for-hire anglers own fishing businesses and are partially dependent on the red snapper fishery for their livelihood. In contrast, private anglers participate in the red snapper fishery as a source of recreation. However, it is important to consider the cultural importance of the fishery and that the boundary between these two sectors is somewhat fluid; for example, a private angler may also operate a charter boat. This only further complicates the management of the fishery.

These differences between the for-hire and private anglers suggest that each group could be more successfully managed with regulations tailored to each sector. Specifically, since the for-hire sector is already federally regulated, it will be easier to monitor their landings and overages when managed as their own group. This is why the GMFMC is considering further dividing the recreational red snapper fishery into a private angler group and a for-hire angler group. The first formal discussions of splitting the recreational sector occurred at a GMFMC workshop in November 2010. Prior to this workshop, regional stakeholders expressed interest in learning about how dividing a recreational fishing sector worked in other fisheries ("Summary Report: Gulf of Mexico Sector Separation Workshop" 1-16). While sector separation has not been implemented on a scale as large as the recreational red snapper fishery in the GOM, there are a few case studies of sector separation on smaller fisheries.

The case study that best applies to GOM red snapper is sector separation within the striped bass (*Morone saxatilis)* fishery in Maryland. A separate TAC was given to the for-hire anglers. However, unlike GOM red snapper, the striped bass fishery was completely closed in the 1980s due to overfishing. Thus, when the fishery reopened in 1990, the for-hire allocation was the result of a TAC calculation from both the private and commercial sectors. After four years of sector separation, the fishery recovered enough for the private and for-hire anglers to recombine their quotas; the increased stock levels made it safe for the fishery to return to recreational management under one sector and one TAC allocation. While the GOM recreational red snapper fishery is different from these examples, it is important to consider real-world applications when analyzing potential impacts of sector separation ("Summary Report: Gulf of Mexico Sector Separation Workshop" 1-16).

V. Conclusions

Overall, there is a lack of literature surrounding the impacts of sector separation on the recreational fisheries, and this confusion is only furthered by the large impact the GOM recreational red snapper fishery currently has on the region. When analyzing the potential biological and economic changes that sector separation may bring, it is important for managers to consider the history of fisheries management in the United States, the prominence of the fishing industry within the GOM, and the biology of the red snapper; with a comprehensive understanding of these topics, managers can craft cohesive policies that will best impact the fishery.

Methodology

Changes in fisheries management facilitate biological, economic, and social consequences. A three-pronged approach was developed to examine the effects of multiple policy options on the red snapper fishery and its stakeholders. Four of these options are based on Total Allowable Catch (TAC) allocations, and the fifth is based on a tradable permit system. Our approach included an age-structured biological model, an economic model at an aggregate scale, and a survey to establish the attitudes and knowledge of the fishermen.

Since the effects of sector separation on the recreational fishery could vary depending on the allocation of catch, four proposed allocations scenarios were analyzed. It is important to mention that current TAC allocations between the commercial and recreational sectors were kept at 51% for the commercial sector and 49% for the recreational sector, and adjustments were made only within the recreational sector. The allocations are listed below, with the percentage of TAC for the for-hire (FH) sector following each description.

1. Allocations based on predicted 2013 landings (FH 28)
2. Allocations based on 2011 landings (FH 34)
3. Allocations based on 2005-2011 landings (FH 42)
4. Allocations based on historical (1986-2011) landings (FH 56)

These landings were converted into percentages of TAC the respective sectors would receive:

Table 5. Allocation of Total Allowable Catch (TAC) per sector per scenario

Allocation	Allocation of TAC	TAC – Private	TAC – For-Hire
FH 28	Predicted 2013 landings	72%	28%
FH 34	2011 landings	66%	34%
FH 42	2005-2011 landings	58%	42%
FH 56	Historical landings	44%	56%

We calculated the Allocation FH 28 values by assuming a linear trend of recent (2007 to 2011) landings proportions, as seen in Figure 2.

Each year, the recreational sector goes over their TAC; these constant overages in catch have significant impacts on the economics of the red snapper fishery. It is hard to assign blame to a specific part of the recreational sector, as it is difficult to track precisely who is catching more than they are allocated. Data from 2007 through 2011 was used to calculate the projected TAC overages in 2013.

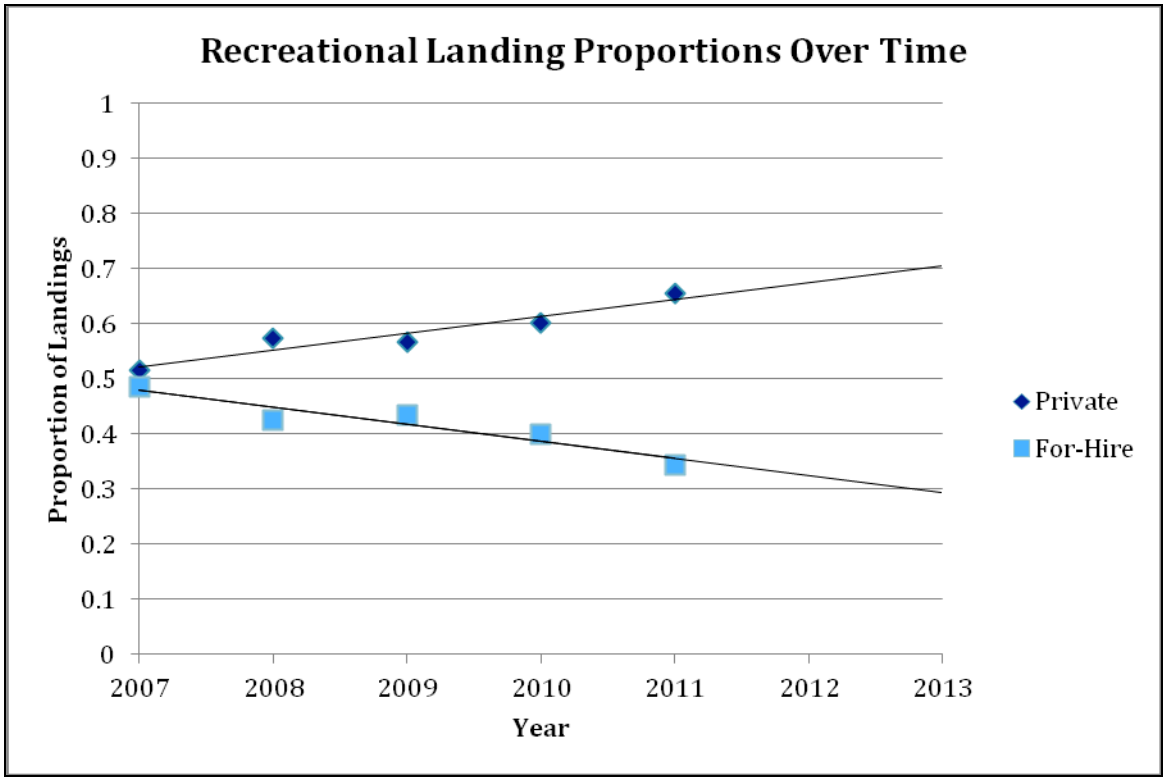

Figure 2. Recreational landing proportions over time used to calculate Allocation FH 28

However, all overage calculations removed data from 2010, as this data is skewed due to the Deepwater Horizon oil spill in the Gulf of Mexico (GOM). To incorporate these overages into our model, we first made several assumptions about the recreational anglers and trips:

1. The same angler behavior seen in 2007-2011 would continue to occur when projected forward
2. The average weight of a red snapper in 2013 would be 7.7 pounds, as predicted by National Oceanographic and Atmospheric Administration (NOAA)
3. The for-hire industry is held to their TAC
4. Anglers caught two red snapper per trip[13]
5. In 2013, charter boats accounted for 48.7% of the allocated for-hire TAC, while headboats accounted for 51.3% (as seen in Figure 3)

[13] In 2011, anglers caught an average of 1.5 red snapper ("Sector Separation Discussion Paper," 1-22). Thus, this assumption of two fish per trip is an overestimation of the success of recreational anglers in the GOM.

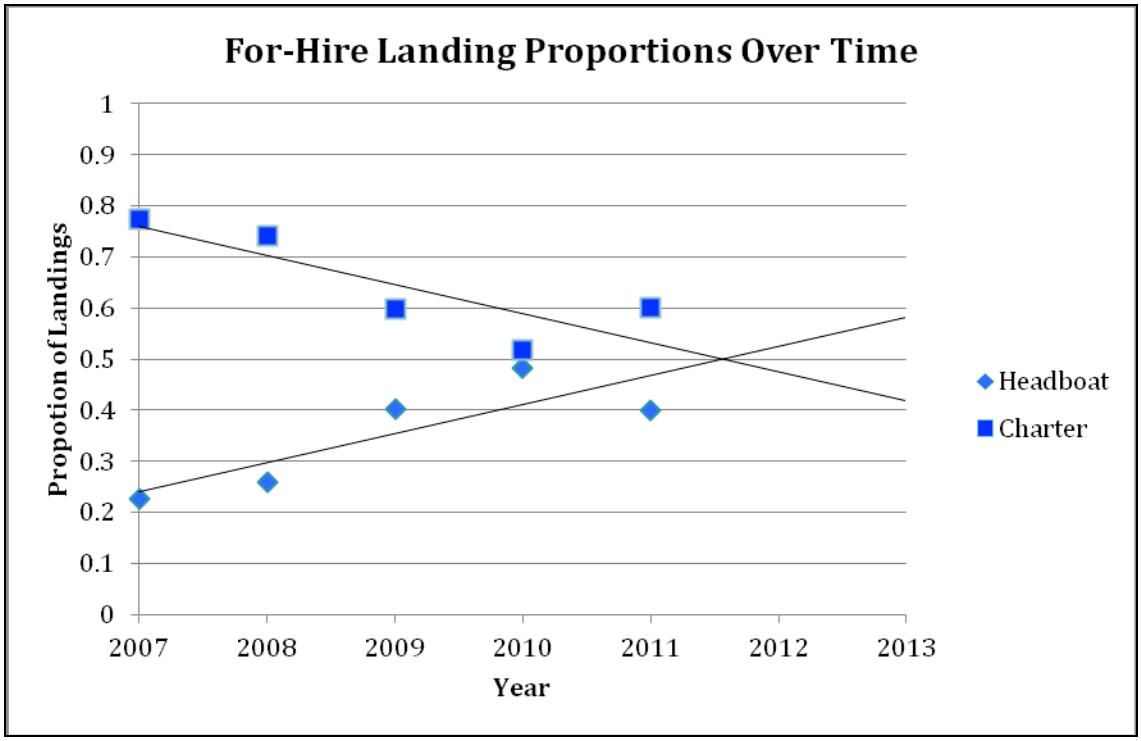

Figure 3. For-hire landing proportions over time used to calculate charter and headboat participation in 2013

Based on these assumptions, the TAC overage in the recreational sector in 2013 will be 49.6%. To best understand how overages will impact the fishery under sector separation, we looked at four different overage scenarios:

1. TAC overage attributed entirely to the private sector
2. TAC overage based on proportion of predicted landings for 2013 (whichever sector is catching more will be causing more of the overage)
3. TAC overage evenly split between the private and for-hire sectors
4. TAC overage attributed entirely to the for-hire sector

Each of these scenarios was then further analyzed with the following management schemes:

1. Current management regulations with season limit, bag limit of two fish per day, and 16-inch minimum size
2. Individual Transferrable Quota (ITQ) system

Furthermore, the results of these scenarios were compared to Status Quo (SQ), which has allocations to the commercial and recreational sectors in tandem with a season limit, two fish bag limit, and 16-inch minimum size for the recreational fishery.

Bio-economic fisheries simulation modeling has become the standard for the

analysis of policy effects on fisheries. With a biological sub-model, an economic sub-model, and a policy component, this model seeks to incorporate all aspects of a fishery and provide the best method of analysis.

Because the value of recreational fishing is not fully captured in markets, other methods, such as revealed and stated preference data, must be used to estimate recreational demand. Since the survey in this project did not capture this data, stated preference data from two studies were used. One study estimated the willingness-to-pay (WTP) for fish caught and kept, as well as for fish caught and released (due to minimum size or bag limit) (Carter and Liese, 2012). Another study surveyed the WTP of fishermen in Alabama to take a recreational fishing trip (Ojumu, Hite and Fields, 2007). Although the last study included all fishermen who take trips in both fresh and saltwater, it was accepted as providing the best estimate of the choke price, or the price an angler is willing to pay to take a recreational fishing trip. With a change in management, there can be an improvement in expected fishing quality and this increase can be contributed to recreationalists who initially do not take recreational red snapper fishing trips but later take a positive number of trips. Policymakers can use these results to design regulations to maximize gains for all stakeholder groups (Gillig *et al*, 2000). Furthermore, economic gains could be made with improved allocations. With sector separation, there could be an improvement in the allocations between the for-hire and private sectors (Agar and Carter, 2012).

I. Biological Model

A biological model was created using both independent and dependent variables from the GOM red snapper fishery, as well as biological parameters determined by SEDAR, NOAA, and previous research. By projecting the model forward to 2032, the outputs of the proposed scenarios can be compared to the outputs of the SQ. The biological model used is an age-structured model, which is commonly used to examine the status of a fishery by separating the population into a number of age classes and incorporating parameters such as growth, natural and fishing mortality, and fecundity (Tahvonen, 2010).

One of the stipulations of this model is to ensure that the Spawning Potential Ratio (SPR) meets the minimum acceptable percentage as defined by the Gulf of Mexico Fishery Management Council (GMFMC). In 2005, the GMFMC passed Amendment 22, which dealt with the biological goals of the GOM reef fish fishery. To be compliant with the SFA, the target rebuilding date was extended to 2032 ("Final Amendment 22 to the Reef Fish Management Plan to Set Red Snapper Sustainable Fisheries Act Targets and Thresholds, Set a Rebuilding Plan, And Establish Bycatch Reporting Methodologies for the Reef Fish Fishery ", 1-218). By standards set in the Sustainable Fisheries Act (SFA), a fishery is considered rebuilt when the stock has an SPR of 26 percent. Thus, one of the most important pieces of the biological model was meeting this federal regulation and safeguarding the growth and rebuilding efforts of the GOM red snapper fishery.

Fisheries data is obtained via stock assessments, which are conducted to gain a better understanding of the condition of the fishery and whether or not new management needs to be implemented. In 2005, the Southeast Data, Assessment, and Review (SEDAR) completed the first GOM red snapper stock assessment. This stock assessment designated that the red snapper fishery was both overfished[14] and undergoing overfishing.[15] In the 2009n an abbreviated stock assessment was conducted and the results indicated that the GOM red snapper stock is no longer undergoing overfishing. This change allowed managers to increase the TAC in both the commercial and recreational sectors. The next red snapper stock assessment is due to be released in 2013. This report is highly anticipated by stakeholders, as the GMFMC has put further discussions regarding sector separation on hold until the release of the report.

i. Parameter Definitions

To build our model, we used parameters established by the Southeast Fisheries Science Center (SFSC) and the South Atlantic Fishery Management Council (SAFMC). SAFMC developed the SEDAR process to improve the accuracy of stock assessments. Table 6 defines all parameters used in our age-structured model. In our age-structured model, the following values from the most recent SEDAR workshop were used, as shown in Table 7.

For all scenarios, the lengths, weights, vulnerabilities, and fecundities across all class years were kept constant. Age classes were set from age zero to age 20 "plus". Fish at age 20 and above are difficult to differentiate from one another. Given the selectivity of the fishery, these fish are grouped together within the stock; this is reflected in the "plus" group. A fish's size can be estimated using the Von Bertalanffy growth model, which estimates the length of fish at age a and is denoted by the following equation:

$$l_{a=} L\infty \ (1\text{-}e^{-K(a-a_0)})$$

In order to estimate weight in pounds at length l at age a, the following equation was used:

$$w_a=al_a^b$$

where both a and b are parameters used in the relating weight (in pounds) as a function of total length (in inches). The population of a stock is affected by both natural and fishing mortality. Fishing mortality can be further broken up into several categories, including commercial and recreational harvest, discards from

[14] A stock that is overfished is defined as a stock below the minimum threshold, which is determined by the number of spawners necessary to sustain the population, the minimum size of individuals being extracted, or the number of individuals that keep an ecosystem functioning in its original state (Pauly, 1984).

[15] Overfishing is defined as "a level of fish harvesting that is higher than that of economic efficiency; harvesting more fish than necessary to have maximum profits for the fishery" (Blackhart *et al*, 2006).

both the commercial and recreational fishery, and shrimp trawling. Because of current management regulations and fishing practices, the vulnerability of the red snapper stock to the commercial sector is different than the vulnerability to the recreational sector. In the model, the vulnerability for different ages classes and each sector was determined by the following equation:

$$v_a = \frac{1}{1 + e^{-\ln(19)[(l_a - s_{50})/(s_{95} - s_{50})]}}.$$

These curves are logistic and are symmetric around the s_{50} inflection point.

Table 6. Age-structured model parameter definitions

Parameter	Definition
$\mathbf{R_0}$	Virgin recruit population
$\mathbf{N_{t,a}}$	Number of fish at age *a* at time *t*
$\mathbf{SB_t}$	Spawning biomass during time *t*
$\mathbf{TB_t}$	Total biomass during time *t*
$\mathbf{XB_t}$	Biomass during time *t* for vulnerability vx_a
$\mathbf{vx_a}$	Vulnerability of biomass at age *a*
$\boldsymbol{l_a}$	Length of age *a*
$\mathbf{w_a}$	Weight at age *a*
$\mathbf{m_a}$	Maturity of age *a*
$\mathbf{M_a}$	Natural mortality of age *a*
h	Steepness
Θ	Stock recruitment parameter
L∞	Maximum length of average individual
K	Von Bertalanffy growth parameter
$\mathbf{t_0}$	Length at age 0
$\mathbf{s_{50}X}$	Age at 50% vulnerability for sector X[16]
$\mathbf{s_{95}X}$	Age at 95% vulnerability for sector X
$\mathbf{m_{50}X}$	Age at 50% maturity for sector X
$\mathbf{m_{95}X}$	Age at 95% maturity for sector X
ux	Harvest rate

Regulations that dictate minimum size limits cause undersized fish to be discarded, both dead and alive. Because the commercial and the recreational sectors have different minimum size regulations, different ages will have different associated discard values. The commercial minimum size limit is set at 13 inches, which red snapper reach at age three.

[16] X represents the particular portion of the stock that has it's own vulnerability. This includes commercial, c, recreational, r, for-hire, f, private, p, dead discards, d, live discards, ld, and shrimp trawling bycatch, s.

Table 7. Parameters for the biological model

Parameter	Definition	Value
$\mathbf{R_0}$	Estimate of virgin recruits	165,000,000
$\mathbf{M_x}$	Natural Mortality rate for age class *x* (M_2 represents age classes two and greater)	M_0= 0.5 yr^{-1} M_1= 0.3 yr^{-1} M_2= 0.1 yr^{-1}
K	Von Bertalanffy growth model parameter to show how fast fish is approaching the average maximum length of fish (L∞)	0.220
$\mathbf{L_{inf}}$ **(L∞)**[17]	Average maximum length of fish	34.522 inches
$\boldsymbol{t_0}$	Initial time of measurement of fish	0.366
a	Parameter used in the equating weight (lbs) as a function of total length (in) in equation $y=ax^b$	0.0004398
b	Parameter used in the equating weight (lbs) as a function of total length (in) in equation $y=ax^b$	3.056

Thus, it was assumed that 50% of age one and 100% of age two snapper are vulnerable to being caught and discarded by the commercial sector due to size restrictions (age two snapper were considered more vulnerable, as they are larger and more susceptible to being caught by hook and line). The minimum size limit for the recreational sector is 16 inches. Therefore, it was assumed that 50% of age one, 100% of age two, and 80% of age three snapper are vulnerable to being caught and released by the recreational sector; we estimated these percentages knowing that age four snapper could be kept by anglers, as they meet the minimum size requirement. When released alive, the average mortality rate of red snapper in the commercial sector is 0.77, while the recreational sector has an average rate of 0.28 (Linton, 2013).

Within the red snapper fishery, young fish are vulnerable as bycatch from shrimp trawling, and this impact is accounted for in the model. Only age zero and age one

[17] SEDAR suggests that both K and L∞ should be used with caution, as they should be fit to the available age data as needed. For this report, the 2005 data is the most updated information available and these are the values used throughout the model.

snapper are vulnerable to shrimp trawling. According to SEDAR, "the shrimp fishery annually removes roughly 25-45 million fish, mainly from the western Gulf in recent years" ("Stock Assessment of Red Snapper in the Gulf of Mexico", 1-224). It was assumed 100% of both age zero and age one red snapper are vulnerable to the shrimp trawling.

Maturity[18] and fecundity[19] are also important elements of an age-structured model. As a fish gets older, it becomes more fecund until a maximum fecundity level is reached. Because of this changing attribute, each age class has a different maturity, which is determined by the following equation:

$$m_a = \frac{1}{1 + e^{-\ln(19)[(l_a - m_{50})/(m_{95} - m_{50})]}}.$$

Similar to the vulnerability curves, the shapes of the maturity curves are logistic and symmetric around the m_{50} inflection point.

ii Virgin Population

Understanding the virgin population (or population of fish prior to fishing) gives managers a baseline value to work with when analyzing fish stocks. The Beverton-Holt equation is used to determine the number of recruits (Hilborn and Walters, 2003). This equation incorporates steepness, which is "the fraction of recruitment from an unfished population obtained when the spawning stock biomass is 20% of its unfished level" (Mangel *et al*, 2009). In the equation, steepness is a parameter valued between zero and one, denoted by *h*.

The recruits for the year are calculated with respect to the spawning biomass from the previous year:

$$R(t) = f(SB_{t-1}) = \frac{0.8R_0 h SB_{t-1}}{0.2\Theta R_0(1-h) + (h-0.2)SB_{t-1}}$$

In 2005, SEDAR estimated that the virgin (prior to fishing) recruit population for red snapper was 165,000,000 fish (Stock Assessment Report of SEDAR 7 Gulf of Mexico Red Snapper", 1-480). This was used as our initial R_0 value in our biological model.

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[18] Maturity is defined as "the ability, on average, of fish of a given age or size to reproduce. Maturity information, in the form of percent mature by age or size, is often used to compute spawning potential" (Blackhart *et al*, 2006).

[19] Fecundity is defined as "the potential reproductive capacity of an organism or population expressed in the number of eggs (or offspring) produced during each reproductive cycle. Fecundity usually increases with age and size. The information is used to compute spawning potential" (Blackhart *et al*, 2006).

iii. Harvest and Discard Rates

Since the GOM red snapper fishery is exposed to pressure from millions of anglers, it is subject to high harvest levels and similarly high discard rates. These are important to consider when creating age-structured models; eliminating these rates from a biological model would be removing a hugely important aspect of the fishery from the calculations. After the last stock assessment, it was estimated that the SPR was four percent for the eastern GOM and 16 percent for the western GOM (Linton, 2013). Excel Solver was used to manipulate the various historical harvest rates to reflect a current SPR of four percent. Since the model assumes that red snapper in the GOM is one stock, the four percent SPR was used as the current SPR to evaluate the situation under a "worst case" scenario. Every time Solver is run, the calculations can change, as the software randomizes the optimizations of these parameters. For our calculations, the values that remained constant for our allocation scenarios were the historical commercial harvest rate, the commercial discard rate (both live and dead), the mortality due to shrimp trawling rate, and the closed season discard rate; the recreational harvest was divided into private and for-hire harvest rates. Each element of impact on the fishery, including commercial and recreational catch, shrimp discards, dead discards for both the recreational and commercial sectors, and live discards for both the recreational and commercial sectors, has a different rate associated with it. Under each scenario, the for-hire and private sectors each had their own catch and discard rates.

From 2006 to 2012, new harvest rates were used to simulate the actual history of the fishery. To achieve harvest rates that best fit the historical data, sums-of-squares (SSQ) was calculated. The SSQ is calculated by the following equation:

$$SSQ = \Sigma_t(\text{obervation}_i - \text{predicted}_i)^2$$

SSQ is a tool that tests to see how well the model's predicted numbers match the actual data. The smaller the SSQ, the better fit the model is to the data. These rates were continued until 2032 for SQ.

Lastly, in years 2013 through 2032, a third set of harvest rates were used to forecast the future of the fishery under the four allocation scenarios. Rates for commercial harvest and discards (both live and dead) and shrimp bycatch were kept constant from the 2006 to 2012 time period. The rates of harvest were matched to the predicted landings using the allocation scenarios based on the 2013 TAC.

iv. Numbers-At-Age

Within a fish population, there are three main groups to be considered: recruits (a=1), intermediate ages ($1<a\leq a_x$), and the plus group (a=x). These three groups best reflect the comprehensive age structure of the red snapper fishery. The following equations represent the three age groups:

$$N_{t,a} = \begin{cases} f(SB_{t-1}) & a=1 \\ N_{t-1,a-1}(1-(uc_{t-1}vc_{a-1}+ur_{t-1}vr_{a-1}+ ucld_{t-1}vcd_{a-1} + urld_{t-1}vrd_{a-1}+ ucd_{t-1}vcd_{a-1}+ urd_{t-1}vrd_{a-1}+us_{t-1}vs_{a-1}))e^{-M} & 1<a\leq a_x \\ N_{t-1,a-1}(1-(uc_{t-1}vc_{a-1}+ur_{t-1}vr_{a-1}+ ucld_{t-1}vcd_{a-1} + urld_{t-1}vrd_{a-1} + ucd_{t-1}vcd_{a-1}+ urd_{t-1}vrd_{a-1}+us_{t-1}vs_{a-1}))e^{-M} + N_{t-1,x}(1- (uc_{t-1}vc_a+ur_{t-1}vr_a+ ucld_{t-1}vcd_a + urld_{t-1}vrd_a + ucd_{t-1}vc_a+ urd_{t-1}vr_a+us_{t-1}vs_a))e^{-M} & a=x \end{cases}$$

When examining the effects of three sectors as opposed to two sectors in SQ, additional parameters need to be included to account for the individual impacts. Instead of a single harvest and discard rate for the entire recreational sector, we incorporated separate harvest and discard rates for the private and for-hire sectors, denoted by "p" and "f" in the equation below:

$$N_{t,a} = \begin{cases} f(SB_{t-1}) & a=1 \\ N_{t-1,a-1}(1-(uc_{t-1}vc_{a-1}+uf_{t-1}vr_{a-1}+ up_{t-1}vr_{a-1} + ucd_{t-1}vc_{a-1}+ ufd_{t-1}vr_{a-1}+ upd_{t-1}vr_{a-1}+ ucld_{t-1}vc_{a-1}+ ufld_{t-1}vr_{a-1}+ upld_{t-1}vr_{a-1} +us_{t-1}vs_{a-1}))e^{-M} & 1<a\leq a_x \\ N_{t-1,a-1}(1-(uc_{t-1}vc_{a-1}+uf_{t-1}vr_{a-1}+ up_{t-1}vr_{a-1} + ucd_{t-1}vc_{a-1}+ ufd_{t-1}vr_{a-1}+ upd_{t-1}vr_{a-1} + ucld_{t-1}vc_{a-1}+ ufld_{t-1}vr_{a-1}+ upld_{t-1}vr_{a-1} + us_{t-1}vs_{a-1}))e^{-M} + N_{t-1,x}(1- (uc_{t-1}vc_a+uf_{t-1}vr_a+ up_{t-1}vr_a + ucd_{t-1}vc_a+ ufd_{t-1}vr_a+ upd_{t-1}vr_a + ucld_{t-1}vc_a+ ufld_{t-1}vr_a+ upld_{t-1}vr_a + us_{t-1}vs_a))e^{-M} & a=x \end{cases}$$

v. Biomass

Spawning biomass is the amount of fish that are able to reproduce at time *t* and age *a*:

$$SB_{t,a}=N_{t,a}w_a m_a$$

Each harvest rate affects a particular biomass at time *t* and age *a*. For SQ, this includes both commercial and recreational biomass that is capable of being harvested by the sector at time *t* and age *a*, both commercial and recreational discard biomass that is capable of being discarded (alive or dead) at time *t* and age *a*, and shrimp bycatch biomass that is capable of being caught at time *t* and age *a*. For each of the scenarios, these are the same biomass types, except that the recreational sector is replaced by the for-hire and private sectors.

$$XB_{t,a}=N_{t,a}w_a vx_a$$

Total biomass is the total amount of fish in the population at time *t* and age *a*:

$$TB_{t,a}= N_{t,a}w_a$$

II. Economic Model

The application of sector separation as a management tool in the red snapper recreational fishery has the potential to affect both the profits of the for-hire industry and the welfare or utility that consumers and private anglers receive. Therefore, the impacts to these sectors must be examined with respect to the benefits and costs associated with an angler-trip. The charter, headboat, and private groups were all analyzed on an aggregate scale for changes in supply, demand, and welfare.

i. Supply

Firms working in the for-hire industry are subject to both fixed and variable costs. Fixed costs include hull and superstructure, engine, electronics, equipment and tackle, docking fees, bookkeeping services, advertising and promotion, insurance, and permits and licenses (Stoll *et al*, 2002). Variable costs include the wages and salaries, maintenance and repair, fuel and oil, bait, food and drink, and ice associated with an angler trip (Stoll *et al*, 2002). Both the fixed and variable costs differ between the charter and headboat industries because of their financial and material sizes.

Charter boats are assumed to have a horizontal marginal cost curve. Within the recreational red snapper season, there is little reason for change in variable costs for each additional angler-trip to occur. The recent short season lengths and the associated trips are assumed to not cause extensive wear on the boat or lead to large fluctuations in oil prices. Anglers do not pay any more to go out on an additional fishing trip than they would to go out on the assumed average number of trips within the red snapper season, which yields a horizontal marginal cost curve. The following assumptions were made for the charter industry:

1. Charter vessels took 48.7% of the total for-hire trips
2. Anglers took one trip per day
3. Anglers caught the maximum of two fish per day
4. Charter boats have an angler capacity of six passengers, and this capacity was met every trip

Using the values generated in a 1997 survey (Stoll *et al*, 2002), we used the Consumer Price Index to calculate the value in 2013 dollars, as seen in Tables 8 and 9.

Table 8. Fixed costs for charter boat industry

Cost Type	Dollars ($) per Unit
Cost per day	$124.28 per day
Average cost per angler	$20.71 per angler

Table 9. Variable costs for charter boat industry

Cost Type	Dollars ($) per Unit
Cost per day	$170.12 per day
Average cost per angler	$28.35 per angler

Unlike charter boats, the headboat industry is characterized by having a large range of angler capacities, or number of passengers each vessel can safely hold. Headboats can carry up to 150 passengers (Ditton *et al,* 1992). In 2012, 79 headboats had permits to operate within the GOM ("Framework Action to the Fishery Management Plans for Reef Fish Resources of the Gulf of Mexico and Coastal Migratory Pelagic Resources of the Gulf of Mexico and South Atlantic Headboat Electronic Reporting Requirements", 1-15). Different sized firms exist within these 79 vessels due to regional cost differences (such as minimum wage, gasoline, cost of bait, etc.) and the profit margin available to each permit holder (smaller boats will have a lower profit margin). To incorporate this facet of the sector into the model, fixed and variable costs per angler trip were calculated for vessels with passenger capacities of 50, 100, and 150 passengers; this captures low cost, medium cost, and high cost firms. For the headboat calculations, the same 1997 survey utilized in the charter boat costs calculations (Stoll *et al,* 1997) was used, as seen in Tables 10 and 11.

Table 10. Fixed costs for headboat industry

Cost Type	Dollars ($) per Unit
Total Cost for GOM Fleet	$273.50 per day
Average cost per angler – low	$5.47 per angler
Average cost per angler – medium	$2.74 per angler
Average cost per angler - high	$1.82 per angler

Table 11. Variable costs for headboat industry

Cost Type	Dollars ($) per Unit
Total Cost for GOM Fleet	$515.91 per day
Average cost per angler – low	$10.32 per angler
Average cost per angler – medium	$5.16 per angler
Average cost per angler - high	$3.44 per angler

We made the following assumptions for the headboat sector:

1. Headboats took 51.3% of for-hire trips
2. Anglers only took one trip per day
3. Anglers caught a maximum of two fish per day
4. There were 26 boats at 50 passengers, 27 boats at 100 passengers, and 26 boats at 150 passengers

5. Anglers will first use firms with low operating costs until their capacity is reached and then shift to higher cost firms

These assumptions are similar to those made earlier in our calculations and modeling. Based on current regulations, the only assumption that could change is the number of fish caught per day. Specifically, if anglers caught a maximum of one fish per day, the total number of trips would increase, which would drive up the profits within the headboat industry.

Using this information, we created an aggregated linear marginal cost curve. It was assumed that there was an equal distribution between the three vessel sizes. Boats were assumed to operate at maximum capacity and, therefore, the number of angler-trips for each vessel size was used to calculate when vessels would enter the market. In order to calculate the slope of the aggregated supply, the equation below was used:

$$\beta_2=(y_2-y_1)/(x_2-x_1)$$

where x_1 and y_1 represent one set of coordinates on the supply line, and x_2 and y_2 represent a second set of coordinates on the supply line.

The set of coordinates were the marginal cost associated with the low cost firm at zero trips and the marginal cost of the high cost firm at the maximum number of angler trips for the industry. This resulted in the general supply curve.

$$MC=0.0002x + 3.44$$

Since private anglers are considered consumers, only the variable costs (fuel and oil, bait, and ice) will affect their welfare. After interviewing anglers, we calculated the average variable cost per trip was $168.91. Similar to charter boats, these costs were assumed to change little over the season and therefore produced a horizontal marginal cost curve.

ii. Demand

The recreational sector's demand is for angler-trips, as this is the unit in which a consumer would pay to enter the market. Anglers receive benefit from fishing not only from the catch they keep and the utility they obtain by catching and releasing a fish either due to minimum size or after reaching their bag limit, but also from the experience of going on a fishing trip. We assumed that the demand for fishing trips is a linear function and that anglers have the same preferences. Based on these assumptions, the following equation represents an individual angler's marginal benefit with respect to number of angler-trips:

$$MB=\alpha+\beta_1*\text{catch per trip}+\gamma_1*\text{released fish due to minimum size per trip}+\gamma_2*\text{released fish due to reaching bag limit per trip}+\beta_{2*}\text{trips}$$

Estimations for the parameters found in the marginal benefit/demand equation are listed in Table 12. It is assumed that the elasticity of demand does not change because there are no equivalent substitutions, as "the price elasticity of demand measures how much the quantity demanded responds to a change in price" (Mankiw, 2007). If substitutes for red snapper are available, the demand for the fish will be more elastic.

Table 12. Parameter values for the economic model[20]

Parameter	Value	Standard Error
β_1	1.12	± 0.054
γ_1	1.97	± 0.254
γ_2	1.22	± 0.270

Demand for items and experiences are considered inelastic when there are no substitutes for the item. While other species of snapper and reef fish can be harvested for longer time periods during the year, the excitement associated with red snapper season prevents fishermen from gaining similar utility from another fish. Because of inelasticity of red snapper fishing, the demand curve will only shift parallel as a result from a change in the biological structure of the population. Vulnerabilities, allocation, and continued overfishing will affect the proportion of red snapper caught and released, as well as the release-induced mortality.

The parameter α from the marginal benefit equation represents an angler's WTP for a trip. This value is held constant amongst the charter, headboat, and private industries so that the choke price will shift accordingly with changes in the population structure observed in the age-structured model. Previous research showed that recreational anglers in the GOM are willing to pay $293.33 for a fishing trip (Ojumu, Hite and Fields, 2009).[21] Because the choke price is represented by the following equation, the value of α was then calculated to be $285.93. This calculation was made with the assumption that under SQ, anglers caught the bag limit of two snapper, released two snapper due to the minimum size limit, and released one snapper due to the maximum bag limit.

$$\text{Choke Price} = \alpha+\beta_1*\text{catch per trip}+\gamma_1*\text{released fish due to minimum size per trip}+\gamma_2*\text{released fish due to reaching bag limit per trip}$$

The law of diminishing marginal utility suggests that consumers obtain marginal benefit at a decreasing rate for every additional trip (Mankiw, 2007). In order to estimate the slope of the demand curve for each industry, the following equation was used:

[20] $\beta_1, \gamma_1,$ and γ_2 were estimated via random parameter logit from a 2003 stated preference choice survey of WTP for catch by recreational fishermen (Carter and Liese, 2012).

[21] WTP was estimated for fishermen throughout Alabama in 2007-2008. The Consumer Price Index was used to equate this in 2012 dollars.

$$\beta_2=(y_2-y_1)/(x_2-x_1)$$

where x_1 and y_1 represent one set of coordinates on the demand line, and x_2 and y_2 represent a second set of coordinates on the demand line.

The choke price for the for-hire industry was one point on the demand line: (0, $293.33). The second point used to determine the demand line was: (7.41 and the associated price paid for a trip). 7.41 is the number of fishing trips that anglers were estimated to have taken in 2012 during red snapper season (Agar and Carter, 2012). It was assumed that the same number of trips per angler will be taken in 2013. We conducted an Internet survey to determine the average cost of a charter boat and headboat trip per consumer. Six firms[22] from multiple regions throughout the GOM were used for each sector to determine this cost. The average cost per angler-trip on a charter boat was $205 and the average cost per angler-trip on a headboat was $77. Because private anglers are considered consumers and not producers on their own boats, the points used to determine the demand line of a private angler-trip were the choke price (0, $293.33) and the following point: (7.41, $169.37). $169.37 is the marginal cost associated with a private angler-trip when 7.41 angler-trips are taken. The slopes calculated for each industry are shown in Table 13 below.

Table 13. Values for β_2 for recreational red snapper fishing industry in the Gulf of Mexico

Industry	Value
Charter	-11.92
Headboat	-29.19
Private	-16.73

iii. Aggregation of Demand Curve

To examine the impact of policies on the recreational sector as a whole, the individual demand curves for charter, headboat, and private anglers were aggregated with respect to the number of anglers expected for each industry per allocation and overage scenario. Depending on the allocation and the overage liability, there will be different effects observed on the number of anglers within each sector. This analysis assumes that the for-hire industry will be held to their TAC. Because of this assumption, there will be fewer anglers in the allocations where the additional quota compared to SQ (28%) does not compensate for the loss in overage landings. Furthermore, the larger the allocation a sector receives, the more anglers will be accommodated in that sector, as seen in Tables 14 through 17.

[22] Because there was little variation between companies, only six firms were researched for each industry.

The number of anglers for the status quo was calculated using estimates of angler-trips from 2011 ("2012 Recreational Red Snapper Quota Closure Analysis" 1-17). The number of anglers was also calculated using predicted numbers of angler-trips based on the 2013 recreational TAC of 4,258,000 pounds, and assuming that each angler would take an average of 7.41 trips per season (Agar and Carter, 2012).

Table 14. Number of expected anglers by industry sector for recreational red snapper fishery in the Gulf of Mexico, 100% overage to private anglers

Allocation Scenario	Private	For-Hire	Charter	Headboat
Status Quo	40,080	10,522	5,124	5,398
FH 28	40,080	10,522	5,124	5,398
FH 34	36,647	12,817	6,242	6,575
FH 42	32,457	15,618	7,606	8,012
FH 56	24,628	20,851	10,154	10,697

Table 15. Number of expected anglers by industry sector for recreational red snapper fishery in the Gulf of Mexico, overage split based on landings

Allocation Scenario	Private	For-Hire	Charter	Headboat
Status Quo	36,332	11,994	5,841	6,153
FH 28	36,332	10,522	5,124	5,398
FH 34	33,221	12,817	6,242	6,575
FH 42	29,422	15,618	7,606	8,012
FH 56	22,325	20,851	10,154	10,697

Table 16. Number of expected anglers by industry sector for recreational red snapper fishery in the Gulf of Mexico, overage split 50/50 between private and for-hire anglers

Allocation Scenario	Private	For-Hire	Charter	Headboat
Status Quo	33,435	13,132	6,395	6,737
FH 28	33,435	10,522	5,124	5,398
FH 34	30,572	12,817	6,242	6,575
FH 42	27,076	15,618	7,606	8,012
FH 56	20,545	20,851	10,154	10,697

Table 17. Number of expected anglers by industry sector for recreational red snapper fishery in the Gulf of Mexico, 100% overage to for-hire anglers

Allocation Scenario	Private	For-Hire	Charter	Headboat
Status Quo	26,791	15,742	7,666	8,075
FH 28	26,791	10,522	5,124	5,398
FH 34	24,497	12,817	6,242	6,575
FH 42	21,696	15,618	7,606	8,012
FH 56	16,463	20,851	10,154	10,697

iv. Welfare

The welfare for both consumers and producers was calculated by aggregating the demand and supply curves for each industry. Revenue was also used as a comparison measurement for the for-hire sector because they are a profit-based industry. The equations below express the consumer surplus (CS)[23] for the for-hire and private sectors, respectively:

$$CS_{for\text{-}hire}=0.5(CP-P)(Q_P)$$

$$CS_{private}=0.5(CP-169.37)(Q^*)$$

where CP is the choke price, P is the price paid by the consumer to go on a for-hire boat, Q_P is the quantity of angler trips demanded at price P, and Q* is the equilibrium quantity.[24]

The following equations represent the producer surplus (PS)[25] for the charter and headboat industries, respectively:

$$PS_{charter}= (Q_P)(P-36.91)$$

$$PS_{headboat}= (Q_P)(P)-.5(Q_P)(0.57+slope_{MC}*Q_P)$$

where Q_P is the quantity of angler trips demanded at price P, P is the price paid by the consumer to go on a for-hire boat, and $slope_{MC}$ is the slope of the MC curve associated with the scenario.

Profits are the best measurement to compare the effect of policy changes on the for-hire industry, as they are in a competitive market. The following equation evaluates the profits for each scenario:

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[23] CS is defined as the difference between the value a buyer is willing to pay for the good or service and the actual amount paid for it, for the for-hire and private sectors, respectively (Mankiw, 2007).

[24] Equilibrium quantity is defined as the quantity supplied and demanded at the equilibrium price (Mankiw, 2007).

[25] PS is defined as the difference between the price a seller paid for a good or service and the cost of providing it (Mankiw, 2007).

$$Profit=PS-(FC*N_{trips})$$

where FC is the industry's fixed cost per angler trip and N_{trips} is number of total industry trips at Q_P.

v. Individual Transferable Quotas

After establishing the aggregated demand and supply curves for the for-hire industry, an ITQ market system was evaluated. It was assumed that the quotas would be initially given to anglers currently in the market. Although ITQs are generally allocated in pounds, quota value was estimated per angler-trip. The following assumptions were made for the initial allocation:

1. For each scenario, the allocation of charter and headboat quotas were 48.7% and 51.3%, respectively. Table 18 shows the allocation of angler-trips for each scenario
2. Quotas were allocated based on an average weight of 7.7 pounds per red snapper
3. Each angler caught the maximum bag limit of two red snapper

Table 18. Number of quotas per allocation per sector

Allocation	Charter	Headboat
FH 28	52,011	25,960
FH 34	63,492	31,480
FH 42	77,574	38,153
FH 56	104,078	50,429

Boat owners would be willing to buy or sell their quota at a certain price. This price must be less than the difference between the price demanded by consumers and the marginal cost to the producer at the quota:

$$QP = \gamma + \varepsilon$$

where QP is the quota price in dollars per trip, γ is the price difference of both marginal benefit and marginal cost at the quota, and ε is 0.001, which is a small fraction incorporated to show that the quota owner would only buy or sell if they made some fraction of profit.

In a theoretical market, for-hire anglers would trade quotas in order to maximize profit. Solver was used to maximize profit for the for-hire sector, setting the price of the quota equal for both charter boats and headboats.

With changes in allocation and responsibility of overage, there are shifts in the supply and demand for each sector as the number of both anglers and total angler

trips change. Because the for-hire firms are businesses, profits were used as a common measurement for comparison amongst the scenarios. CS was used as the comparison measurement for the private sector. From this analysis, the effects of implementing an ITQ system in the for-hire industry under sector separation with current bag and size limits can be compared with the status quo management regime.

III. Survey

In order to elicit the attitudes and preferences of the participants in the recreational red snapper fishery, particularly on issues related to management and sector separation, we conducted a survey. We asked respondents to rank what they wanted most out of the recreational red snapper fishery so that we could see if and how sector separation could align with those preferences. Our hypotheses were:

1. Members of the recreational red snapper fishery in the GOM lack enough knowledge about the concept of sector separation, and this limited knowledge inhibits their support of the topic
2. Private anglers will not be in support of sector separation of the recreational red snapper fishery; private anglers have different interests from the rest of the recreational sector and do not deem it necessary to be restrained by a group quota
3. For-hire anglers will be in support of sector separation of the recreational red snapper fishery, and this is due to the possibility of more flexible management versus abiding by the rules of a closed season

i. Sample Design

In order to fully gauge the opinion of the GOM recreational red snapper fishery, we sampled the following groups: the commercial sector, the for-hire sector, and private anglers. A random sample of the population offers the best results, as it is representative of the entire population, reduces the risk of bias, and can have statistical significance. Additionally, a random sample permits the calculation of confidence intervals. Confidence intervals indicate the probability the population average (or other parameters) is within a certain range of the sample's statistics. This ultimately allows the researcher to make inferences about the entire population (Alreck & Settle, 2003).

We used a random sample from three separate databases to target each interest group. For the commercial sector, we used the NOAA Fisheries Service Southeast Regional Office's Individual Fishing Quota Gulf Reef-Fish Shareholder database, selecting only those involved in the red snapper fishery. For the for-hire sector, we used the NOAA Fisheries Service Southeast Regional Office's Record of Gulf of Mexico Charter/Headboat for Reef Fish. Lastly, private anglers were sampled from the Florida state license database. Private anglers are notoriously difficult to sample due to their extensive number and geographic range (Muehlstein, 2013). Due to legal privacy issues, the remaining four GOM states were unable to provide us with their private angler databases.

We assume Florida anglers are representative of private anglers throughout the GOM for the following reasons:

1. Florida has a well-developed recreational fishing industry; its fishing grounds encompass most of the red snapper habitats used throughout the GOM, and Florida anglers also land high volumes of red snapper
2. Both Florida and Texas have nine miles of state waters before reaching the border of the Exclusive Economic Zone (EEZ)
3. Through conversations with state officials, our client, and other regional experts, we came to the conclusion that Florida tends to align its state practices with the three central GOM states (Mississippi, Alabama, and Louisiana); historically, Texas tends to be relatively compliant with federal regulations but does not have similar fishing practices or participate in GOM-wide surveys (Landon *et al*, 2012)

Due to the large number of participants within the GOM recreational red snapper fishery, our budget limited our sample size. We calculated the largest possible sample size that we could reasonably reach, understanding that the larger the sample size, the lower the sampling error. Due to these factors, our sample size was 1,200 participants.

ii. Mail Surveys

The primary method of delivery for our survey was mail. Mail surveys are known to have a low response rate, typically between five and ten percent (Alreck & Settle, 2003). For mail surveys, "the reliability of the data depends on the size of the sample *obtained,* and not the number of surveys sent" (Alreck & Settle, 2003). The ideal delivery method would have been e-mail, but due to legal issues, we were unable to obtain e-mail addresses for our sample population; we also did not want to create additional bias by assuming our sample population used e-mail. Due to time constraints and the size of our sample population, we could not conduct a phone survey.

iii. Allocation and Response Rates

After determining the total number of participants we could sample, we allocated the following percentage of the 1,200 surveys to each sector: 10% to commercial, 30% to for-hire, and 60% to private anglers. Although commercial fishermen are not going to be affected by sector separation in our modeling scenarios, we wanted to solicit their opinion, as the topic is socially and politically divisive. Furthermore, we felt that there would be some crossover between the commercial and for-hire sectors. Lastly, our client requested we allocate some surveys to the commercial sector. Because private anglers are difficult to sample and produce the lowest response rates of the three sectors, we allocated the majority of our surveys to that sector (Muehlstein, 2013).

In order to boost our response rate, we incorporated two additional pieces to our survey. First, we included an incentive and conducted a lottery for a fishing reel. Second, we sent reminder cards[26] to our sample population two weeks after our initial mail-out date; these cards included an invitation to complete the original paper survey or to fill out an online version via Survey Monkey. Survey reminders have been shown to increase response rates by approximately 10% (Alreck & Settle, 2003).

iv. Forced Ranking Scales

The main component of our survey was a forced ranking scale.[27] This scale asked respondents to rank the desired management preference that they would like to be implemented in the recreational red snapper fishery. This scale "indicates what [the respondents'] choices are likely to be from an *ever-shrinking* number of alternatives…the parallel between the actual life choice situation and the measurement format is an advantage of forced ranking" (Alreck & Settle, 2003). The results from this question illustrate what respondents' want most from the recreational red snapper fishery. Our intention was to use these results to understand the attitudes of recreational anglers and, at the same time, to test potential acceptability of sector separation and other management options.

v. Survey Bias

As with any survey, it is important to minimize survey bias as much as possible. As mentioned before, using a random sample helps to reduce survey bias because all relevant participants within the red snapper fishery are included, regardless of their relative abundances. Our survey was crafted to avoid as much survey bias as possible, taking particular care to avoid instrumentation bias, which can occur due to the order of questions or the way questions are worded.

vi. Standard Error

Standard error is dependent on sample size and, when calculated, can "determine the confidence interval around a predicted value of the dependent variable at a given probability" (Alreck & Settle, 2003). Throughout the process, a primary goal of the team was to have as low a standard error as possible. As seen in Table 19, we estimated the standard error of our hypothesized response rates by sector.

Table 19. Survey response rates with standard error, by sector

Sector	Predicted Response Rate	Standard Error
Commercial	15-25%	±0.999992525
For-Hire	15-25%	±0.999992525
Private	6-15%	±0.957442807

[26] Please see Appendix B for a copy of our survey reminder card.

[27] Please see Appendix C for a copy of our survey.

Because angler opinions are important when creating new management, including an opinion survey in this project was necessary to gain an understanding of stakeholder attitudes. Knowing what anglers prefer from the red snapper fishery can serve as a powerful tool to illustrate the potential benefits of a change in management.

Results

Throughout our analysis, for-hire anglers were more tightly regulated under sector separation than private anglers; our models assume that for-hire anglers would stay within their Total Allowable Catch (TAC). Historically, this has not been the case, as both private and for-hire anglers have consistently gone over their TACs for many years. Staying within the TAC is a crucial part of effective management of the red snapper stock, and this was the primary reason we made this assumption in our model. However, despite these restrictions on the for-hire anglers, private anglers lose more economically under sector separation than for-hire anglers. This is important to recognize, especially when thinking of stakeholders who will need to accept sector separation as a viable policy change. However, the flexibility given to for-hire anglers under an Individual Transferrable Quota (ITQ) system could ease this tension.

When analyzing the economic impacts of shifting TAC allocations, as well as the landings overages associated with the recreational red snapper fishery, private anglers will see a reduction in welfare in most of the sector separation scenarios analyzed. The one scenario that private anglers did not lose economic welfare was when they were allocated the landings that they would be expected to catch which incorporated their projected growth. With "FH" representing "For-Hire," Allocation FH 34, Allocation FH 42, and Allocation FH 56 all give private anglers less than what they are currently catch, which is why they would experience economic loses under these allocation scenarios.

I. Biological Results

The age-structured model used in this analysis has three main outputs: spawning potential ratio (SPR), landings, and numbers-at-age. Because there is no way of knowing if the for-hire anglers or the private anglers are contributing to the overage and by how much, four variations of overage assumptions were analyzed. Because the sector contributing to the overages is obtaining welfare benefits gained from exceeding their TAC, thus it was necessary to account for the overage within the model. The overage assumptions analyzed in this report are outlined in Table 20. Under each of the four overage assumptions, four allocation scenarios were then evaluated, as outlined in Table 21.

Table 20. Overage assumptions

Scenario	Percentage Attributed to Private	Percentage Attributed to For-Hire
100% Private	100%	0%
Proportional to Predicted Landings	72%	28%
50%/50%	50%	50%
100% For-Hire	0%	100%

Table 21. Total Allowable Catch (TAC) allocation scenarios

Scenario	Allocation of TAC	TAC – Private	TAC – For-Hire
Allocation FH 28	Predicted 2013 landings	72%	28%
Allocation FH 34	2011 landings	66%	34%
Allocation FH 42	2005-2011 landings	58%	42%
Allocation FH 56	Historical landings	44%	56%

i. Spawning Potential Ratio

SPR is an important output to evaluate because it is what the Gulf of Mexico Fishery Management Council (GMFMC) uses as a management goal. On a rebuilding plan, the defined management goal is to reach 26% SPR by 2032. Thus, when we ran our model scenarios, we modeled out the SPR to 2032 to ensure that a particular scenario did not fall below this management objective.

In our model, running the Status Quo (SQ) (or the current management scenario) out to 2032, we found that the SPR would be 43.06%. While this is significantly higher than the goal set by the GMFMC, it was used as our model baseline against which to compare the various alternative scenarios in our analysis. Overall, we found that no matter the overage assumption or the allocation assigned, all scenarios with sector separation implemented yielded SPRs approximately four percent above the SPR that could be expected under SQ. This result suggests that the evaluated changes would not result in spawning potential biomass below what is being projected by the current management.

Table 22 illustrates the results of running the biological model for the 16 overage and allocation combinations. Regardless of the overage assumption and the allocation, the resulting SPR in year 2032 was approximately 47%, which suggests that neither the overage assumption nor allocation would have an impact on the biology of the stock.

Table 22. Spawning potential ratio (SPR) in 2032

	Allocation FH 28	Allocation FH 34	Allocation FH 42	Allocation FH 56
100% Private	46.71%	46.75%	46.81%	46.91%
Proportional to Predicted Landings	46.85%	46.89%	46.93%	47.01%
50%/50%	46.97%	47.00%	47.03%	47.09%
100% For-Hire	47.25%	47.25%	47.26%	47.27%

Figure 4 is one example of the SPR from a historic virgin level projected out to 2032. The graph shows the decrease from the virgin population, which is representative of the historical overharvesting resulting in the estimated SPR of four percent in the 1980s and 1990s. From 2005 through 2013, harvest rates were changed to reflect the management changes that decreased fishing mortality. The stock begins to rebound in 2005. In 2013, the trajectory of the allocations analyzed increase slightly more than under SQ.

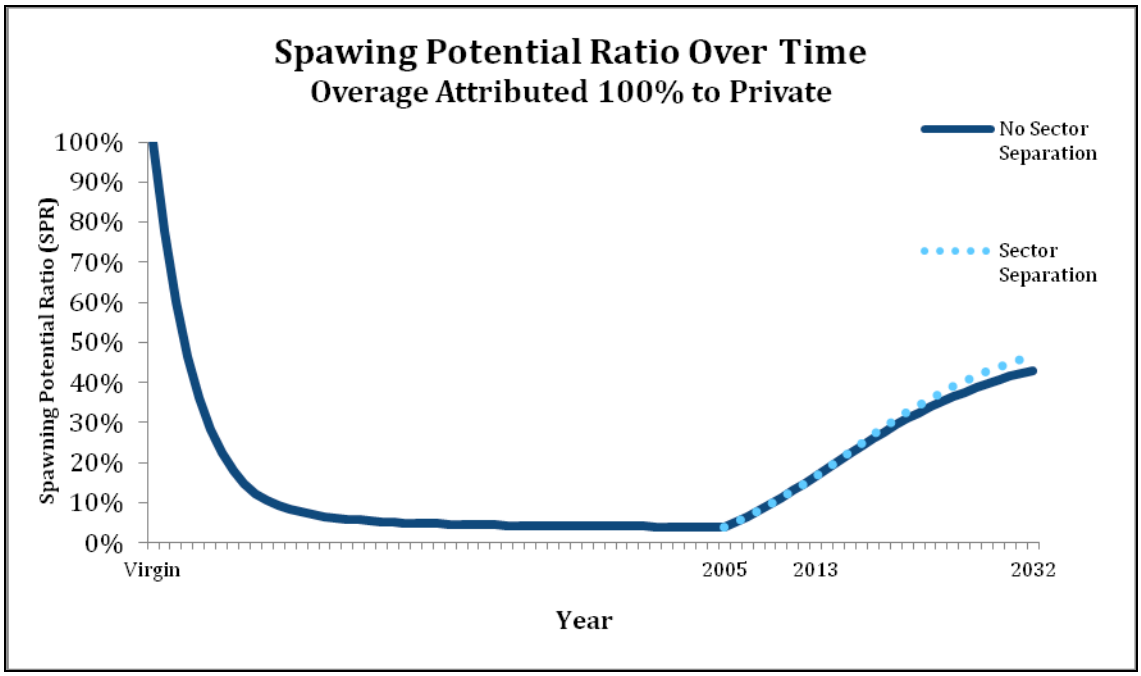

Figure 4. Spawning potential ratio over time with 100% of overages allocated to private anglers

ii. Landings

Red snapper landings were determined to be a biological output of interest because both managers and anglers would want to know the effect on landings from a change in management. Decreased landings results in decreased fishing mortality, which would be biologically beneficial. However, there would be social costs. In our

analysis, we used the trajectory of landings under current management projected to 2032 as a baseline to compare landings under management changes. Scenarios in which the landings by 2032 are greater than that of SQ landings projections would likely be more appealing to stakeholders than the scenarios that would yield landings under SQ trajectories.

Using landings as an output also allowed us to see which sector might be most impacted by sector separation, depending on the assumptions made. Overall, most results illustrated that the private sector would be most impacted. Conversely, sector separation could be more beneficial for the for-hire industry by allowing them to increase their landings over time under certain assumptions and allocations.

a.100% Overage Attributed to Private Anglers

Under the assumption that the private anglers within the recreational sector contribute to all of the catch overage, the for-hire sector would see increased landings by the year 2032 under sector separation and all allocations, as seen in Figure 5. Conversely, the private sector would see a decrease in landings under all sector separation allocation scenarios when compared to SQ, as seen in Figure 6. However, it is important to note that the differences between the status quo and FH28 are primarily due to model assumptions. (The calculation method used for the harvest rate estimations resulted in a slight difference in the rates for these two allocations.) When private anglers are responsible for all of the overage, the for-hire sector reaps the benefits of this overage. With the implementation of sector separation, even with the greatest allocation of 72% of the TAC, the private sector landings would still be less than what they would land under the current management.

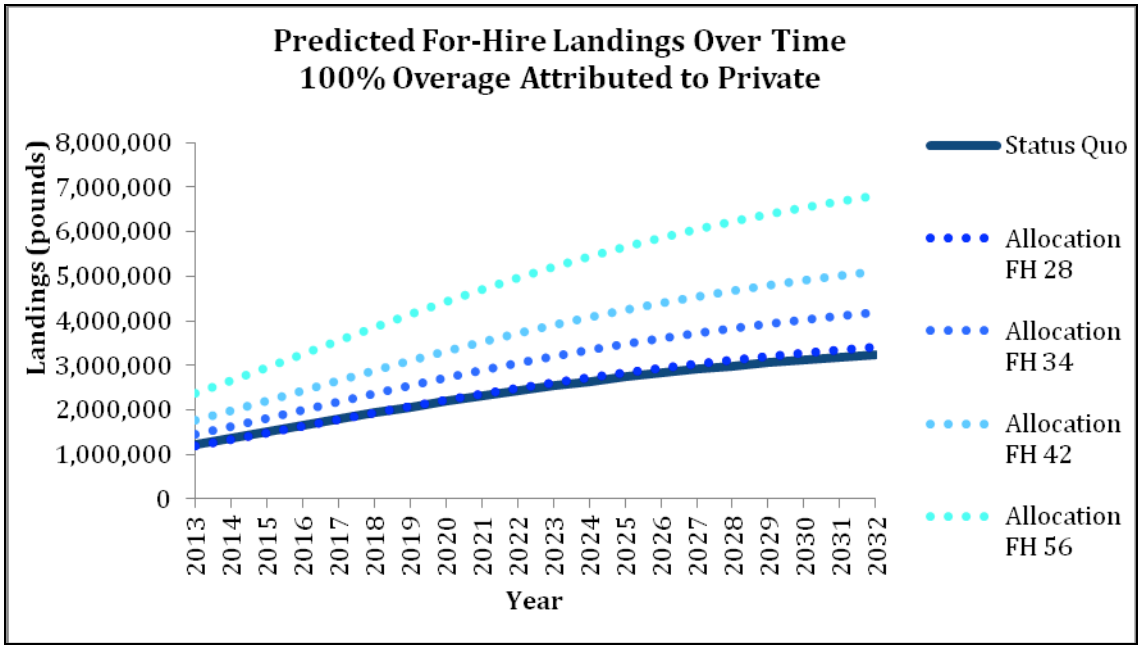

Figure 5. Predicted for-hire landings over time with 100% of overages assigned to private anglers

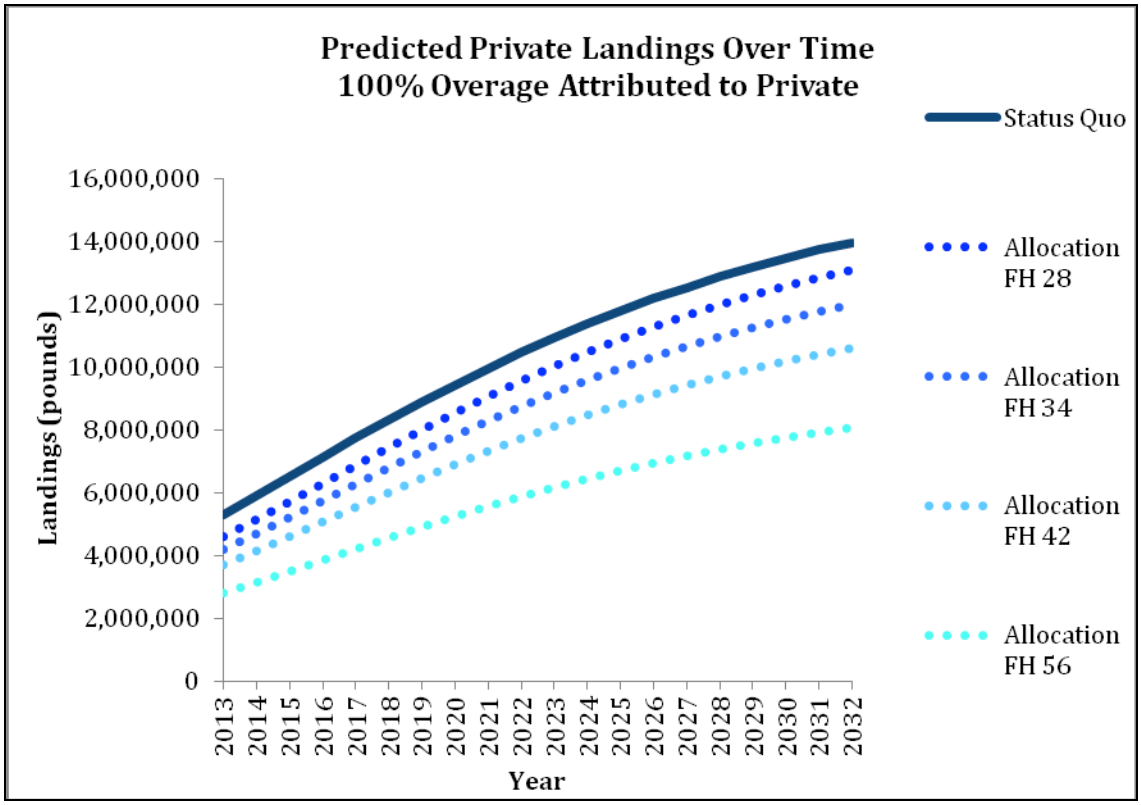

Figure 6. Predicted private landings over time with 100% of overages assigned to private anglers

b. Overage Attributed Proportionally Based On Landings

Private anglers currently land more snapper than anglers on for-hire boats. Thus, the model was run under an assumption that the landings overage that is occurring is proportional to the predicted landings of each sector in 2013. Under this assumption, private anglers would account for 72% of the overage, and the for-hire sector would account for 28% of the overage. Running the model under this assumption for the four allocation scenarios yielded results similar to that of the previous overage assumption in which the private anglers were responsible for all of the overage. Private anglers would again experience a reduction in landings because they would always be restricted further than what they would land under SQ, as seen in Figure 8. Depending on the allocation, for-hire anglers could see an increase in landings by 2032 or a decrease. If the for-hire sector gets larger TAC allocations (specifically, 42% and 56%), they could expect to see an increase in their landings over time, as seen in Figure 7.

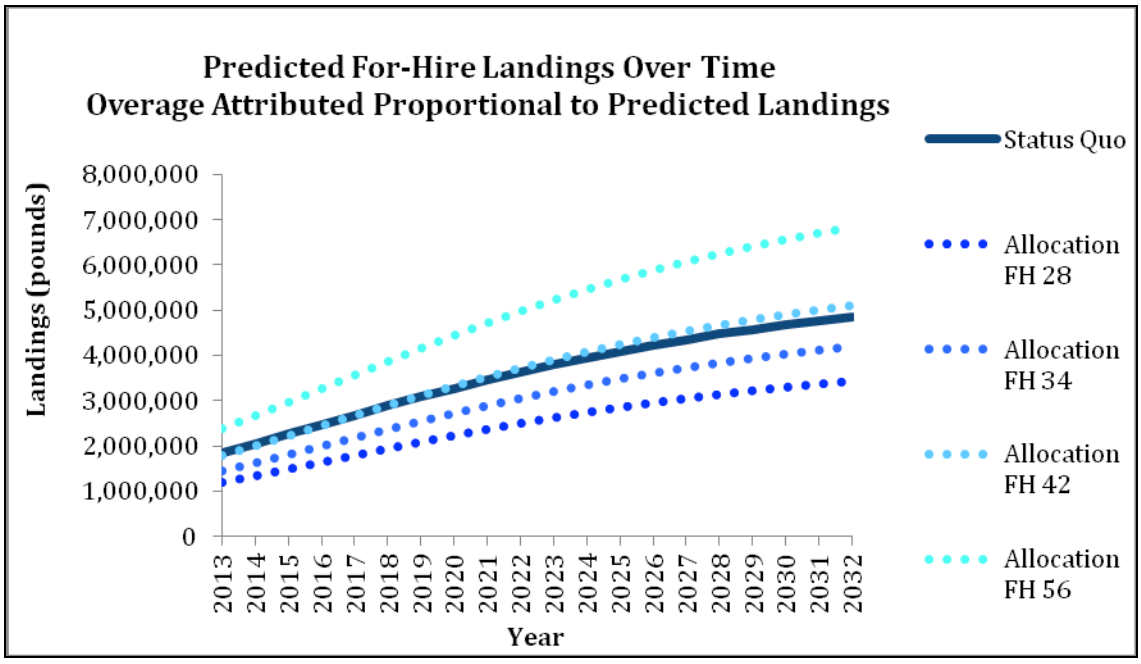

Figure 7. Predicted for-hire landings over time with overages split between private and for-hire anglers based on current landings

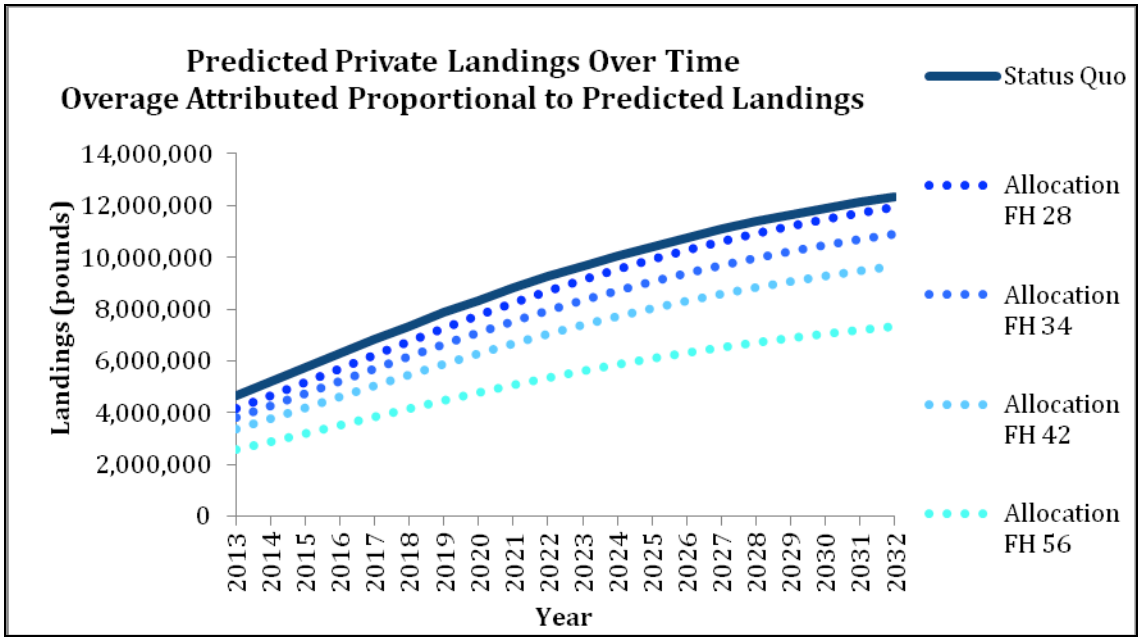

Figure 8. Predicted private landings over time with overages split between private and for-hire anglers based on current landings

c. Overage Attributed 50% Private and 50% For-Hire

The biological model was also run under the assumption that both sectors contribute equally to the landings overages. With this assumption, we found that private anglers would experience decreased landings over the 19-year trajectory under sector separation when compared with landings that would be expected under SQ, as seen in Figure 10. However, with the for-hire sector contributing to more of the overage than the previous scenario, only the greatest allocation of 56% would benefit them with greater landings than the SQ, as seen in Figure 9.

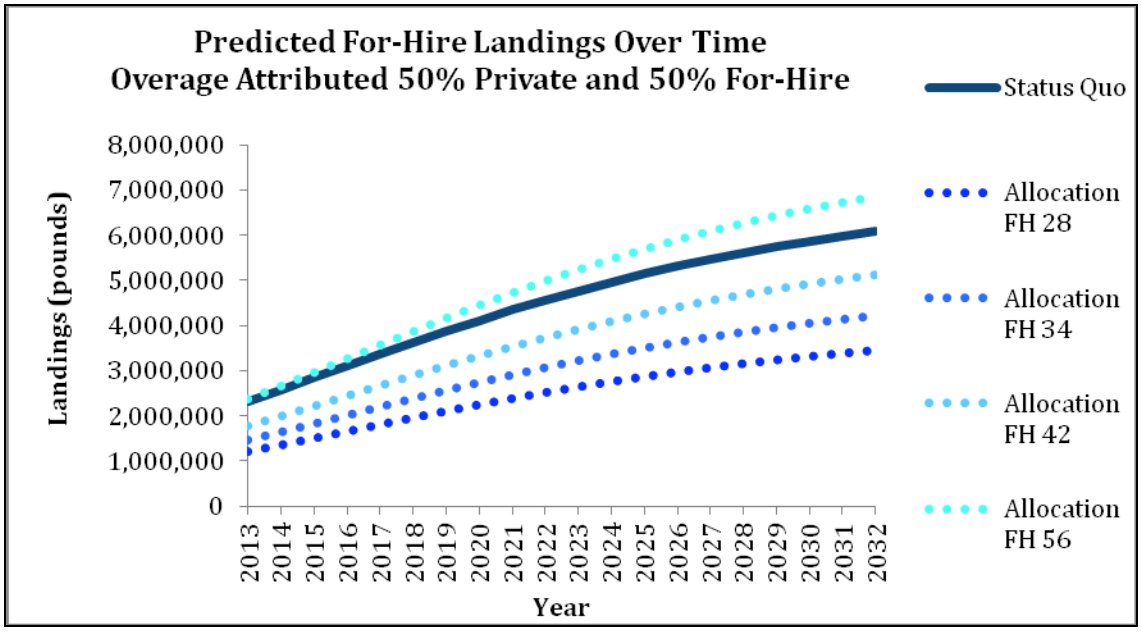

Figure 9. Predicted for-hire landings over time with 50/50 split of overages between private and for-hire sectors

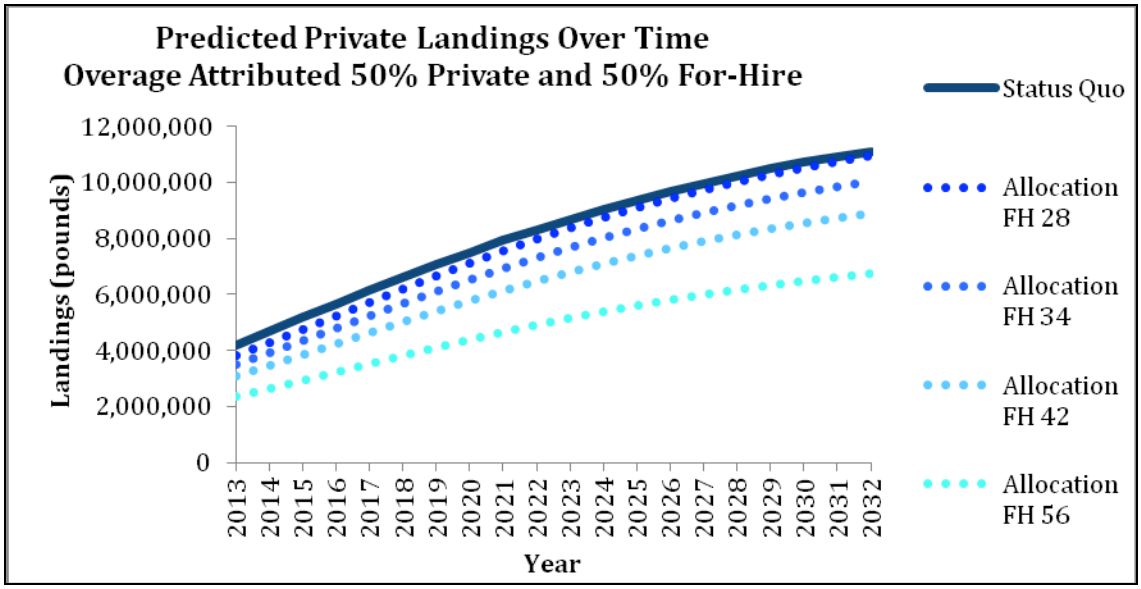

Figure 10. Predicted private landings over time with 50/50 split of overages between private and for-hire sectors

d. 100% Overage Attributed to For-Hire

The fourth assumption under which the model was run was that the for-hire industry contributes to 100% of the overage landings. This yielded the most differences in the results than the model runs under the previous assumptions. If the for-hire industry is responsible for all of the overage landings, they would expect to see a reduction in landings under all allocations by 2032, as seen in Figure 11.

Under this assumption, if the private is allocated the greatest allocation (72%) of the TAC, they could see landings slightly greater than under SQ, as seen in Figure 12.

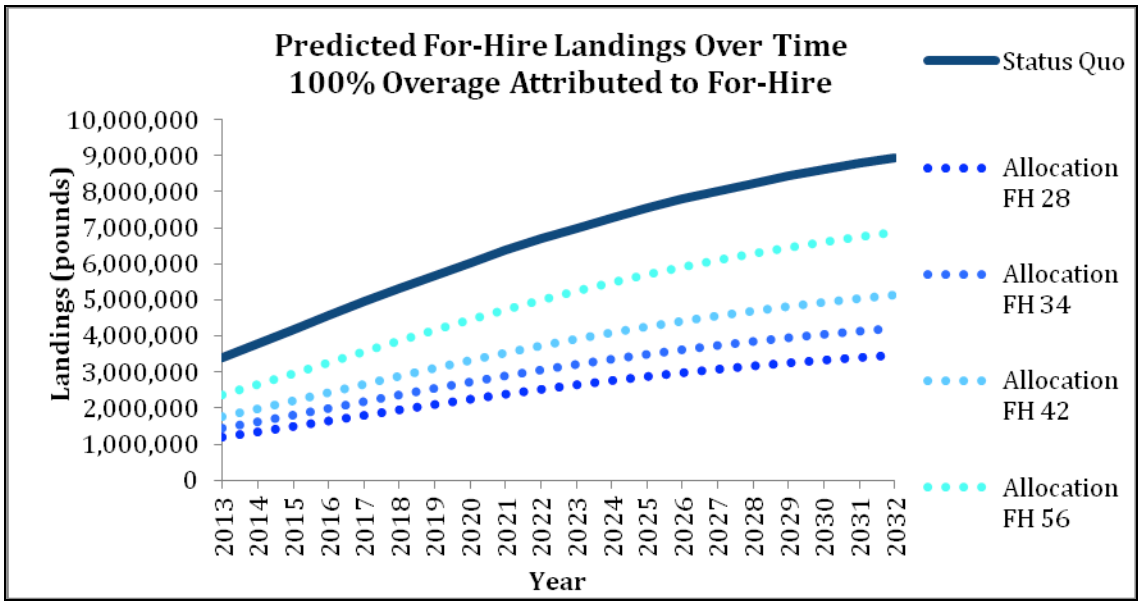

Figure 11. Predicted for-hire landings over time with 100% of overages assigned to for-hire anglers

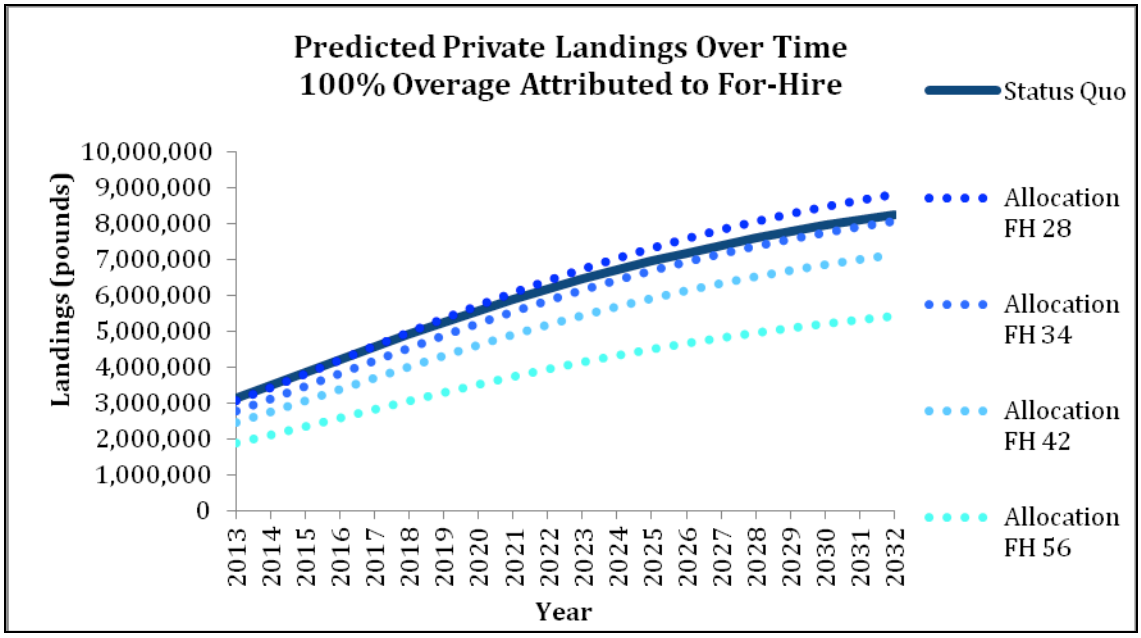

Figure 12. Predicted private landings over time with 100% of overages assigned to for-hire anglers

iii. Red Snapper Stock Age-Structure

The age-structured model allowed us to compare the numbers at each age class within the red snapper stock in 2032 under various allocations with sector

separation. Stock age structure is important, because as fish age they get larger and thus have higher fecundity rates. This helps to replace fish that are taken out of the stock through natural and fishing mortality.

Our model suggests that regardless of the overage assumption and allocation distribution, red snapper age classes two, three, and four will have between two and four percent increases in 2013, as seen in Figure 13. All other age classes will see less than a 0.5% increase from the current management. This result again suggests that sector separation will have minimal affects on the status of the stock in the year after it is implemented. The age classes that have the greatest percentage increase are expected, as the current stock has few old large fish, which is the result of overfishing. Table 23 illustrates the trend in the age structure, regardless of overage assumption and allocation distribution.

Analyzing the projection of the red snapper age structure in 2032 showed the potential for the real biological benefit that may be realized under sector separation. Figure 14 shows approximately a 10% increase in age classes four through 19 in 2032, as compared to the numbers in these age classes under the current management projected to 2032. While the overall increase in biomass from SQ was only four percent, this result suggests that the increases in the two to four-year-olds in 2013 translates into increases in the numbers in all age classes by 2032.

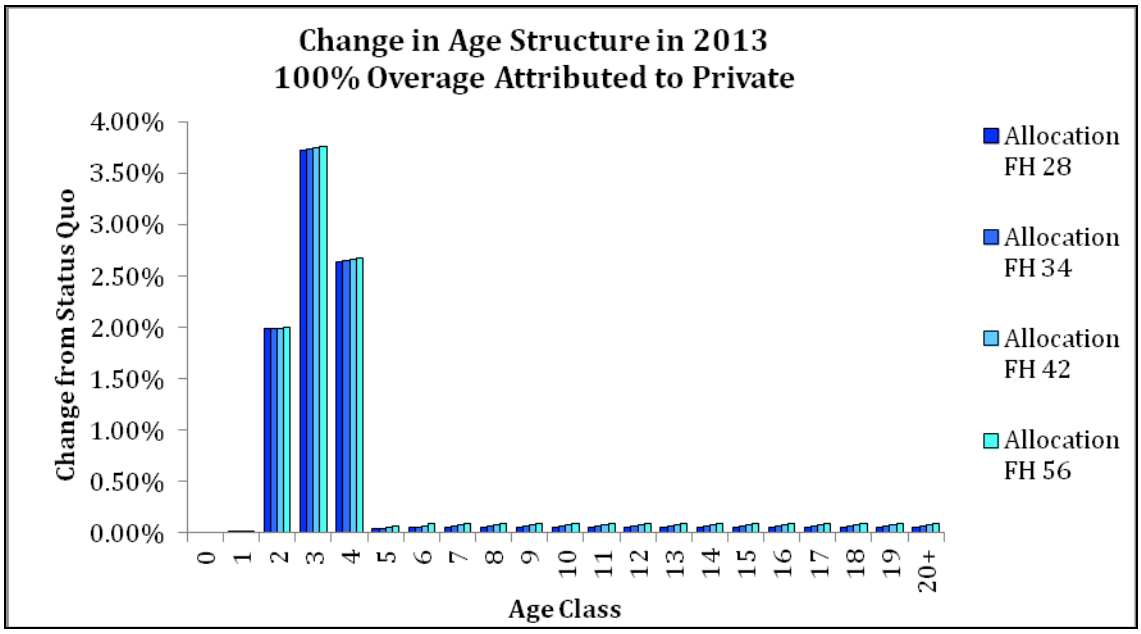

Figure 13. Changes in numbers-at-age in 2013 with 100% of overages assigned to private anglers

Table 23. Age structure with 100% overage assigned to private anglers

	2013				2032			
Age Class	FH 28	FH 34	FH 42	FH 56	FH 28	FH 34	FH 42	FH 56
0	0.00%	0.00%	0.00%	0.00%	0.49%	0.49%	0.50%	0.51%
1	0.00%	0.00%	0.00%	0.00%	0.49%	0.49%	0.50%	0.51%
2	1.98%	1.99%	1.99%	2.00%	2.48%	2.49%	2.50%	2.53%
3	3.73%	3.74%	3.75%	3.77%	6.30%	6.32%	6.34%	6.39%
4	2.64%	2.65%	2.66%	2.68%	9.11%	9.14%	9.17%	9.24%
5	0.04%	0.04%	0.05%	0.07%	9.15%	9.18%	9.23%	9.30%
6	0.05%	0.06%	0.07%	0.09%	9.20%	9.24%	9.29%	9.40%
7	0.05%	0.06%	0.07%	0.09%	9.25%	9.30%	9.36%	9.49%
8	0.05%	0.06%	0.07%	0.09%	9.29%	9.36%	9.43%	9.58%
9	0.05%	0.06%	0.07%	0.09%	9.33%	9.41%	9.50%	9.66%
10	0.05%	0.06%	0.07%	0.09%	9.37%	9.46%	9.56%	9.75%
11	0.05%	0.06%	0.07%	0.09%	9.41%	9.50%	9.61%	9.82%
12	0.05%	0.06%	0.07%	0.09%	9.43%	9.53%	9.66%	9.89%
13	0.05%	0.06%	0.07%	0.09%	9.45%	9.56%	9.70%	9.95%
14	0.05%	0.06%	0.07%	0.09%	9.46%	9.58%	9.73%	10.00%
15	0.05%	0.06%	0.07%	0.09%	9.46%	9.59%	9.75%	10.04%
16	0.05%	0.06%	0.07%	0.09%	9.44%	9.58%	9.75%	10.07%
17	0.05%	0.06%	0.07%	0.09%	9.43%	9.58%	9.76%	10.10%
18	0.05%	0.06%	0.07%	0.09%	9.42%	9.58%	9.77%	10.13%
19	0.05%	0.06%	0.07%	0.09%	9.42%	9.59%	9.79%	10.17%
20+	0.05%	0.06%	0.07%	0.09%	4.66%	4.84%	5.07%	5.48%

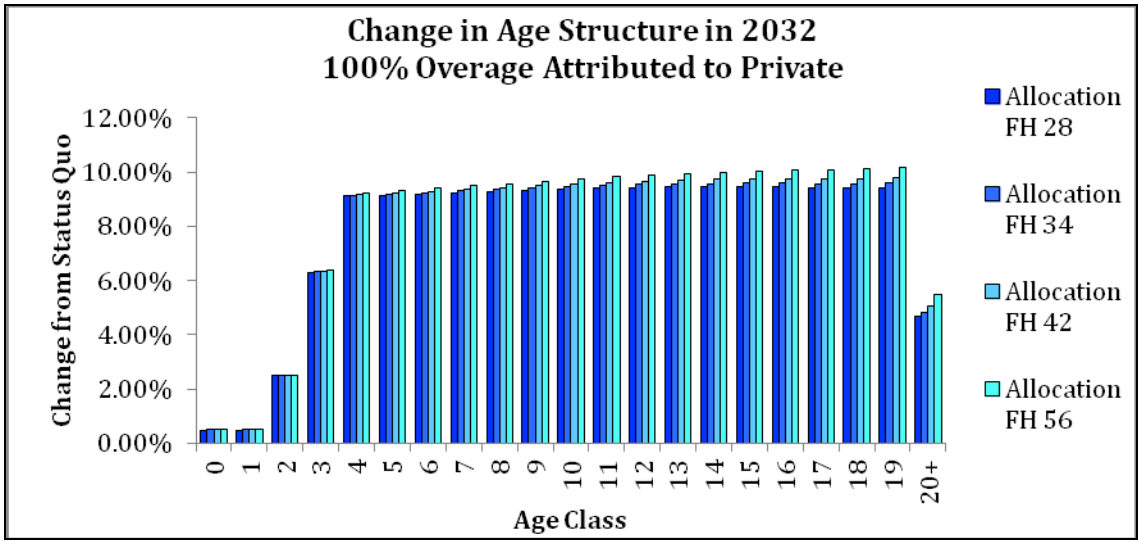

Figure 14. Changes in numbers-at-age in 2013 with 100% of overages assigned to for-hire anglers

Overage and allocation distributions under sector separation do not have implications on the biology of the red snapper fishery, as all results followed the same trend as illustrated by Figures 13 and 14 above.[28] These numbers-at-age results were used as an input for the economic model.

II. Economic Results

Using a biological model, we were able to see that implementing sector separation would not have negative implications on the biology of the red snapper stock. However, it was also necessary to analyze the potential changes that would be experienced by the stakeholders of the fishery. In order to evaluate and model the economic changes that might be expected within each sector, the aggregate demand curves were constructed. From the demand curves, consumer surplus (CS) for private anglers and profit for the for-hire industry were calculated. Comparing profit and CS calculations for each model run with the various assumptions and allocation distributions allowed us to understand how sector separation might translate into economic changes.

i. Demand Curves

Because of the differences in the price of trips, charter boats and headboats have different demand curves. In general, ticket prices to fish on a charter boat are much more expensive than ticket prices to fish on a headboat. Thus, there is a greater difference between the price and supply of trips for charter boats than the price and supply on a headboat. Additionally, there is a different demand for trips on private boats, which is also a function of the cost of a fishing trip on a private boat. Our analysis showed that there would be many shifts in the demand for trips in the various groups of the recreational sector from SQ, depending on the overage assumption and allocation. These demand changes translate into economic changes that would be realized with sector separation.

Tables 24 through 26 summarize the changes in the demand for trips in the charter boat industry, headboat industry, and for private anglers under the four overage assumptions used in the analysis for each allocation. The "↑" arrow denotes an upward shift demand for trips, and the "↓" arrow denotes a downward shift in the demand for trips. The "-" denotes little to no change in the demand for trips. The demand curves are included in Appendix E.[29]

The demand for trips in the for-hire sector would increase with greater allocations (28% to 56%), as seen in Tables 24 and 25. However, with Allocation FH 28 (based on the predicted landings for 2013), there will be a downward shift in demand when the for-hire sector is responsible for some of the overage. The for-hire industry

[28] The remaining figures associated with the biological results of this project can be found in Appendix D.

[29] The remaining figures associated with the economic results of this project can be found in Appendix E.

would experience little to no change where the allocation increase is enough to compensate for the overage restriction.

Table 24. Shift in demand curve for charter boat industry

Overage	Allocation FH 28	Allocation FH 34	Allocation FH 42	Allocation FH 56
100% Private	-	↑	↑	↑
Proportional to Predicted Landings	↓	↑	↑	↑
50%/50%	↓	-	↑	↑
100% For-Hire	↓	↓	-	↑

Table 25. Shift in demand curve for headboat industry

Overage	Allocation FH 28	Allocation FH 34	Allocation FH 42	Allocation FH 56
100% Private	-	↑	↑	↑
Proportional to Predicted Landings	↓	↑	↑	↑
50%/50%	↓	-	↑	↑
100% For-Hire	↓	↓	-	↑

Contrary to the increases in demand in the for-hire industry, the private anglers experience a decrease in demand for fishing trips with Allocations FH 34, FH 42, and FH 56, as seen in Table 26. This is because the allocations are providing more of the TAC to the for-hire sector as opposed to the private anglers. Allocation FH 28 gives private anglers landings that they are predicted to take in 2013, without holding them to a lower TAC, thus there would be little to no change in the demand under Allocation FH 28.

Table 26. Shift in demand for private anglers

Overage	Allocation FH 28	Allocation FH 34	Allocation FH 42	Allocation 56
100% Private	-	↓	↓	↓
Proportional to Predicted Landings	-	↓	↓	↓
50%/50%	-	↓	↓	↓
100% For-Hire	-	↓	↓	↓

ii. Changes in Welfare

To understand the impacts of sector separation, the changes in economic welfare for each sector were evaluated under the four overage assumptions for each allocation distribution. To implement sector separation, an allocation decision will have to be made. The economic changes that could be expected will depend on how the TAC is allocated between the private sector and the for-hire sector. The current trend is that the private sector is increasing the percentage of the landings that they catch each year, so any allocation that distributes less catch than what they are exhibiting would cause economic losses by the private sector. However, implementing sector separation results in some economic gains for the for-hire industry. This is not surprising, because any allocation would give the for-hire sector greater landings than what they currently land, even under the assumption that they are contributing to all of the overage.

a. Allocation FH 28

Allocation FH 28 is based on the predicted fishing activities in the red snapper fishery for 2013. The economic welfare changes under this allocation suggest that it is not sector separation that would drive economic changes, but rather the allocation designation and the overage assumption. Private anglers would experience no significant change from SQ because, in this allocation, they are not being regulated and are landing the proportion of the TAC predicted for SQ in 2013. However, the for-hire sector can experience different effects depending on the overage. If the private sector is responsible for all of the landings overage, then they would not experience a change in economic welfare. This is because, under this allocation, they are given the catch that they are predicted to land and do not need to be restricted. If any of the overage is landed by the for-hire sector, then the for-hire industry would expect to see decreases in economic welfare. This is not a surprising result, as the trend over time has been that the for-hire sector has decreased landings each year, while the private sector grows. Figure 15 illustrates these results and thus is a realistic snapshot of the trends under SQ.

In the three other allocations evaluated, the TAC assigned to the private industry is less than what they are currently fishing at, regardless of the assumption made regarding the overage. Thus, in the next three economic welfare comparisons, the private sector loses economic benefits.

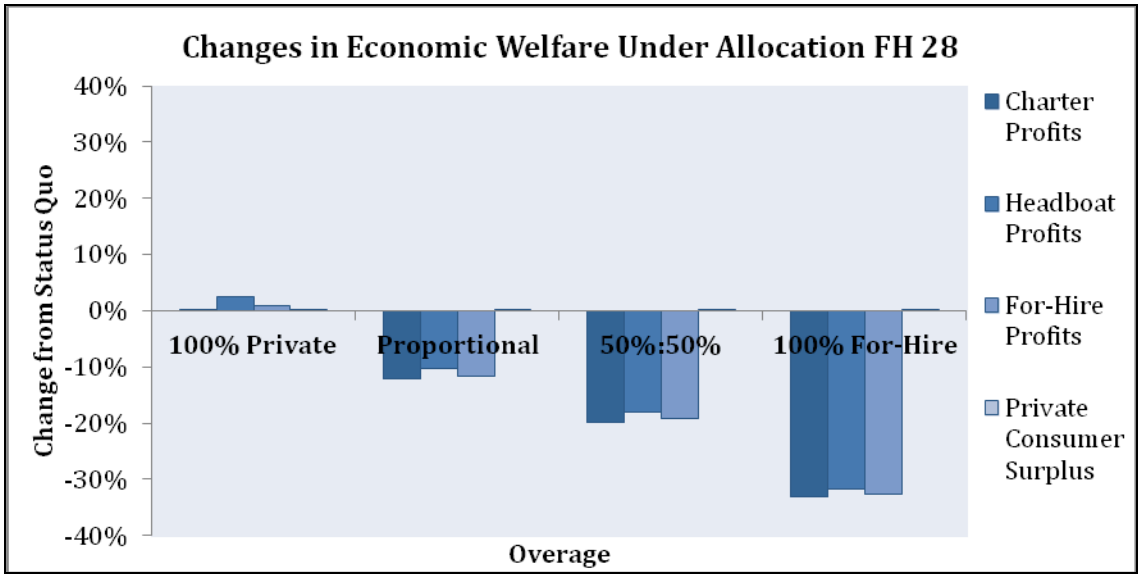

Figure 15. Changes in economic welfare under Allocation FH 28

b. Allocation FH 34

Under Allocation FH 34, the private sector would see the smallest welfare losses, as they are allocated 66% of the TAC, as seen in Figure 16. The for-hire begins to see welfare gains under this allocation, even though they would only receive 34% of the TAC; under this allocation, the sector can finally compensate for the losses seen when they are held to their TAC. If the majority of the overage is caught by the private sector (100% private scenario and proportional to landings scenario), than the for-hire sector stands to see some gains when allocated 34% of the TAC when compared to SQ. However, if the for-hire industry is contributing to 50% or more of the overages landed, then they will still have economic losses under sector separation when compared to SQ.

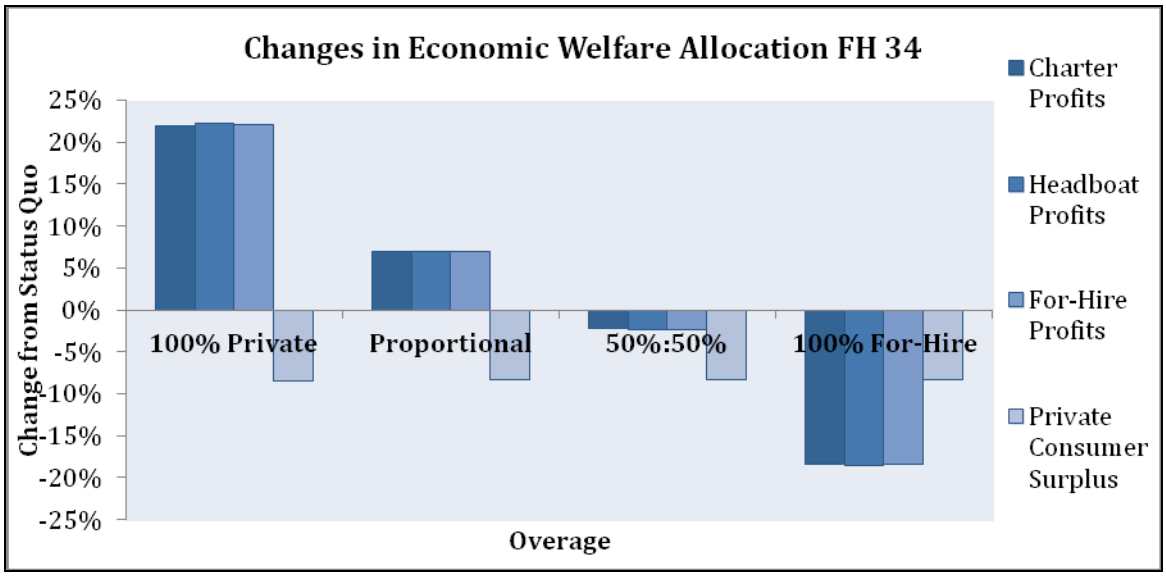

Figure 16. Changes in economic welfare under Allocation FH 34

c. Allocation FH 42

In the next two allocations evaluated, the for-hire sector is allocated more of the TAC: 42% and 56%, respectively. Both of these evaluations show that the for-hire sector can expect to see considerable gains under sector separation when compared to SQ. Figure 17 illustrates that, when allocated 42% of the TAC, the for-hire sector will see economic gains, even if the sector is currently taking 50% of the overage landings.

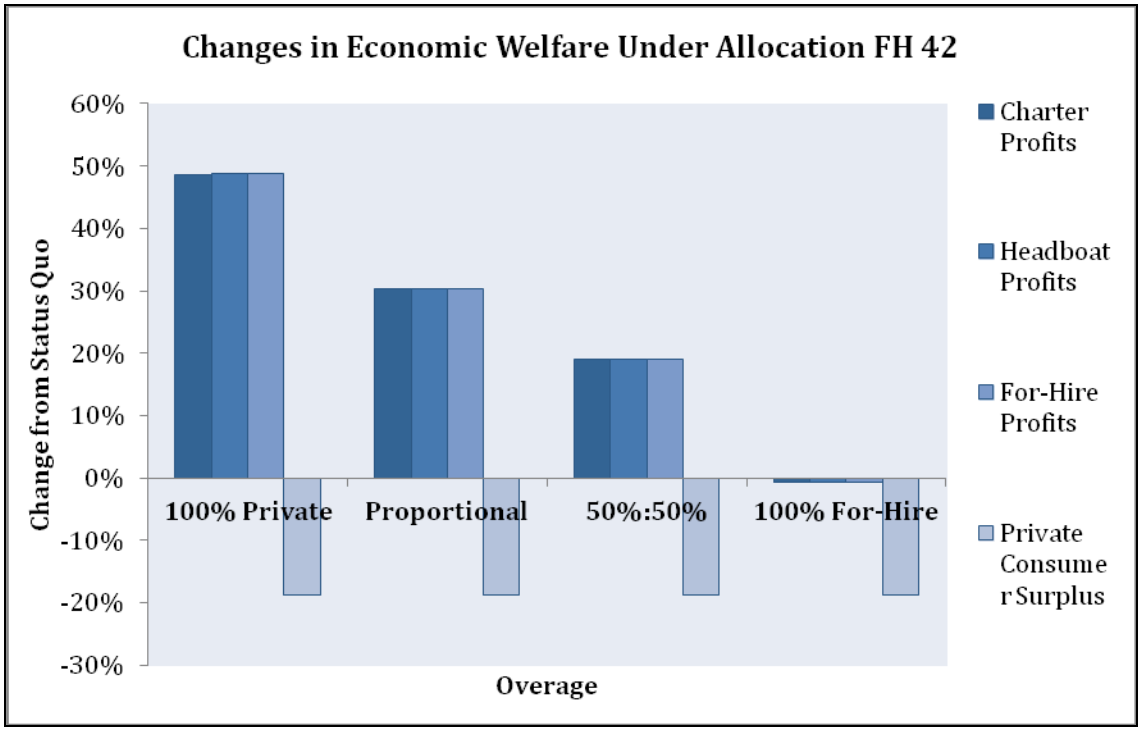

Figure 17. Changes in economic welfare under Allocation FH 42

d. Allocation FH 56

Allocation FH 56, illustrated in Figure 18, allocates 56% of the landings to the for-hire sector. This is the only scenario analyzed in which the for-hire sector is allocated over 50% of the TAC. In this model run, the private sector would see the greatest economic loss, which is not surprising, as they would be allocated the smallest TAC compared to what they are currently landing. In this allocation scenario, even if the for-hire sector is currently landing all of the overage, the sector receives economic gains.

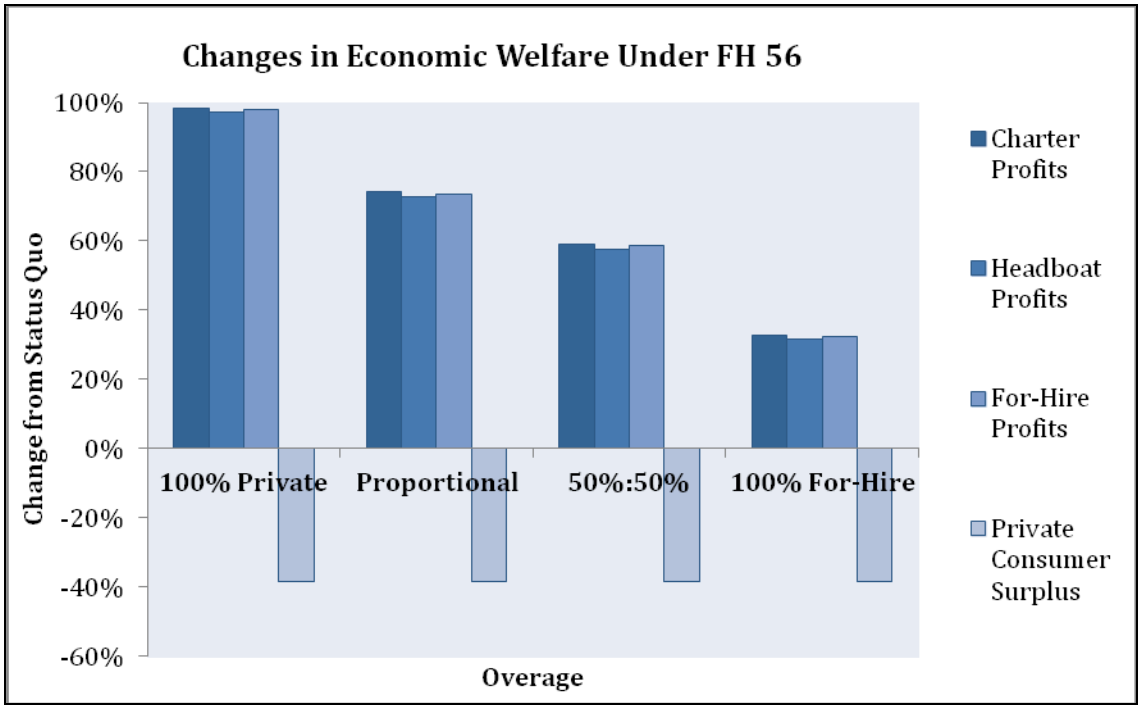

Figure 18. Changes in economic welfare under Allocation FH 56

iii. Individual Transferable Quotas

In the red snapper commercial fishery, an Individual Fishing Quota (IFQ) system was implemented in 2005 to address the problem of short fishing seasons, quota overages, unsafe fishing conditions, and high bycatch and mortality rates ("2011 Recreational Red Snapper Quota Closure Analysis", 1-42). The goals of implementing the IFQ system included reducing the overcapacity during the derby fishing seasons. The commercial red snapper fishery improved under the IFQ system; for this reason, we analyzed the economic impacts of implementing a similar system in the for-hire industry.

Our analysis shows that implementing an ITQ system can improve profits from the current management in a majority of the scenarios. This is illustrated in Figure 19, which shows the change from SQ profits under each allocation. If all of the overage landings are being taken by the for-hire sector and the sector gets allocated 28% of the TAC, they could see a small decrease in profits under an ITQ system. This would be likely because they would be allocated such a small amount and held to their TAC that it would essentially be a restriction. Therefore, the profits would be smaller than SQ where the for-hire sector is accounting for 100% of the overage and can take more trips during the season.

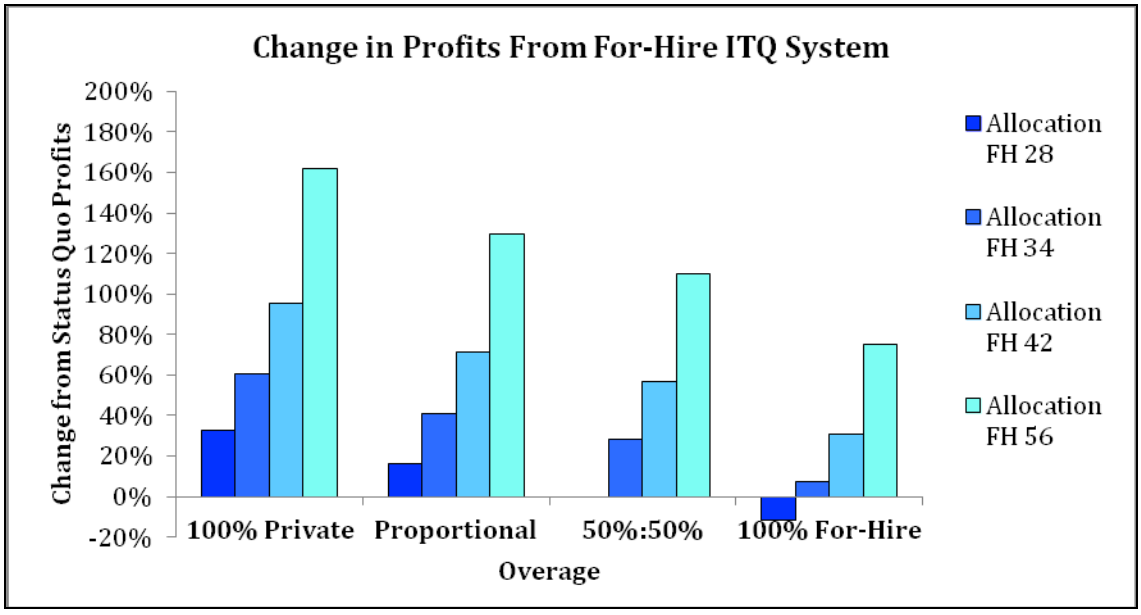

Figure 19. Change in Status Quo profits from for-hire ITQ system

However, positive gains can be expected when implementing an ITQ system when compared to implementing sector separation under current management. These gains in the for-hire sector are illustrated in Figure 20, which shows at least a 30% increase in profits, regardless of the overage assumption and allocation. This result is significant as it suggests the large economic gains that could be associated with a market scheme such as an ITQ system. The economic gains seen in our model are promising support of an ITQ system as a viable option in the for-hire sector.

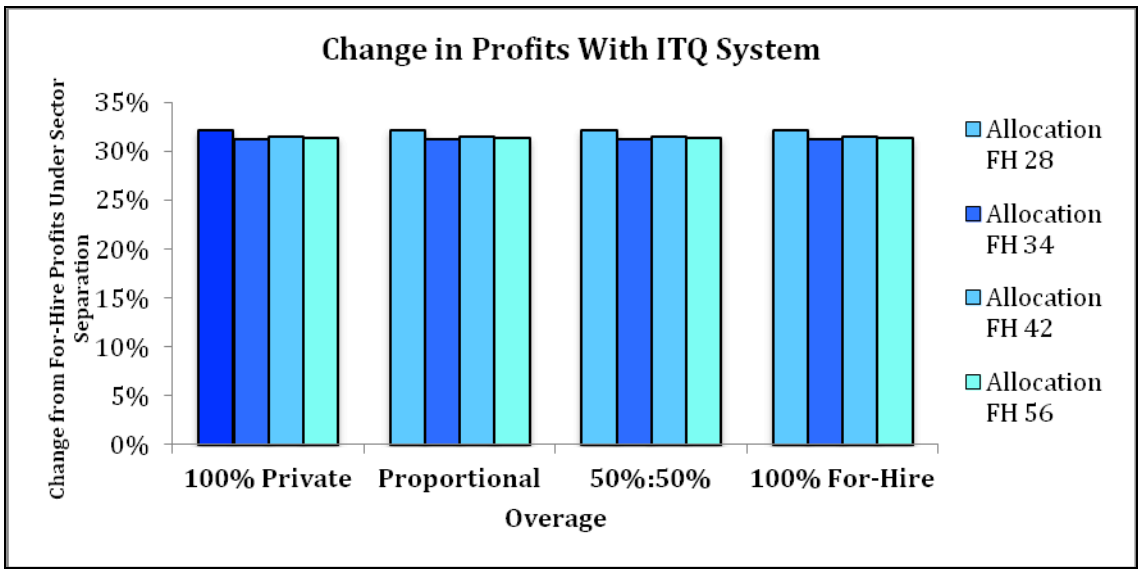

Figure 20. Change in for-hire profits with ITQ system

The quota prices calculated were $9.24 for Allocation FH 28, $9.32 for Allocation FH 34, $9.28 for Allocation FH 42, and $9.36 for Allocation FH 56.

III. Survey

A survey including questions on the knowledge of sector separation, support of sector separation, involvement in the GOM recreational red snapper fishery, and desired management outcomes for the fishery was sent to 1,200 people. Overall, when asked to rank what result they wanted most out of the fishery, respondents were most in favor of extending the recreational red snapper season length.

i. Response Rate

A total of 151 people responded to the survey: 134 responded via mail, and 17 responded online. This yielded a response rate of 12.58 percent. On average, mail surveys have a response rate of five to ten percent; when determining the sample size, we expected a response rate of seven percent. Figure 21 shows the distribution of response rates by angler sector. For this survey, we hypothesized that the majority of private anglers would be against sector separation because of the possibility of being even more restricted in both number of fishing days and catch.

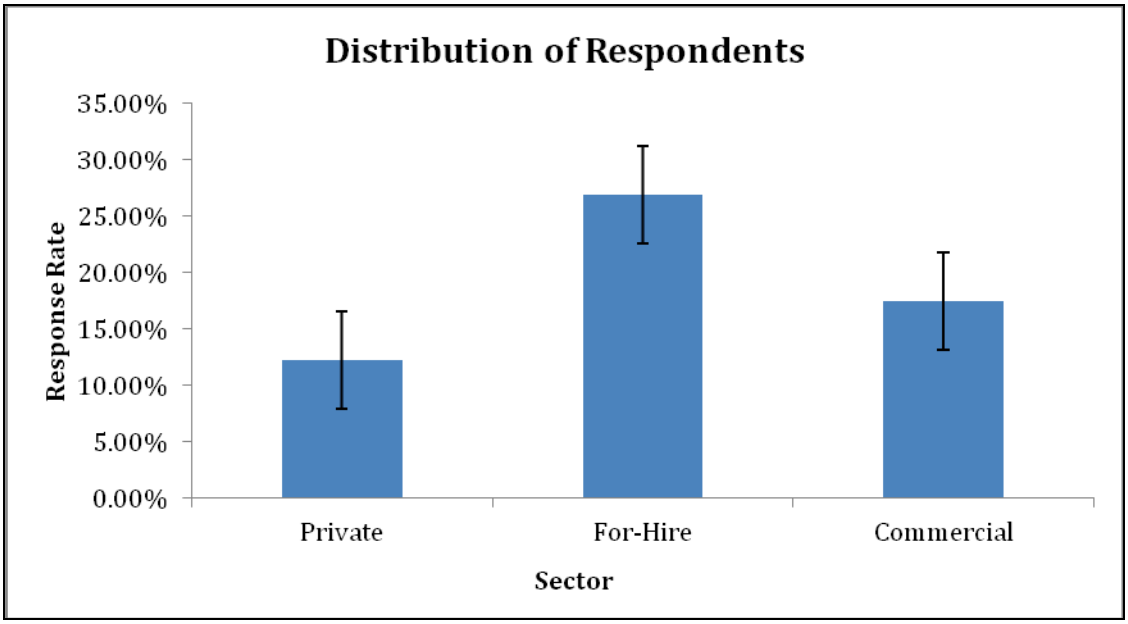

Figure 21. Distribution of survey respondents by industry sector

After analyzing our results, it is possible that some of the more opposed members of the community may have opted out of our survey due to the untrustworthy perception anglers towards policy changes within the community. This is known as self-selection bias. We did not have any control over who did and did not respond to our survey. However, it is important to take this missing population into consideration when reviewing the analysis from this survey, and some of these anglers did contact us after receiving the survey to express their doubts and concerns about our project. Furthermore, there is some bias within the population we surveyed due to the allocations of our surveys amongst the anglers within the GOM; because of this, our results are skewed towards the private and for-hire anglers, as they were allocated the majority of our surveys.

ii. Demographics

The average respondent was male, aged 51-60, and from Florida, as seen in Tables 27 and 28.

Table 27. Age of survey respondents

Age	Number of Respondents
19-30	6
31-40	10
41-50	34
51-60	55
61-70	38
71-80	3
81-up	2

Table 28. Survey respondents and percentage of recreational red snapper catch by state ("Sector Separation Discussion Paper", 1-24)

State	Percentage of Respondents	Percentage Catch (2009)
Texas	6.62	14.28
Louisiana	3.97	15.71
Mississippi	0.66	1.75
Alabama	9.27	31.87
Florida	76.82	36.38
Other	2.65	N/A

Table 28 shows the number of respondents by state compared to their relative share of the recreational red snapper fishery. Florida has the highest percentage catch and the highest response rate (but was allocated the highest number of surveys). Similarly, Mississippi has the lowest percentage catch and the lowest response rate. There is no reason to think that these relative rates would vary significantly, as these catch rates have been similar for each GOM state for several years ("Sector Separation Discussion Paper", 1-24).

When counting the number of participants in each sector, respondents who were involved in more than one sector (for example, a respondent who is both a private fishermen and a party boat owner) were counted in each sector, as seen in Figure 20. Although this may be seen as "double counting," we carried this method throughout our analysis in order to associate their responses with each of their industry sectors and, more importantly, to detect desired management outcomes that could match interests across different sectors. In future calculations, we combined the party boat, charter boat owner/operator, and for-hire angler categories to compare the for-hire industry as a whole.

iii. Desired Management Preferences

The main element of our survey was a question asking respondents to rank their management preferences in order of value for the recreational red snapper fishery. Preferences to rank were: more fish per person, more fish per trip, more fishing days per year, the ability to submit fishing data, the ability to purchase fishing days, and the ability to choose fishing days. 100 respondents, or 66.22% of our respondents, answered this question. Many respondents filled out this question incorrectly and did not rank the options properly; because of this, their answers for this question were not analyzed. Our hypotheses stated that the industry would want a higher bag limit or a greater TAC. However, across sectors, the most popular option was more fishing days per year, as seen in Figure 22. It is clear that anglers do not perceive the improvements in fish stocks as overall improvements in fishery, which ultimately creates a lot of dissatisfaction.

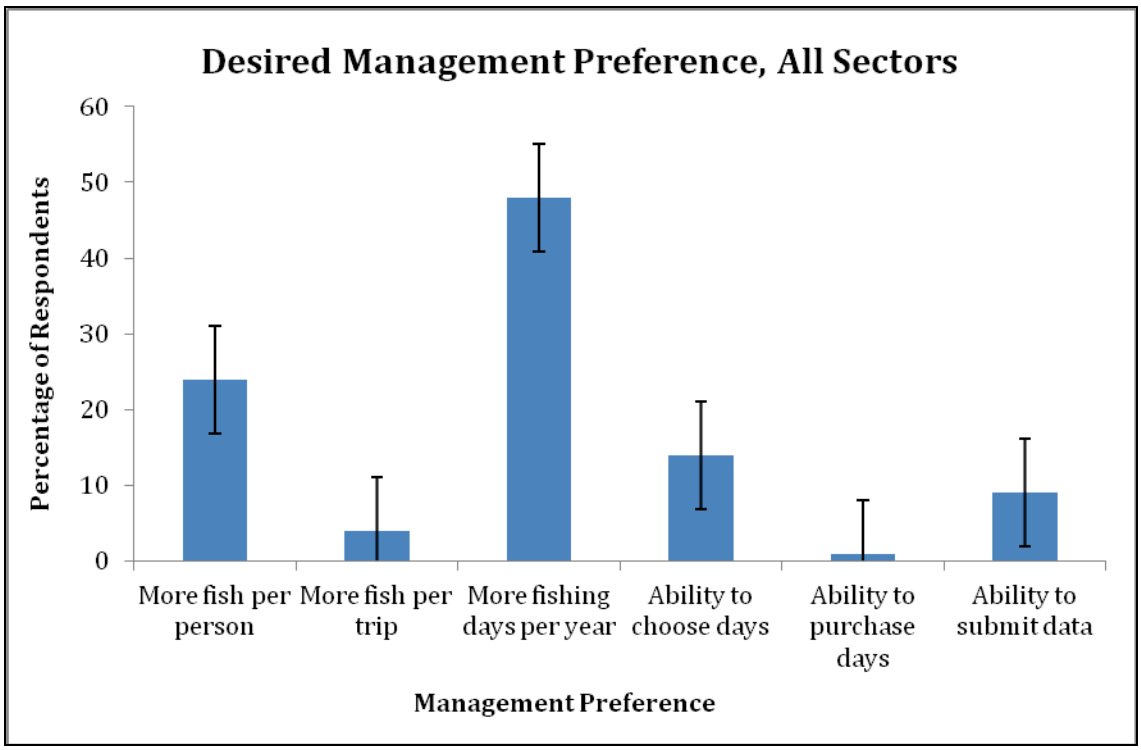

Figure 22. Desired recreational red snapper management preference for industry stakeholders in the Gulf of Mexico

Out of 151 respondents, 88 respondents identified as private fishermen, and 97 identified with the for-hire industry. When analyzing this question by sector, the most chosen option by both private and for-hire anglers was more fishing days, as seen in Figures 23 and 24.

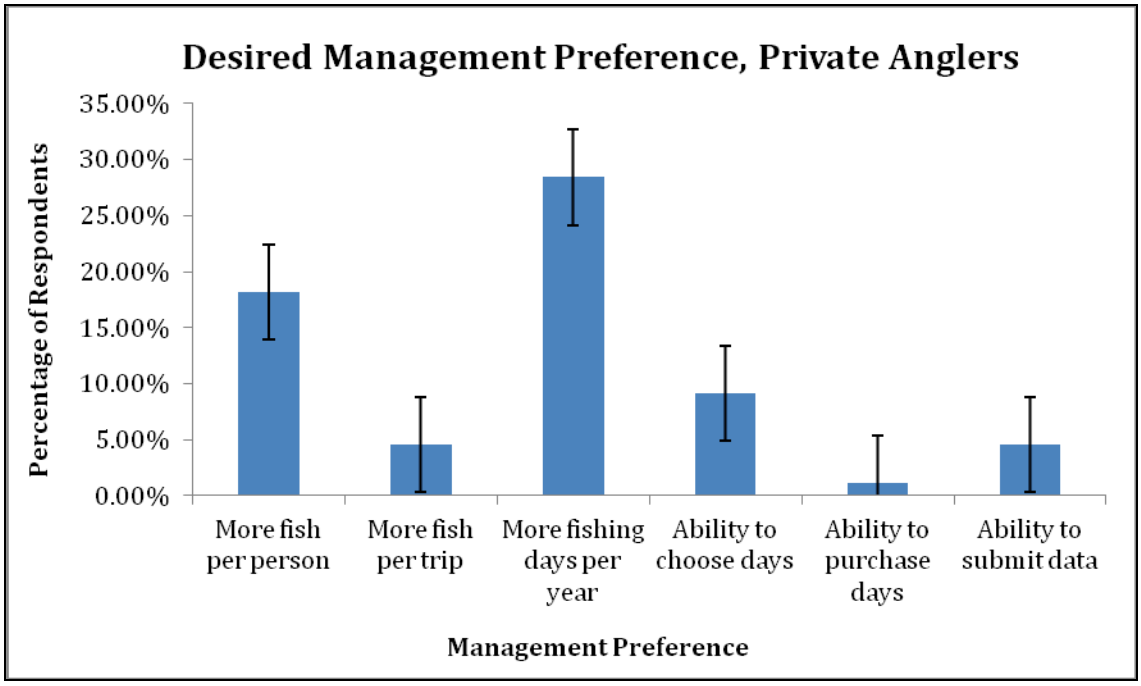

Figure 23. Desired recreational red snapper management preferences for private fishermen in the Gulf of Mexico

For private anglers, 25 respondents (or 28.41% of private angler respondents) ranked more fishing days per year as their top management preference for the recreational red snapper fishery, as seen in Figure 23. 16 respondents (or 18.18%) ranked more fish per person as their top management preference.

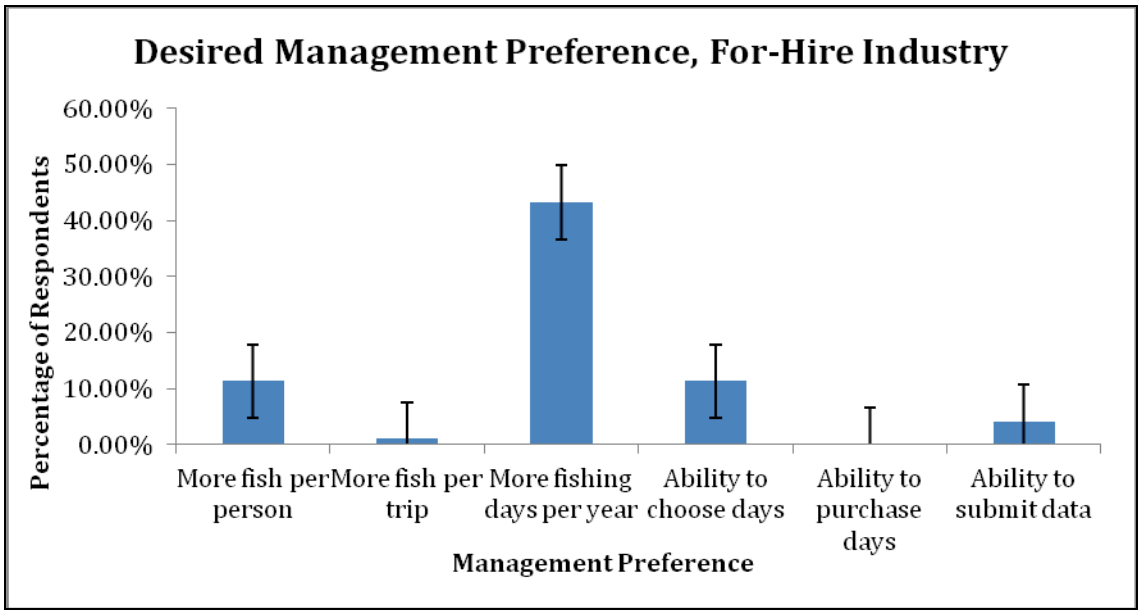

Figure 24. Desired recreational red snapper management preferences for the for-hire industry in the Gulf of Mexico

The for-hire industry supports more fishing days per year overwhelmingly; 42 respondents (or 43.30%) ranked more fishing days as their top management preference for the recreational red snapper fishery, as seen in Figure 24. Within the for-hire industry, more fish per person is tied with the ability to choose fishing days as the second most popular desired management preference; each preference had 11 respondents (or 11.34%) who selected it as their top management preference for the recreational red snapper fishery.

iv. Knowledge and Opinion of Sector Separation

Another important part of the survey was determining whether the respondents were in favor of or against sector separation. Based on our results, sector separation would increase the welfare of the for-hire sector but reduce the welfare of the private sector; the biology of the red snapper fishery would have very slight improvements. Several respondents were supportive of sector separation, as seen in Figure 25. 89 respondents (or 58.94%) were in favor of sector separation, 51 respondents (or 33.77%) were opposed, and 11 respondents (or 7.28%) did not respond. However, the 95% confidence intervals overlap between the two opinions of sector separation, which means there is no statistical difference in these two groups of responses.

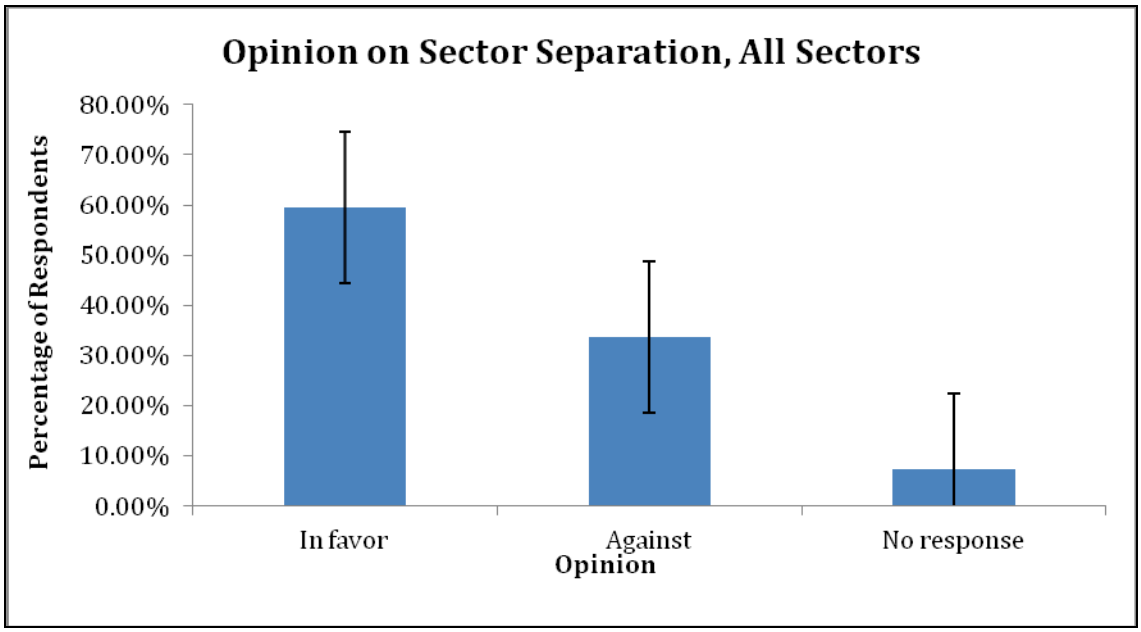

Figure 25. Industry opinion on sector separation of the recreational red snapper fishery in the Gulf of Mexico

Despite our hypothesis that private anglers would not be in support of sector separation of the GOM recreational red snapper fishery, both the private and for-hire sectors seem to be in favor of sector separation, as seen in Figure 26. 53 private anglers (or 35.10%) were in favor of sector separation, and 28 (or 18.54%) were against it. 54 for-hire anglers (or 35.76%) were in favor of sector separation, and 35 (or 23.18%) were against it. The commercial sector was evenly split, with 11

respondents (or 7.28%) both in favor and against sector separation. However, it is important to note that the only results that are statistically significant are when the commercial sector is compared to the private and for-hire sectors by opinion.

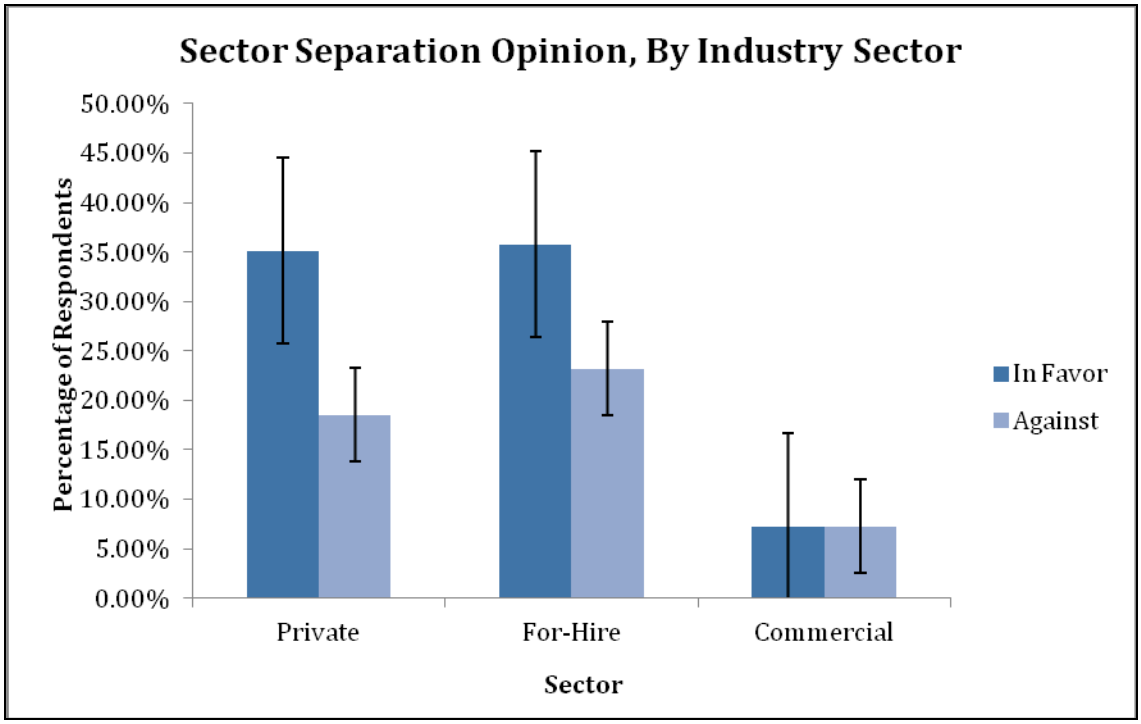

Figure 26. Industry opinion on sector separation within the Gulf of Mexico recreational red snapper fishery

The split in sector separation opinions within the commercial sector, as seen in Figure 26, could be a result of the sector's successful ITQ system. With sector separation, some of the overall red snapper TAC might get shifted into the newly split recreational sector. This could potentially take away from the commercial quota holders and disrupt the market system in place. Since sector separation is focused on the recreational fishery, a chi-squared test was conducted comparing the private and for-hire sectors and their opinion on sector separation. The x^2 value was 1.300, with a p-value of 0.25. These values show that the opinions on sector separation between the private and for-hire industry are not different. Furthermore, the error bars on the figure show that the responses from private anglers on this question are statistically significant, while those from for-hire and commercial anglers are not.

As seen in Figure 27, 57.5% of private anglers had no knowledge of sector separation; of those with no knowledge, 37.5% (or 30 respondents) were in favor of sector separation, and 20% (or 16 respondents) were against sector separation. 42.5% of private anglers had previous knowledge of sector separation; of those with knowledge, 28.75% (or 23 respondents) were in favor of sector separation, and 13.75% (or 11 respondents) were against sector separation.

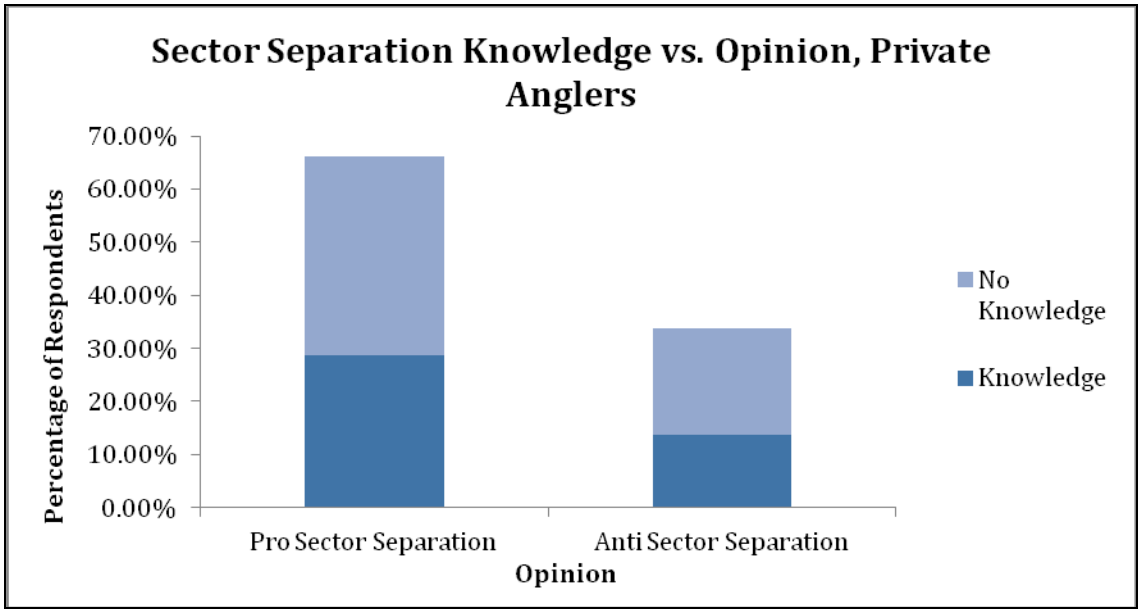

Figure 27. Knowledge and opinion of sector separation within the recreational red snapper fishery for private anglers in the Gulf of Mexico[30]

As seen in Figure 28, 47.7% of for-hire respondents had no knowledge of sector separation; of those with no knowledge, 29.85% (or 20 respondents) were in favor of sector separation, and 17.91% (or 12 respondents) were against sector separation. 88% of for-hire respondents had previous knowledge of sector separation; of those with knowledge, 50.75% (or 34 respondents) were in favor of sector separation, and 37.31% (or 25 respondents) were against sector separation.

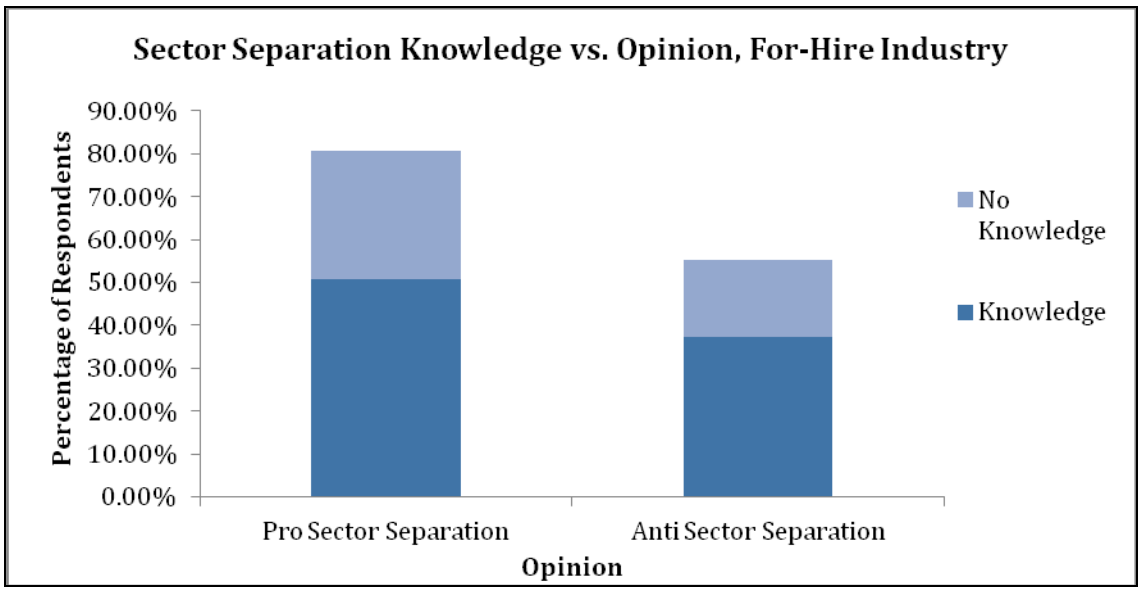

Figure 28. Knowledge and opinion of sector separation within the recreational red snapper fishery for the for-hire industry in the Gulf of Mexico[31]

[30] This figure does not include the respondents that did not answer this question.

We hypothesized that knowledge (or lack thereof) of sector separation would be a limiting factor in the region's support of the management strategy. However, the results suggested that this was not the case; both the private and the for-hire sectors were generally more in favor of sector separation, with or without knowledge. The private industry was more greatly in favor than the for-hire industry, as seen in Figure 26. We conducted a chi-squared test for those with knowledge of sector separation and their opinion on the topic. The x^2 value for those with knowledge was 1.01 with a p-value of >0.25. The x^2 value for those with no knowledge of sector separation was 1.7249 with a p-value of 0.2. These values suggest that the opinions of sector separation are not different depending on the level of knowledge.

v. Survey Comments

Survey respondents provided comments on how to best improve the management of the recreational red snapper fishery in the GOM, as seen in Figure 29. Out of the 69 respondents who provided commentary, the common themes of these comments were to incorporate better data into fisheries management, to improve fisheries legislation and management at a federal and state level, especially the Council process, and, lastly, to incorporate more flexible regulations into the fishery (for example, having the ability to choose fishing days). In order to rank their comments according to the number of times they were mentioned, three broad categories were created: better data, flexible regulations, and improved management/GMFMC process.

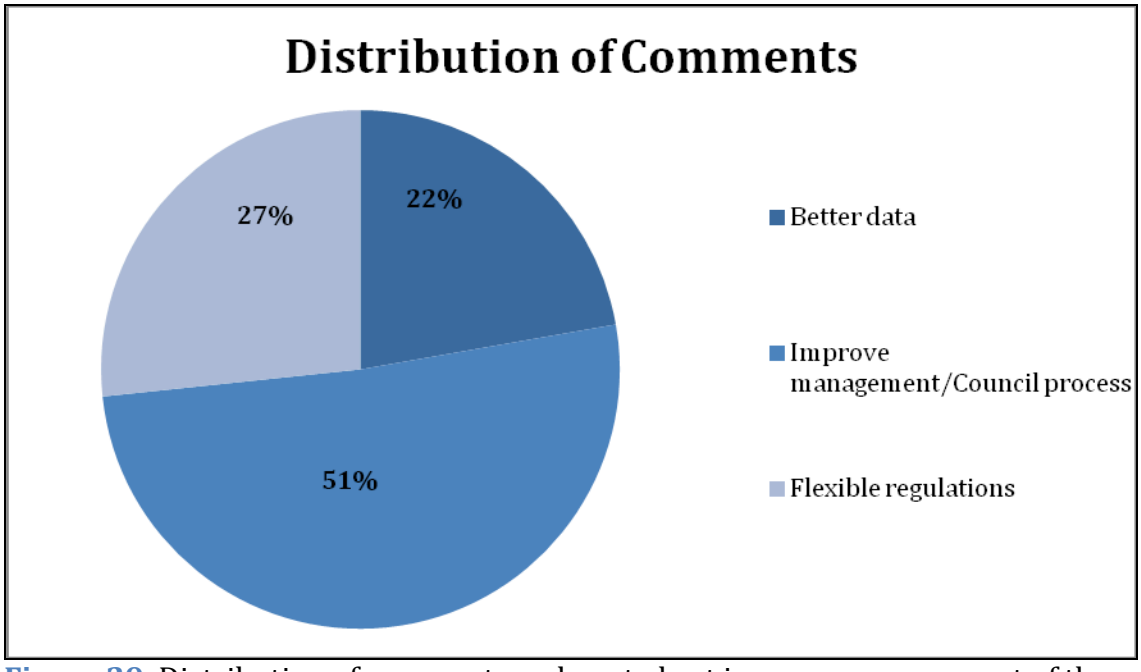

Figure 29. Distribution of comments on how to best improve management of the recreational red snapper fishery in the Gulf of Mexico

[31] This figure does not include the respondents that did not answer this question.

Interestingly, many respondents wrote comments about incorporating better data into the management of the recreational red snapper fishery, but when asked to rank this strategy, ability to submit data was the fourth most popular option across industry sectors, after having more fishing days per year, having more fish per person, and having the ability to choose fishing days. It was clear that recreational anglers could perfectly match the ability to submit better fishing data with increased flexibility, but would not trade flexibility for a better reporting system.

Including the results from this survey with the results from our biological and economic models will help to create the most robust analysis of the impacts of sector separation on the GOM. The socio-political aspects of a management change are equally as important as the changes seen in the biology or economics, and without stakeholder approval, any proposed amendment will inevitably run into compliance issues.

Conclusions

Sector separation has minimal impacts on the biology of the red snapper fishery in the Gulf of Mexico (GOM). The main biological component of concern to managers and the Gulf of Mexico Fishery Management Council (GMFMC), the 26% Spawning Potential Ratio (SPR), is exceeded when the recreational sector is split into two angler groups. This ensures that the health of the red snapper stock will be protected. Additionally, more older and larger red snapper will be incorporated into the stock, as sector separation leads to increases at each age class.

Under sector separation, for-hire anglers are allocated more Total Allowable Catch (TAC) (which increases 22% from Allocation For-Hire (FH) 28 to Allocation FH 56) and receive more economic benefits under all overage scenarios. When comparing sector separation to Status Quo (SQ), for-hire anglers will be allowed to land much more than what they are currently landing. When analyzing the scenario when for-hire anglers are responsible for 100% of overage landings), for-hire anglers can still see positive economic changes under Allocation FH 56. This is because for-hire anglers are getting a large enough portion of the TAC that they are able to compensate for the losses associated with being tightly regulated and unable to fish over their TAC. All for-hire angler results were calculated assuming that sector separation would hold this sector to their TAC, as opposed to the current trend of anglers exceeding their TAC. Based on these results, for-hire anglers in the GOM should be more supportive of sector separation than private anglers.

If an Individual Transferrable Quota (ITQ) system is adopted, sector separation can benefit the recreational red snapper fishery in the GOM. When a trading scheme is implemented under the various TAC allocations, Allocation FH 56 has the greatest benefits for each overage scenario. The for-hire sector will see the greatest percent increase from SQ when they receive the majority of the TAC and are making none of the overages. Permit trading can yield profit increases of up to approximately 160% when compared to those found under SQ, but perhaps the most sensational benefit from this policy option is that it allows anglers more flexibility in fishing days. As a permit holder, anglers can decide when they fish and have the ability to spread their fishing days out over as many days as they want, so long as they do not exceed their allocation.

Based on the results from our opinion survey, both for-hire and private anglers want the opportunity to go fishing more days of the year for red snapper. Since our model results show increasing health of the red snapper stock as well as increased landings depending on the assigned allocation, sector separation could give these angler groups the aspect they desire most out of the fishery.

The anglers that will be most supportive of sector separation are the for-hire anglers. They stand to benefit the most from the economic changes of sector separation, as seen under each allocation and landings overage assumption. Since

for-hire anglers are already federally regulated, applying sector separation to this sector would be an easy change. However, private anglers will be less supportive of sector separation. While some anglers may support the change realizing they may be able to fish more days out of the year, many may not support the change due to their loss of welfare and reduction in TAC.

It is important for managers to take into consideration the potential side effects of implementing sector separation within the private angler community; possible behavioral changes could lead to unwanted consequences. Specifically, in an effort to make up for the TAC that is being taken away, private anglers could create an even larger overage margin. As accurate catch data is hard to track within the private angler community, this could only increase the difficulties that the GMFMC are experiencing. Furthermore, private anglers may be resistant to these changes, leading to socio-political unrest within the community and an overall unwillingness to adopt any changes in management.

We recommend sector separation be used as a management tool within other fisheries. It will be much easier to implement when managers have more control over the stock and when there are fewer stakeholders involved. Sector separation could be applied to such fisheries as the Pacific Coast groundfish fishery and the South Atlantic red drum (*Sciaenops ocellatus*) fishery. Smaller fish stocks, such as those mentioned, will be easier to monitor and determine if biological improvements are indeed occurring. Fewer stakeholders will allow for less socio-political unrest and disagreement; furthermore, it will be easier to track if angler groups are receiving economic benefits under sector separation. Ultimately, this report can serve as a framework to fisheries managers considering sector separation.

We suggest that our client and the GMFMC consider the results put forward in this report when drafting possible amendments to the recreational red snapper Fisheries Management Plan (FMP). With several meetings on the agenda for the remainder of the 2013 calendar year, the GMFMC has ample opportunity to review our analysis and propose changes to the Council and to stakeholders. If adopted, an ITQ system when combined with sector separation could produce the balance between biology, economics, and social desires within the red snapper fishery that the GMFMC has sought after for so long.

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Appendix A – Definitions of Fisheries Terms

All definitions come from the June 2006 version of the NOAA Fisheries Glossary (Blackhart *et al,* 2006).

Age Class: A group of individuals of the same age range in a population. The age 0 group are the fish in their first year of life. A fish born in April of a given year remains in the age 0 group until April of the following year. The term usually refers to a year class in long-lived annually breeding species, but shorter units of times are also used, particularly in the tropics.

Allocation: 1. Distribution of the opportunity to fish among user groups or individuals. The share a user group gets is sometimes based on historic harvest amounts; 2. A quantity of catch, effort, or biomass attributed to a person, a vessel, and a fishing company. The allocation can be absolute (e.g. a number of tons) or relative (e.g. a percentage of the annual allowable catch).

Bag Limit: The number and/or size of a species that a person can legally take in a day or trip. This may or may not be the same as a possession limit.

Best Available Science: The term "best available science" comes from National Standard 2 listed in the Magnuson-Stevens Act, and is the informational standard mandated for decision making.

Bioeconomic Modeling: Mathematical formulae that simulate the interaction between biological behavior of fish stocks and human behavior of users of the resource as it is shaped by economic factors.

Biomass: 1. Or standing stock. The total weight of a group (or stock) of living organisms (e.g. fish, plankton) or of some defined fraction of it (e.g. spawners) in an area, at a particular time; 2. Measure of the quantity, usually by weight in pounds or metric tons (2,205 pounds or 1 metric ton), of a stock at a given time.

Bycatch: Fish other than the primary target species that are caught incidental to the harvest of the primary species. Bycatch may be retained or discarded. Discards may occur for regulatory or economic reasons.

Catch: 1. To undertake any activity that results in taking fish out of its environment dead or alive. To bring fish on board a vessel dead or alive; 2. The total number (or weight) of fish caught by fishing operations. Catch should include all fish killed by the act of fishing, not just those landed; 3. The component of fish encountering fishing gear, which is retained by the gear.

Catchability: In general, the extent to which a stock is susceptible to fishing.

Charter Boat: Any vessel-for-hire engaged in recreational fishing and hired for a charter fee by an individual or group of individuals (for the exclusive use of that individual or group of individuals), which results in that vessel being unavailable for hire to any other individual or group of individuals during the period of the charter.

Closed Season: Seasonal closure. The banning of fishing activity (in an area or of an entire fishery) for a few weeks or months, usually to protect juveniles or spawners.

Commercial Fishery: A term related to the whole process of catching and marketing fish and shellfish for sale. It refers to and includes fisheries resources, fishermen, and related businesses.

Consumer Surplus: The welfare (or well-being) consumers derive from a good or service, represented by the difference between the maximum a consumer is willing to pay for a good or service and what the consumer actually pays. "Consumer" also applies to those gaining value from non-consumptive uses (e.g. observing salmon runs) and to nonuse benefits (e.g. protecting marine mammals from exploitation).

Demand Function: A function that relates the quantity of a good or service demanded to price. It is usually an inverse relationship where at higher (or lower) prices, less (or more) quantity is consumed. Other factors which influence willingness-to-pay are incomes, tastes, preferences, and price of substitutes.

Demersal: Living in close relation with the bottom and depending on it. Cods, groupers, crabs, and lobsters are demersal resources. The term usually refers to the living mode of the adult, i.e. demersal fish.

Discard: To release or return fish to the sea, dead or alive, whether or not such a fish are brought fully on board a fishing vessel.

Effort: The amount of time and fishing power used to harvest fish; includes gear size, boat size, and horsepower.

Exclusive Economic Zone (EEZ): The EEZ is an area that extends from the seaward boundaries of the coastal states (3 nautical miles (n.mi.) in most cases, the exceptions are Texas, Puerto Rico, and the Gulf coast of Florida at 9 n.mi.) to 200 n.mi. off the U.S. coast. Within this area the United States claims and exercises sovereign rights and exclusive fishery management authority over all fish and all continental shelf fishery resources.

Fecundity: The potential reproductive capacity of an organism or population expressed in the number of eggs (or offspring) produced during each reproductive cycle. Fecundity usually increases with age and size. The information is used to compute spawning potential.

Fishery: 1. Generally, a fishery is an activity leading to harvesting of fish. It may involve capture of wild fish or raising of fish through aquaculture; 2. A unit determined by an authority or other entity that is engaged in raising or harvesting fish. Typically the unit is defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats, and purpose of the activities; 3. The combination of fish and fishers in a region, the latter fishing for similar or the same species with similar or the same gear types.

Fishery Management Council (FMC): A regional fisheries management body established by the Magnuson-Stevens Act to manage fishery resources in eight designated regions of the United States.

Fishery Management Plan (FMP): 1. A document prepared under supervision of the appropriate fishery management council (FMS) for management of stocks of fish judged to be in need of management. The plan must generally be formally approved. An FMP includes data, analyses, and management resources; 2. A plan containing conservation and management measures for fishery resources, and other provisions required by the Magnuson-Stevens Act, developed by fishery management councils or the Secretary of Commerce.

Fishing: Any activity, other than scientific research conducted by a scientific research vessel, that involves the catching, taking, or harvesting of fish; or any attempt to do so; or any activity that can reasonably be expected to result in the catching, taking, or harvesting of fish and any operations at sea in support of it.

Fixed Costs: Costs that do not vary with output. Fixed costs can only be avoided if the firm goes out of business.

Growth: Usually an individual fish's increase in length or weight with time. Also may refer to the increase in numbers of fish in a population with time.

Headboat: A fishing boat that takes recreational (sport) fishermen out for a fee per person. Different from a charter boat in that people on a headboat pay individual fees as opposed to renting the boat.

Highgrading: Form of selective sorting of fish in which higher value, more marketable fish are retained and fish that could be legally retained, but are less marketable, are discarded.

Hook and Line: A type of fishing gear consisting of a hook tied to a line. Fish are attracted by natural bait that is placed on the hook, and are impaled by the hook when biting the bait. Artificial bait (lures) with hooks are often used. Hook-and-line units may be used singly or in large numbers.

Incidental Catch: Retained or discarded nontarget species caught when fishing for the primary purpose of catching a different species.

Individual Fishing Quota (IFQ): A type of limited entry, an allocation to an individual (a person or a legal entity, e.g. a vessel owner or company) of a right [privilege] to harvest a certain amount of fish in a certain period of time. It is also often expressed as an individual share of an aggregate quota, or total allowable catch (TAC).

Individual Transferrable Quota (ITQ): A type of individual fishing quota (IFQ) allocated to individual fishermen or vessel owners that can be transferred (sold or leased) to others.

Landings: 1. The number or poundage of fish unloaded by commercial fishermen or brought to shore by recreational fishermen for personal use. Landings are reported at the locations at which fish are brought to shore; 2. The part of the catch that is selected and kept during the sorting procedures on board vessels and successively discharged at dockside.

Landings Data: Information on the amount of fish caught and landed per year.

Magnuson-Stevens Act (MSA): Federal legislation responsible for establishing the fishery management councils (FMCs) and the mandatory and discretionary guidelines for Federal fishery management plans (FMPs). This legislation was originally enacted in 1976 as the Fishery Management and Conservation Act; its name was changed to the Magnuson Fishery Conservation and Management Act in 1980, and in 1996 it was renamed the Magnuson-Stevens Fishery Conservation and Management Act.

Management: The art of taking actions that affect a resource and its exploitation with a view to achieve certain objectives, such as maximizing the production of that resource. Management includes, for example, fishery regulations such as catch quotas or closed seasons. Managers are those who practice management.

Marginal Yield: The increase in yield obtained by an increase in fishing effort (or fishing mortality) by one unit. In mathematical terms, it is given by the slope of the tangent to the relationship between effort and yield (or between fishing mortality and yield-per-recruit).

Marine Recreational Fisheries Statistical Survey (MRFSS): An annual national survey conducted by the National Marine Fisheries Service (NMFS), in cooperation with the coastal states, to estimate the number, catch, and effort of recreational fishermen. It serves as a basis for many parts of fisheries management plans (FMPs).

Maximum Sustainable Yield (MSY): The largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others.

Minimum Size: The smallest individual size allowed in landings or markets. Established by fishery management councils (FMCs) and enforced through control at landing sites or markets, it is intended to minimize the catch of small (undersized) fish or juveniles giving them a better chance to grow before being vulnerable to fishing. Based on yield per recruit considerations and models, it aims at avoiding or correcting growth overfishing.

Model: In fisheries science, a description of something that cannot be observed. Often a set of equations and data used to make estimates.

Modeling: The construction of physical, conceptual, or mathematical simulations of the real world. Models help to show relationships between processes (physical, economic, or social) and may be used to predict the effects of changes in the components of a system.

Mortality: Measures the rate of death of fish. Mortality occurs at all life stages of the population and tends to decrease with age. Death can be due to several factors such as pollution, starvation, and disease but the main source of death is predation (in unexploited stocks) and fishing (in exploited ones).

Mortality Rate: The rate at which the numbers in population decrease with time due to various causes. Mortality rates are critical parameters in determining the effects of harvesting strategies on stocks, yields, revenues, etc. The proportion of the total stock (in numbers) dying each year is called the "annual mortality rate."

National Marine Fisheries Service (NMFS): Federal agency within the National Oceanic and Atmospheric Administration (NOAA) and responsible for overseeing fisheries science and regulation of the fisheries.

National Oceanic and Atmospheric Administration (NOAA): A bureau within the Department of Commerce responsible for atmospheric, ocean, and coastal sciences and Federal management.

Net Present Value: The value of an enterprise at the present time, after applying the process of discounting its costs and benefits.

Numbers-at-Age: The numbers of fish in each age class of a stock, in a particular year.

Optimum Yield (OY): 1. The harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. Optimum

yield (OY) is different from maximum sustainable yield (MSY) in that MSY considers only the biology of the species. The term includes both commercial and sport yields; 2. The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a "ceiling" for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for the rebuilding stock to achieve biomass at MSY.

Overexploited: When stock abundance is too low. The term is used when biomass has been estimated to be below a limit biological reference point that is used as the threshold that defines "overfished conditions."

Overfished: 1. An overfished stock or stock complex "whose size is sufficiently small that a change in management practices is required to achieve an appropriate level and rate of rebuilding." A stock or stock complex is considered overfished when its population size falls below the minimum stock size threshold (MSST). A rebuilding plan is required for stocks that are deemed overfished; 2. A stock is considered "overfished" when exploited beyond an explicit limit beyond which its abundance is considered "too low" to ensure safe reproduction. In many fisheries fora, the term is used when biomass has been estimated to be below a limit biological reference point that is used as the signpost defining an "overfished condition."

Overfishing: 1. According to the National Standard Guidelines, "overfishing occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield (MSY) on a continuing basis." Overfishing is occurring if the maximum fishing mortality threshold (MFMT) is exceeded for 1 year or more; 2. In general, the action of exerting fishing pressure (fishing intensity) beyond the agreed optimum level. A reduction of fishing pressure would , in the medium term, lead to an increase in the total catch.

Party Boat: Any vessel-for-hire engaged n recreational fishing and hired (or leased, in whole or part) per a per-capita fee on a first-come, first-served basis.

Population: The number of individuals of a particular species that live within a defined area.

Population Dynamics: The study of fish populations and how fishing mortality, growth, recruitment, and natural mortality affect them.

Possession Limit: The number and/or size of a species that a person can legally have at any one time. Applies to commercial and recreational fishermen. A possession limit generally does not apply to the wholesale market level and beyond.

Producer Surplus: Producer surplus is defined as the differences between what producers actually receive when selling a product and the amount they would be willing to accept for a unit of the good.

Productivity: Relates to the birth, growth and death rates of a stock. A highly productive stock is characterized by high birth, growth, and mortality rates, and as a consequence, a high turnover and production to biomass ratios (P/B). Such stocks can usually sustain higher exploitation rates and, if depleted, could recover more rapidly than comparatively than less productive stocks.

Quota: A specified numerical harvest objective, the attainment (or expected attainment) of which causes closure of the fishery for that species or species group.

Quota Shares: A share of the total allowable catch (TAC) allocated to an operating unit such as a vessel, a company or an individual fishermen (individual fishing quota, IFQ) depending on the system of allocation. Quotas may or may not be transferable, inheritable, and tradable. While generally used to allocate total allowable catch, quotas could be used also to allocate fishing effort or biomass.

Race-to-Fish: A pattern of fishing characterized by an increasing number of highly efficient vessels fishing at an increasing pace, with season length becoming shorter and shorter.

Rate of Removal: An inexactly defined term that can mean either rate of exploitation or rate of fishing, depending on the context.

Rebuilding: 1. Implementing management measures that increase a fish stock to its target size; 2. For a depleted stock, or population, taking action to allow it to grow back to a predefined target level. Stock rebuilding at least back to the level at which a stock could produce maximum sustainable yield (MSY).

Rebuilding Plan: 1. A document that describes policy measures that will be used to rebuild a fish stock that has been declared overfished; 2. A plan that must be designed to recover stocks to the maximum sustainable yield (MSY) level within 10 years when they are overfished.

Recreational Fishery: Harvesting fish for personal use, sport, and challenge (e.g. as opposed to profit or research). Recreational fishing does not include sale, barter, or trade of all or part of the catch.

Recruit: 1. A young fish entering the exploitable stage of its life cycle; 2. A member of "the youngest age group which is considered to belong to the exploitable stock."

Recruitment: 1. The amount of fish added to the exploitable stock each year due to growth and/or migration into the fishing area. For example, the number of fish that grow to become vulnerable to the fishing gear in one year would be the recruitment

to the fishable population that year; 2. This term is also used in referring to the number of fish from a year class reaching a certain age. For example, all fish reaching their second year would be age 2 recruits.

Recruits: The numbers of young fish that survive (from birth) to a specific age or grow to a specific size. The specific age or size at which recruitment is measured may correspond to when the young fish become vulnerable to capture in a fishery or when the number of fish in a cohort can be reliably estimated by a stock assessment.

Reef: A large ridge or mound-like structure within a body of water that is built by calcareous organisms such as coral, red algae, and bivalves.

Reef Fish: Fish that live mostly on or around reefs. Reef fish include snappers, groupers, grunts, porgies, and others.

Regression Analysis: A statistical method to estimate any trends that might exist among important factors; an example in fisheries management is the link between catch and other factors like fishing effort and natural mortality.

Scientific and Statistical Committee (SSC): An advisory committee of a regional fishery management council (FMC) composed of scientists, economists, and other technical experts. The Magnuson-Stevens Act requires that each council maintain an SSC to assist in gathering and analyzing statistical, biological, ecological, economic, social, and other scientific information that is relevant to the management of council fisheries.

Size Limit: A minimum or maximum limit on the size of fish that may be legally be caught.

Size-at-Age: Length or weight at a particular age.

Socio-Economic: Pertaining to the combination in interaction of social and economic factors and involves topics such as distributional issues, labor market structure, social and opportunity costs, community dynamics, and decision-making processes.

Spawning: Release of ova, fertilized or to be fertilized.

Spawning Biomass: The total weight of all sexually mature fish in the population.

Spawning Potential Ratio (SPR): The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. SPR can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.

Species: Group of animals or plants having common characteristics, able to breed together to produce fertile (capable of reproducing) offspring, and maintaining their "separateness" from other groups.

Stakeholder: 1. A large group of individuals and groups of individuals (including governmental and non-governmental institutions, traditional communities, universities, research institutions, development agencies and banks, donors, etc.) with an interest or claim (whether stated or implied) that has the potential of being impacted by or having an impact on a given project and its objectives. Stakeholder groups that have a direct or indirect "stake" can be at the household, community, local, regional, national, or international level; 2. An actor having a stake or interest in a physical resource, ecosystem service, institution, or social system, or someone who is or may be affected by public policy.

Standard Length: The length of a fish as measured from the tip of the snout to the hidden base of the tail fin rays.

Status Quo (SQ): Can mean the general current state of affairs in a fishery.

Stock: A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. A fish stock may be treated as a total or a spawning stock. Total stock refers to both juveniles and adults, either in numbers of by weight, while spawning stock refers to the numbers or weight of individuals that are old enough to reproduce.

Stock Assessment: The process of collecting and analyzing biological and statistical information to determine the changes in the abundance of fishery stocks in response to fishing, and, to the extent possible, to predict future trends of stock abundance. Stock assessments are based on resource surveys; knowledge of the habitat requirements, life history, and behavior of the species; the use of environmental indices to determine impacts on stocks; and catch statistics. Stock assessments are used as a basis to assess and specify the present and probable future condition of a fishery.

Sustainable Fisheries Act (SFA): The SFA is a statute enacted in 1996, which amended the Magnuson-Stevens Act. Among its provisions were mandatory overfishing elimination and stock rebuilding, the establishment of a program to protect essential fish habitat, and the establishment of a new national standard for bycatch reduction.

Total Allowable Catch (TAC): The annual recommended or specific regulated catch for a species or species group. The regional fishery management council sets the TAC from the range of acceptable biological catch (ABC).

Total Catch: Total catch (optimum yield, OY). The landed catch plus discard mortality.

Total Length: The length of a fish defined as the straight-line distance from the tip of the snout to the tip of the tail (caudal fin) while the fish is lying on its side, normally extended.

Total Welfare: The sum of consumer surplus and producer surplus

Trade-Off: A balancing of factors all of which are not attainable at the same time (e.g. maximum economic yield, MEY, and maximum sustainable yield, MSY). A giving up of one thing in return for another.

Trawling: Fishing technique in which a net is dragged behind the vessel and retrieved when full of fish. This technique is used extensively in the harvest of Pollock, cod, and other flatfish in North pacific and New England fisheries. It includes bottom- and midwater fishing activities.

Utility: 1. The level of welfare that a person gets from consuming a good or undertaking an activity; 2. In economics, the measure of the degree of satisfaction or happiness of a person.

Variable Costs: Costs that vary with the level of output.

Virgin Biomass: The average biomass of a stock that has yet not been fished (in an equilibrium sense). Biomass of an unexploited (or quasi unexploited) stock. Rarely measured. Most often inferred from stock modeling. Used as a reference value to assist the relative health of a stock, monitoring changes in the ratio between current and virgin biomass.

Virgin Stock: A stock of fish with no commercial or recreational harvest. A virgin stock changes only in relation to environmental factors and its own growth, recruitment, and natural mortality.

Vulnerability: A term equivalent to catchability but usually applied to separate parts of a stock, for example, those of a particular size, or those living in particular part of the range.

Welfare: The prosperity or, more broadly, the well being of a person or group.

Appendix B – Survey Reminder Card

Gulf of Mexico Recreational Fishing Survey

Recently, you received a survey in the mail from our master's thesis team at the University of California, Santa Barbara. The survey was designed to assess the preferences and viewpoints of recreational reef fish fishermen in the Gulf of Mexico regarding improved management strategies.

If you have filled out the survey, thank you for taking the time to do so.

If you have not had a chance to take our survey, you are still welcome to complete the mail survey you received previously. If you no longer have the mail survey, you now have the option to complete it online at the following link:

https://www.surveymonkey.com/s/GoMex

The survey should take only **5 minutes to complete**. If you return the survey and provide us with their name and mailing address, you will be entered into a raffle for a free saltwater fishing reel (valued at $300). Please complete the survey by **December 31st, 2012**.

Thank you for taking the time to complete this survey.

Sincerely,

The "GoMex" Master's Thesis Team
University of California, Santa Barbara

Appendix C - Survey

Gulf of Mexico Recreational Fishing Survey

This survey was designed to assess the preferences and viewpoints of recreational reef fish fishermen in the Gulf of Mexico regarding improved management strategies and **should only take 5 minutes to complete**. The results of this survey will be an important supplement to the recommendations made by our master's thesis project to regional stakeholders on novel management strategies in the recreational fishery.

Respondents who return the survey and provide us with their name and mailing address will be entered into a raffle for a free saltwater fishing reel (valued at $300). Entering the raffle is not required, and the likelihood of winning the fishing reel is 1 out of 1,200, or 0.08%. If you do enter the raffle, your name and address will be removed from the survey upon receipt and stored in a locked container in order to protect your identity. After the drawing is completed, your information will be destroyed. Your participation is voluntary and poses no particular risks. You may withdraw from participation at any time.

Thank you for taking the time to complete this survey.

Sincerely,

The "GoMex" Master's Thesis Team
University of California, Santa Barbara

Fishing Activities

1. How are you involved with the Gulf of Mexico reef fish fishery? (Please check all that apply)

___Private boat owner 1 ___Charter boat operator 5
___Party boat operator 2 ___Fisherman on a for-hire boat (charter/party boat) 6
___Gulf of Mexico Fishery Management Council member 3
___Bait or tackle provider 4 ___Fishermen on a commercial boat 7
___Other: Please list _____ 8

2. Are you a member of a recreational angling club, group or association?

___Yes (continue to Question 2a) 1 ___No (continue to Question 3) 2

2a. If yes, which one?

_____

3. Do you fish for red snapper?

___Yes (continue to Question 3a) 1 ____No (continue to Question 4) 2

3a. If yes, in what waters do you fish?
_____ State 1 _____Federal 2 _____Both 3 _____N/A 4

Background Information
Currently, the regulations for red snapper are a daily bag limit of two fish per person and a 16-inch minimum size length.

Management Preferences
4. For red snapper, rank the following management improvements in order of importance to you (1 being most important, 6 being least important). You must rank each item:

_____More fish per person
_____More fish per trip
_____More fishing days per year
_____Ability to choose your own fishing days
_____Ability to purchase additional fishing days
_____Ability to submit fishing data (size, number, fishing zone, skeletons, etc.) directly to managers

5. Is there another management improvement not listed in Question 4 that would be feasible for Gulf of Mexico reef fisheries?
____ Yes (continue to Question 5a) 1 ____ No (continue to Question 6) 2

5a. If yes, please explain.
_____
_____

6. Have you heard about the proposed sector separation of the recreational fishing community in the Gulf of Mexico?
____Yes 1 ____No 2

7. Have you ever attended a Gulf of Mexico Fishery Management Council meeting?
____Yes (continue to Question 7a) 1 ____No (continue to Question 8) 2

7a. If yes, when?
____Past 6 months 1 ____6 months to 3 years 2 ____Over 3 years 3

Background Information
Amendment 28 includes a newly proposed management strategy for the recreational reef fishery in the Gulf of Mexico. Specifically, the recreational sector would be split into a for-hire component (charter boats, head boats, etc.) and a private component for management purposes. Each component would have its own set of rules and regulations. For the purpose of this project, we will be focusing on fishing and management preferences for the red snapper fishery.

8. Would you be in support of creating 3 fishing sectors for red snapper: commercial, for-hire recreational, and private recreational?
___Yes 1 ___No 2

Basic Information

9. Gender
___Male 1 ___Female 2

10. Age
___ 18 or under 1 ___19-30 2 ___31-40 3 ___41-50 4
___51-60 5 ___61-70 6 ___71-80 7 ___81 or above 8

11. State of Residence
___Texas 1 ___Louisiana 2 ___Mississippi 3 ___Alabama 4 ___Florida 5
___Other: Please list _____ 6

Additional Comments (Please feel free to write any additional comment related to the survey or recreational fisheries in the Gulf of Mexico.)

_____
_____
_____
_____
_____

Thank you!

Please return your survey in the enclosed postage-paid envelope by **December 10th, 2012.** If you have any questions or need assistance, please contact the GoMex Team (Katie Hentrich, Molly Troup, Jessi Doerpinghaus, and Aristoteles Stavrinaky) at the University of California, Santa Barbara during normal business hours at (805) 364-4388 or at gomex.bren@gmail.com. You may also contact the University of California, Santa Barbara Human Subjects Committee at (805) 893-3807 during normal business hours.

Raffle

If you would like to be entered into a raffle for a fishing reel (valued at $300), please provide us with your name and mailing address below. Entering this raffle is not required. However, if you would like to enter the raffle, your identifying information will be separated from your responses and destroyed after the drawing occurs.

Name: _____
Address: _____

Appendix D – Additional Figures, Biological Results

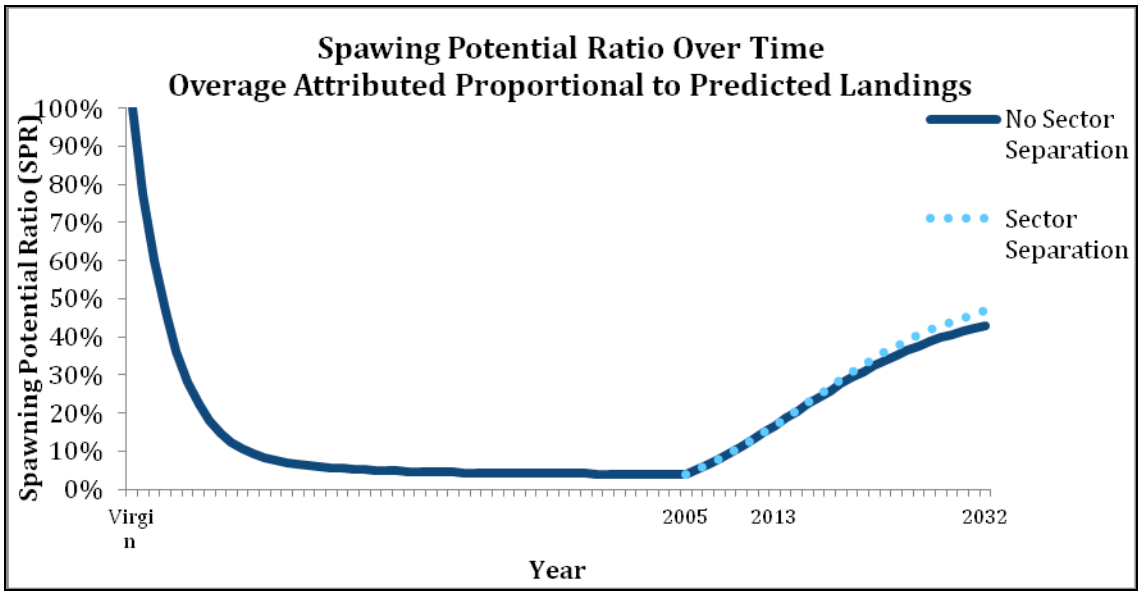

Figure 30. Spawning potential ratio over time with overages split between private and for-hire anglers based on current landings

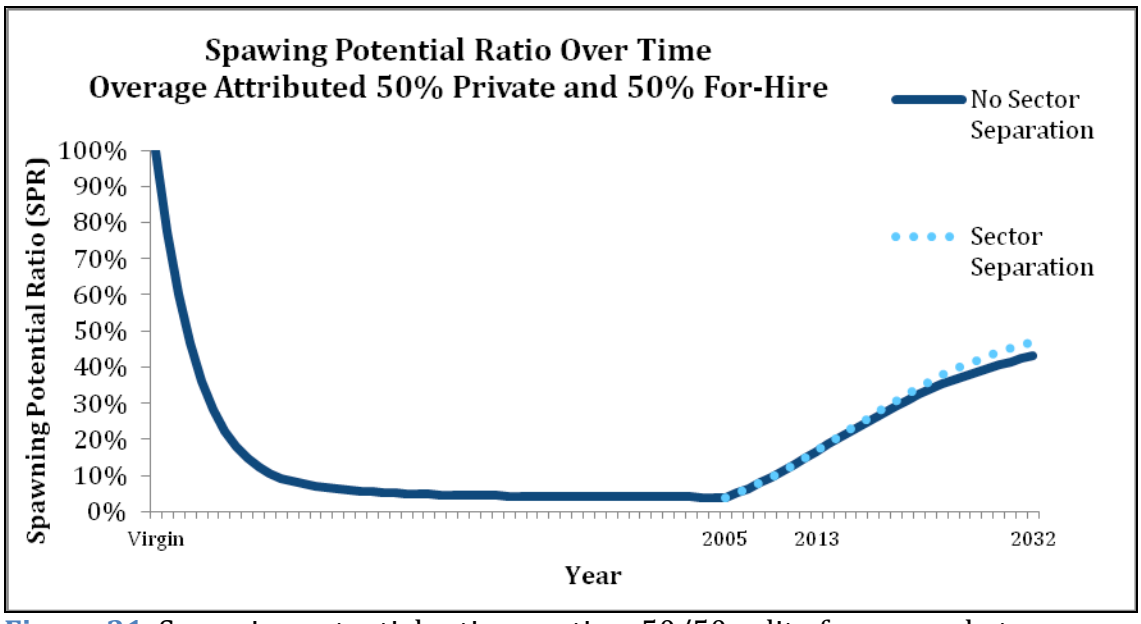

Figure 31. Spawning potential ratio over time 50/50 split of overages between private and for-hire sectors

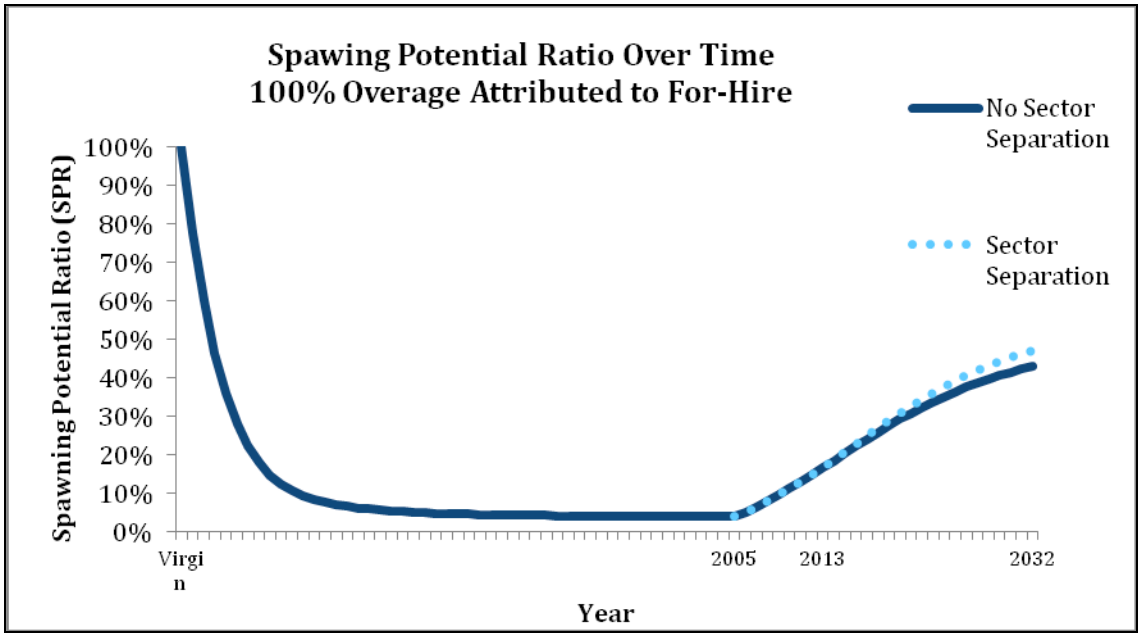

Figure 32. Spawning potential ratio over time with 100% of overage attributed to for-hire sector

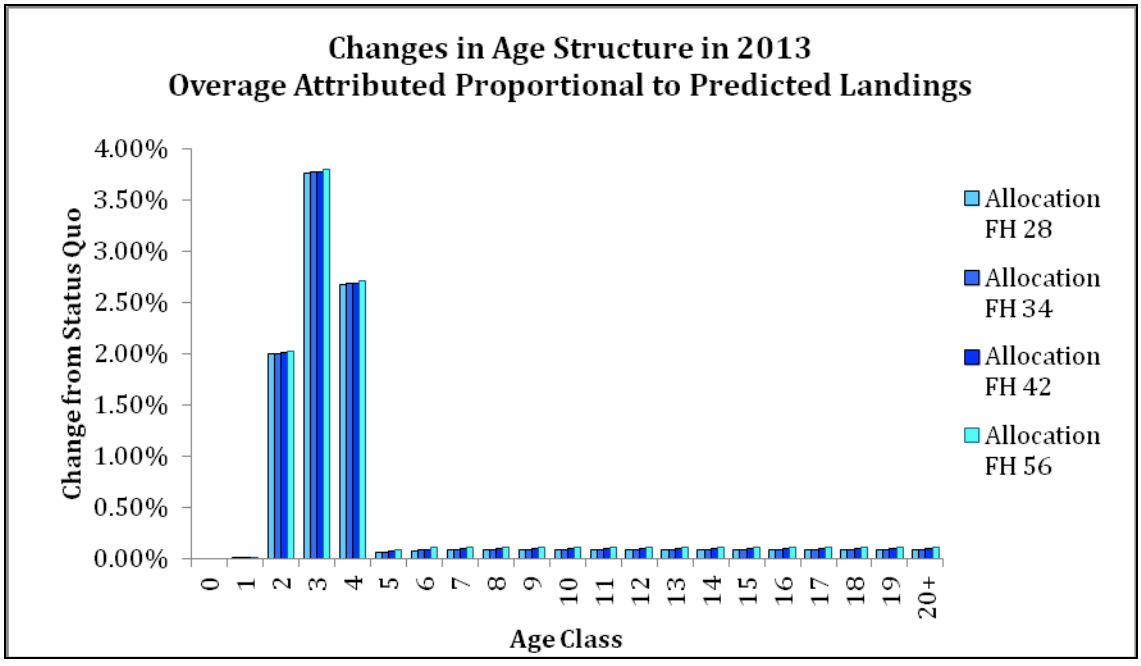

Figure 33. Changes in numbers-at-age in 2013 with overages split between private and for-hire anglers based on landings

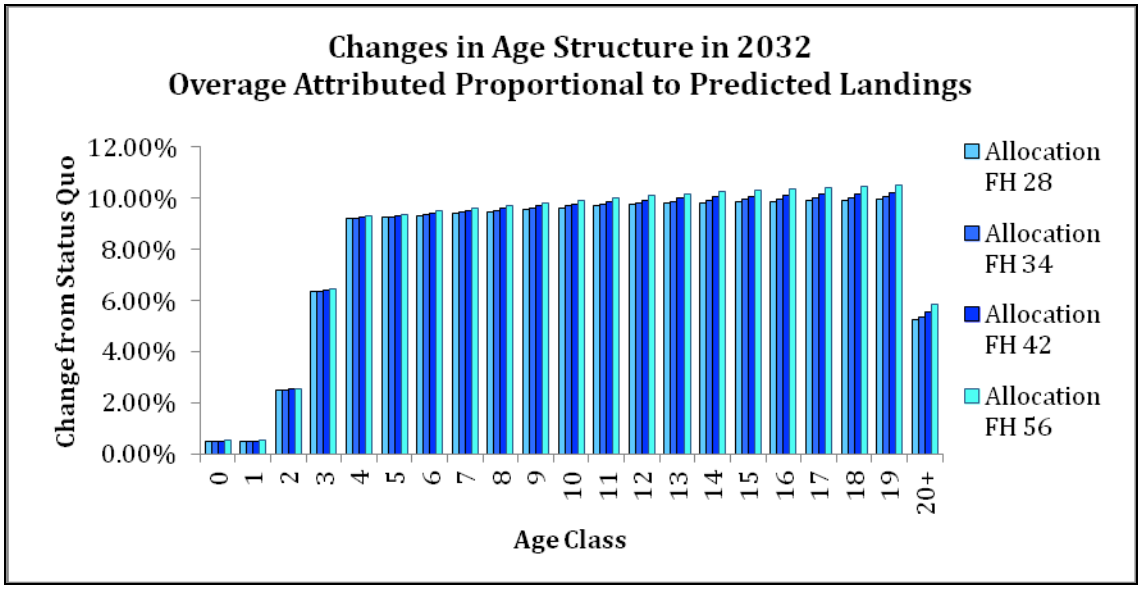

Figure 34. Changes in numbers-at-age in 2032 with overages split between private and for-hire anglers based on landings

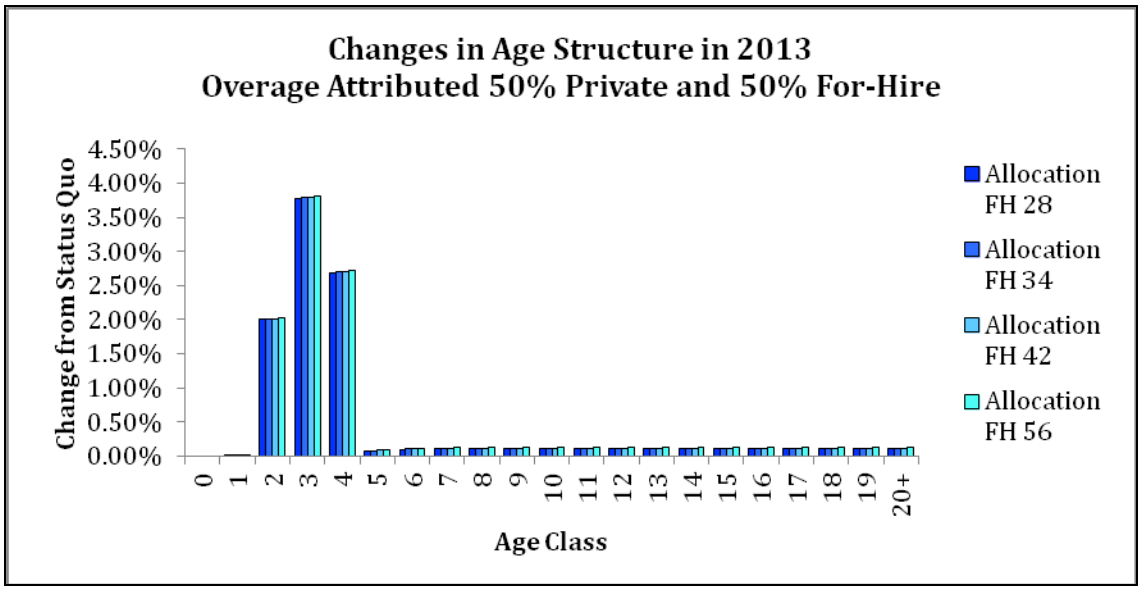

Figure 35. Changes in numbers-at-age in 2013 with 50/50 split of overages between private and for-hire anglers

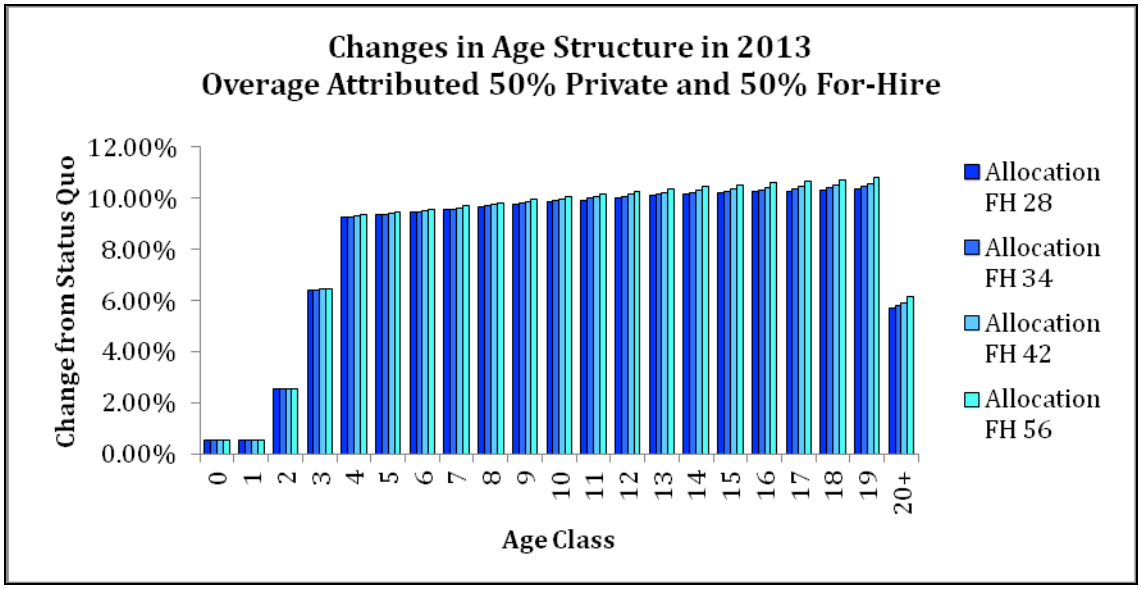

Figure 36. Changes in numbers-at-age in 2032 with 50/50 split of overages between private and for-hire anglers

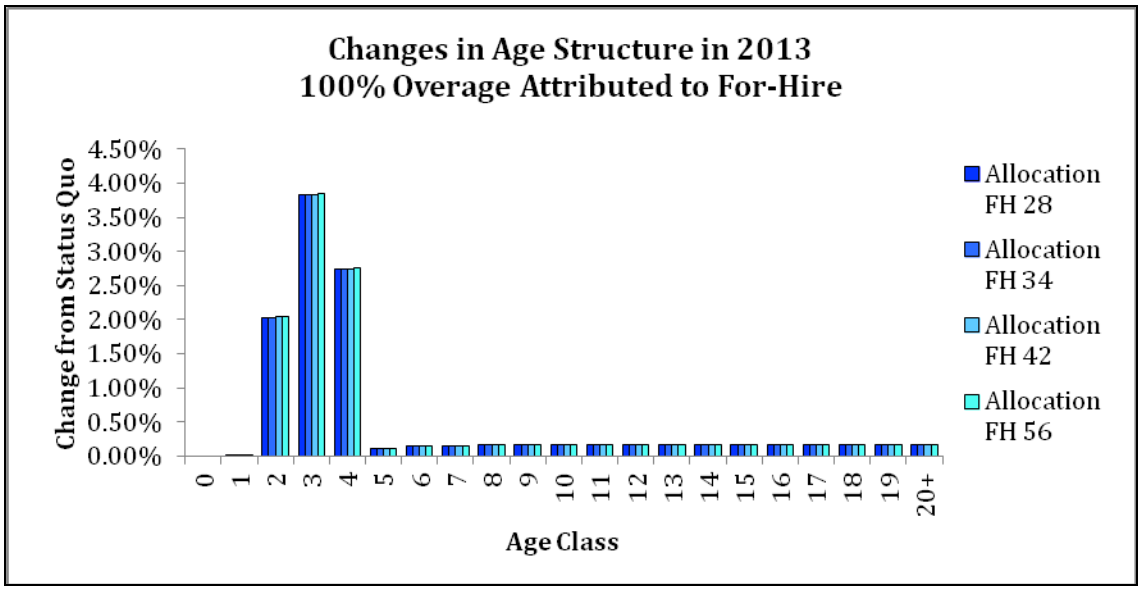

Figure 37. Changes in numbers-at-age in 2013 with 100% of overages attributed to for-hire anglers

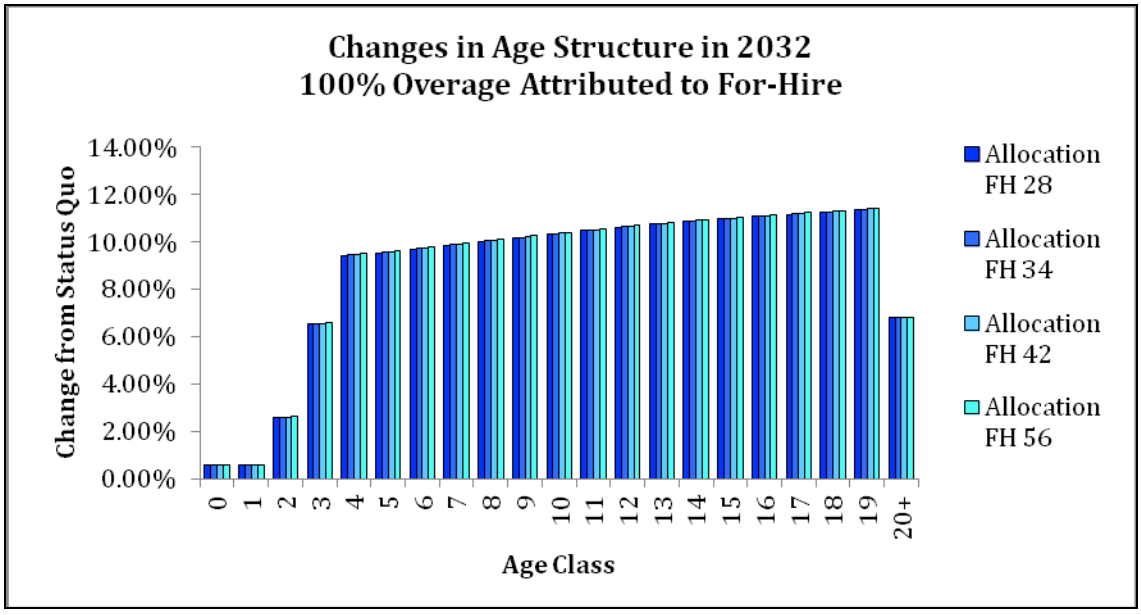

Figure 38. Changes in numbers-at-age in 2032 with 100% of overages attributed to for-hire anglers

Appendix E – Additional Figures, Economic Results

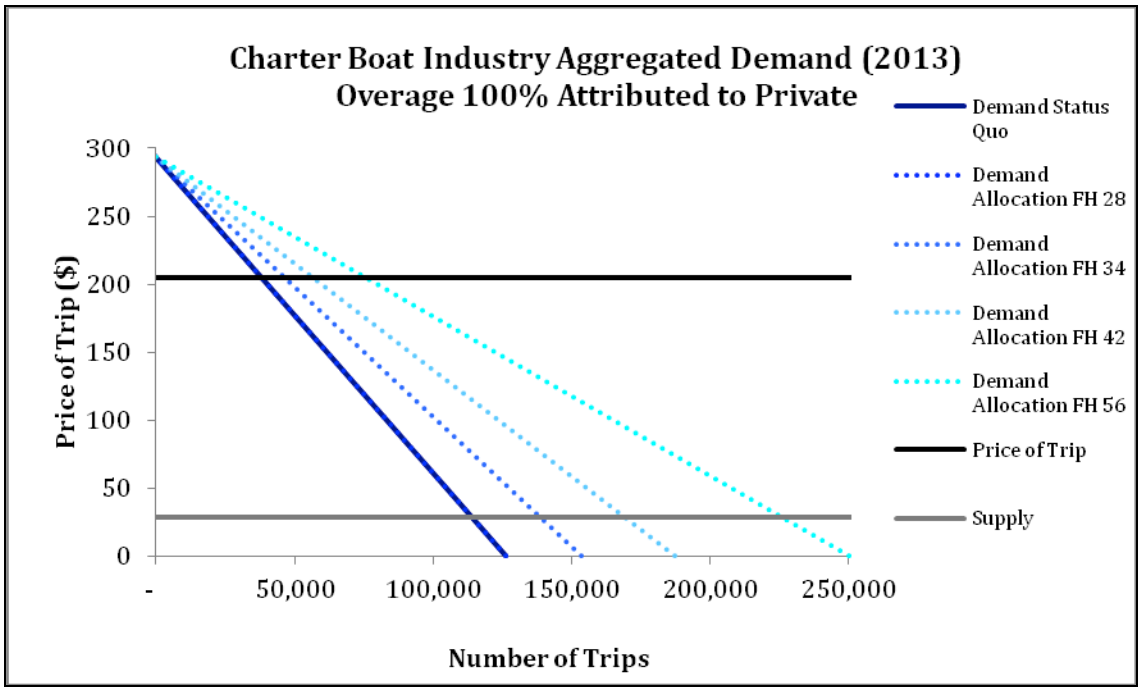

Figure 39. Aggregated demand in 2013 for charter boat industry with 100% of overage attributed to private anglers

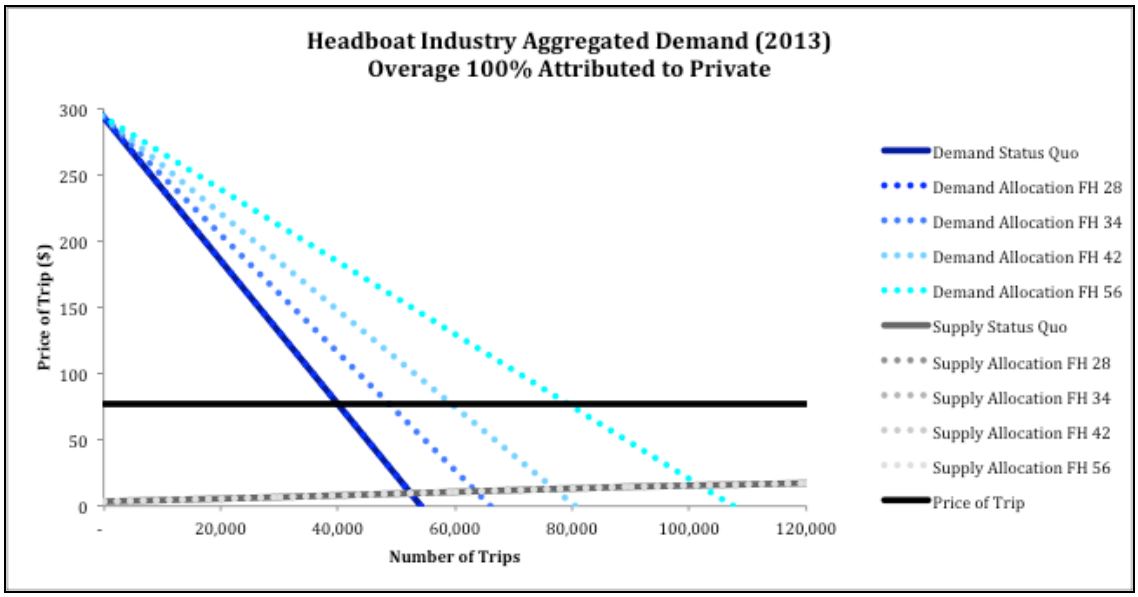

Figure 40. Aggregated demand in 2013 for headboat industry with 100% of overage attributed to private anglers

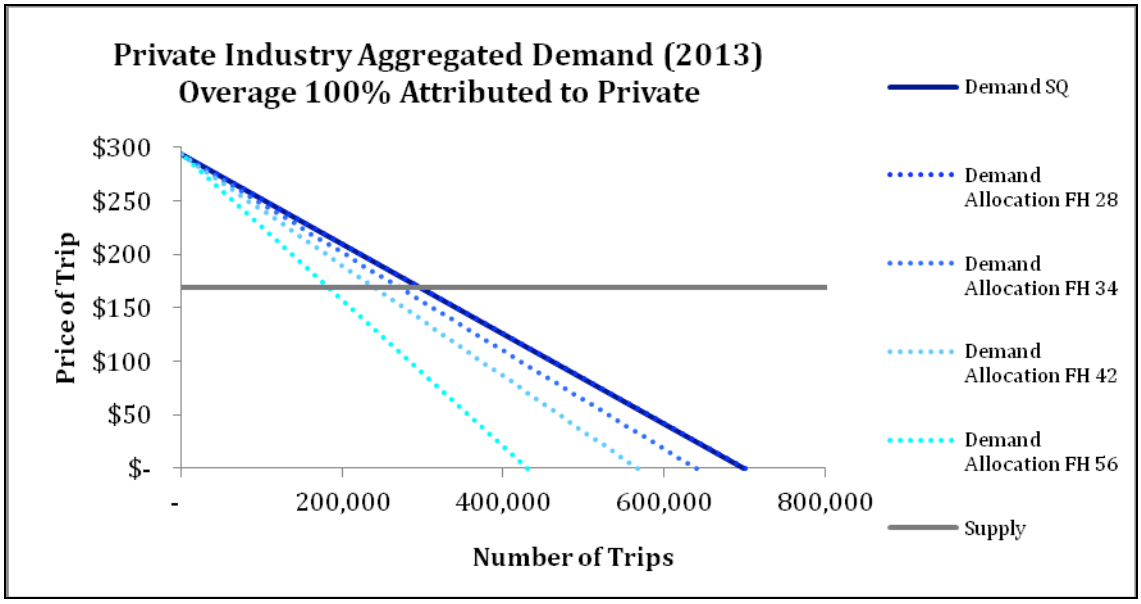

Figure 41. Aggregated demand in 2013 for private anglers with 100% of overage attributed to private anglers

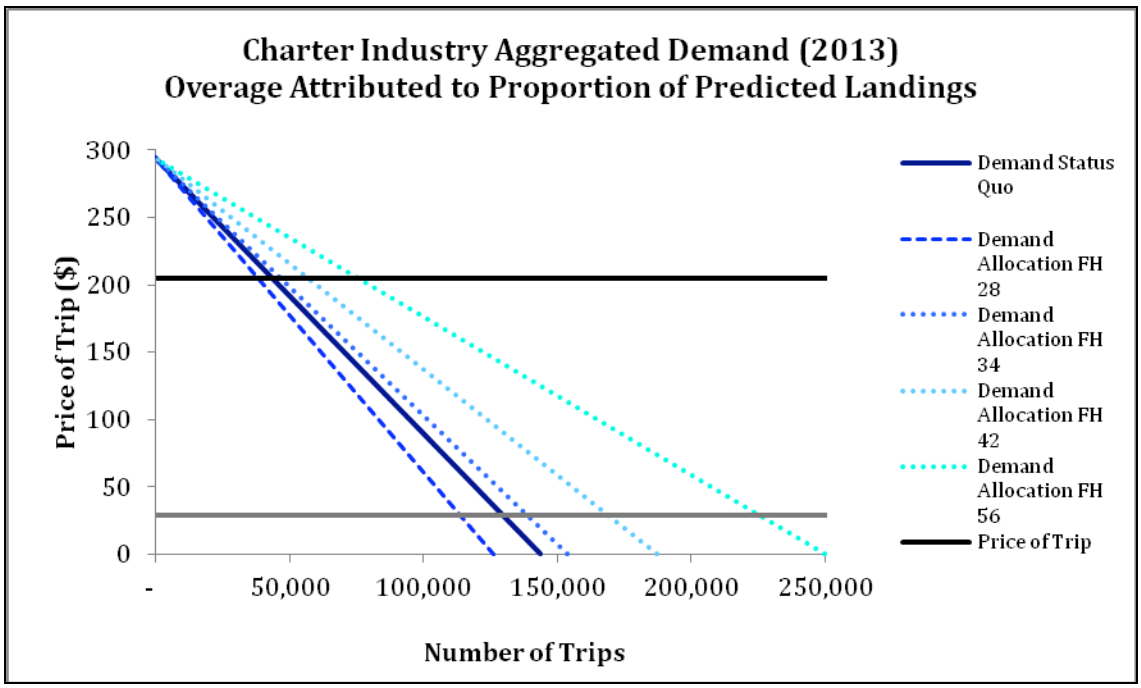

Figure 42. Aggregated demand in 2013 for charter boat industry with overages split between private and for-hire anglers based on landings

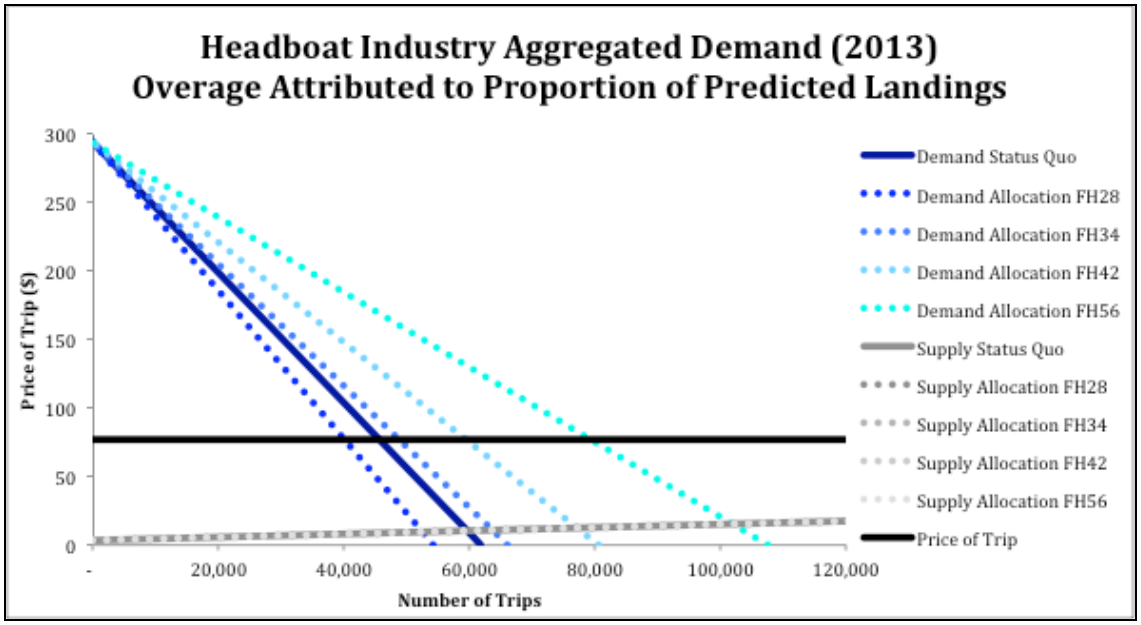

Figure 43. Aggregated demand in 2013 for head boat industry with overages split between private and for-hire anglers based on landings

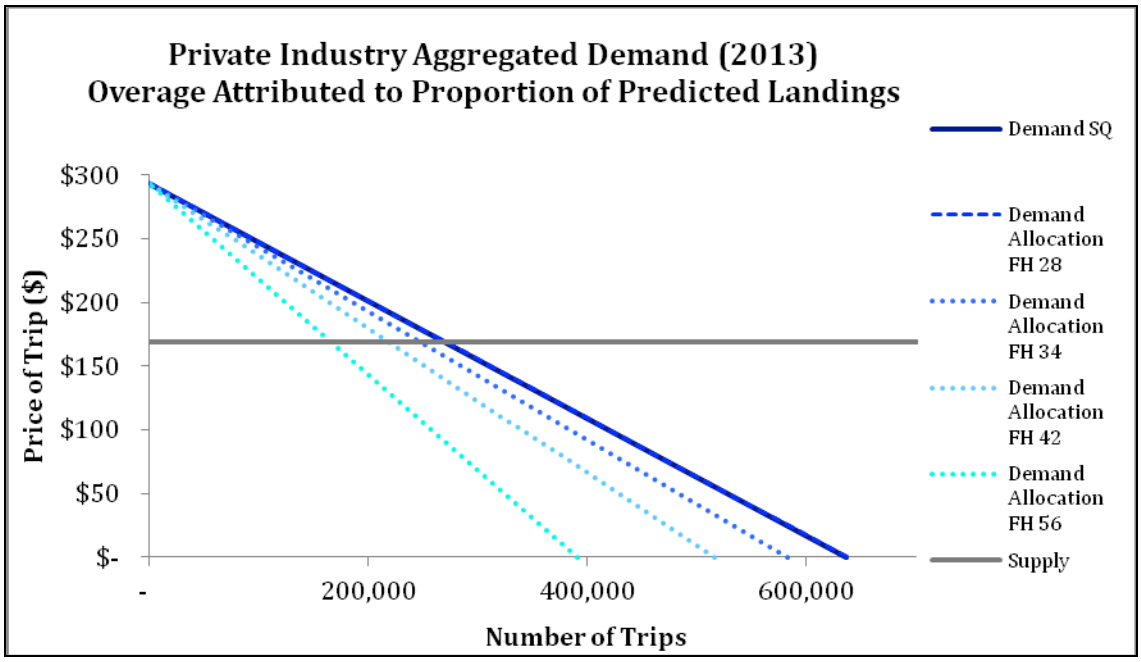

Figure 44. Aggregated demand in 2013 for private anglers with overages split between private and for-hire anglers based on landings

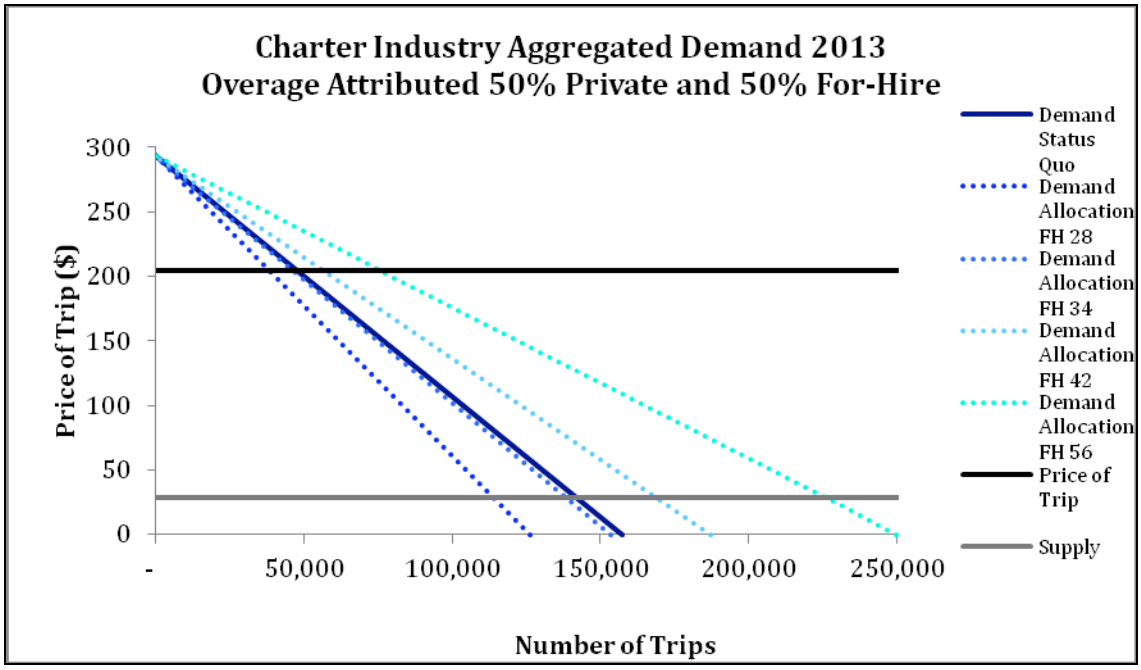

Figure 45. Aggregated demand in 2013 for charter boat industry with 50/50 split of overages between private and for-hire anglers

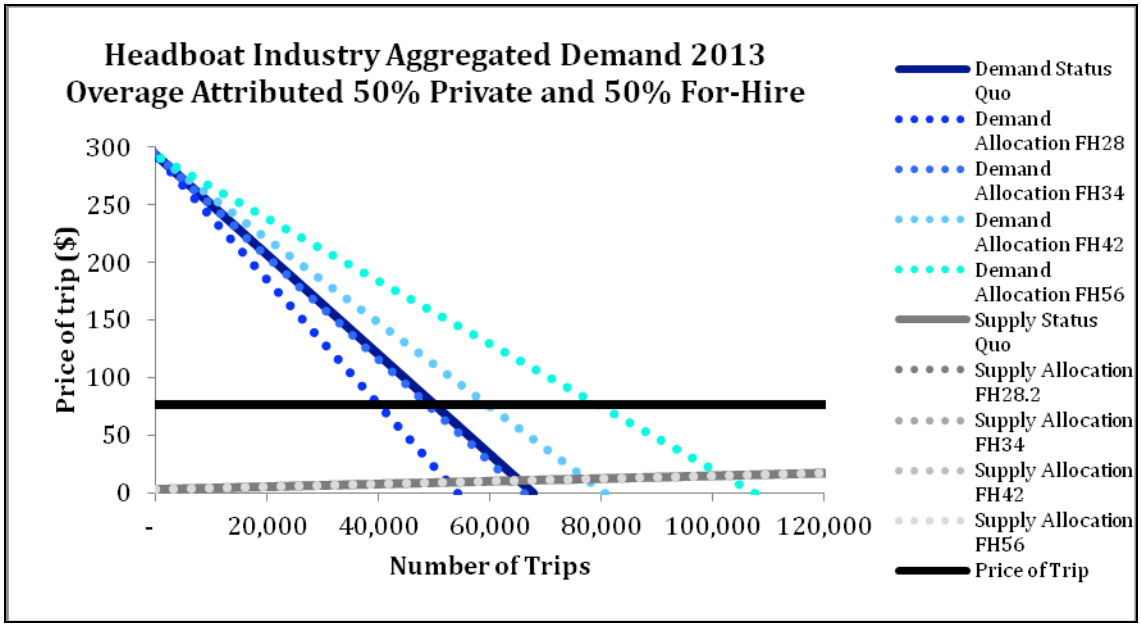

Figure 46. Aggregated demand in 2013 for headboat industry with 50/50 split of overages between private and for-hire anglers

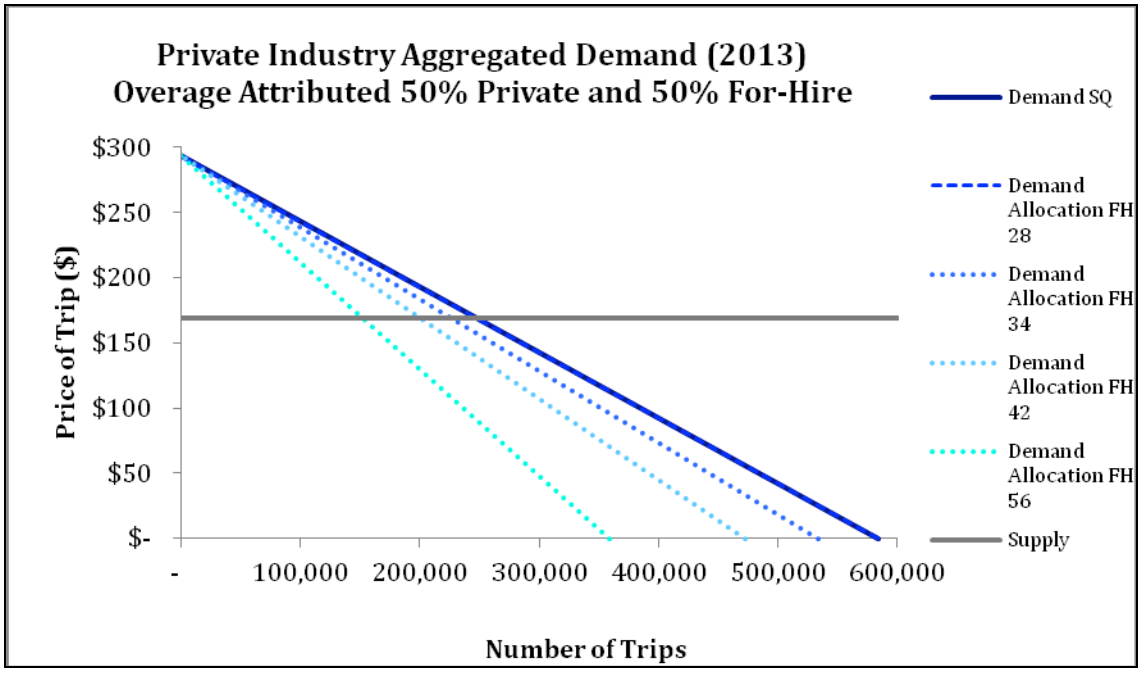

Figure 47. Aggregated demand in 2013 private anglers with 50/50 split of overages between private and for-hire anglers

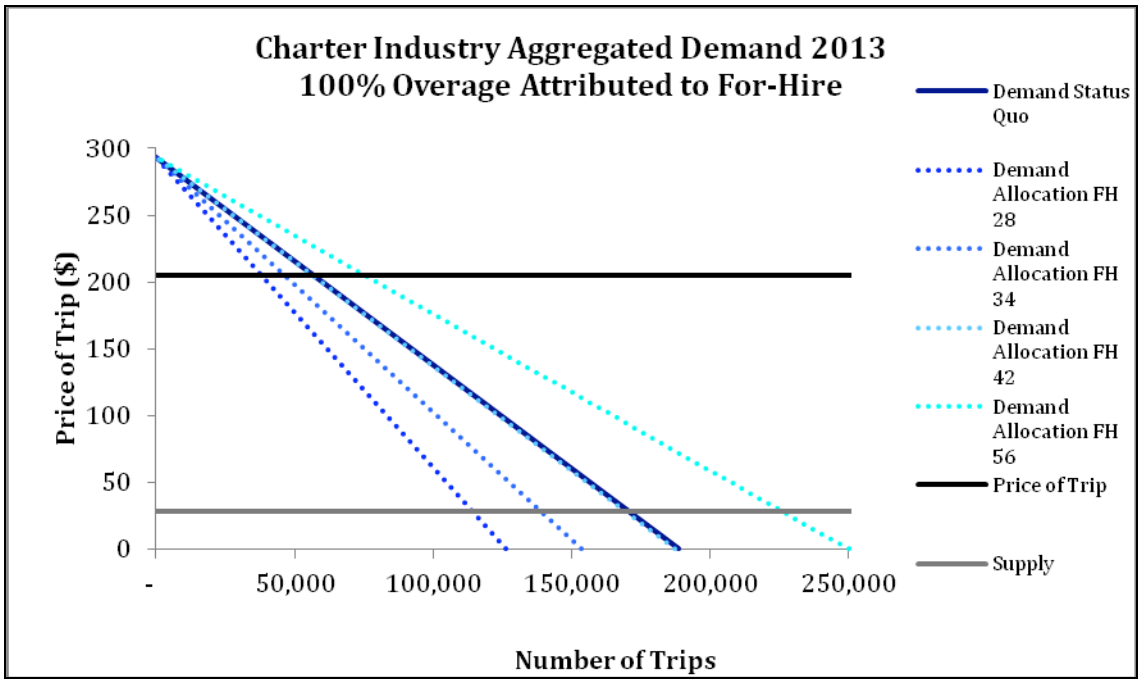

Figure 48. Aggregated demand in 2013 for charter boat industry with 100% of overage attributed to for-hire anglers

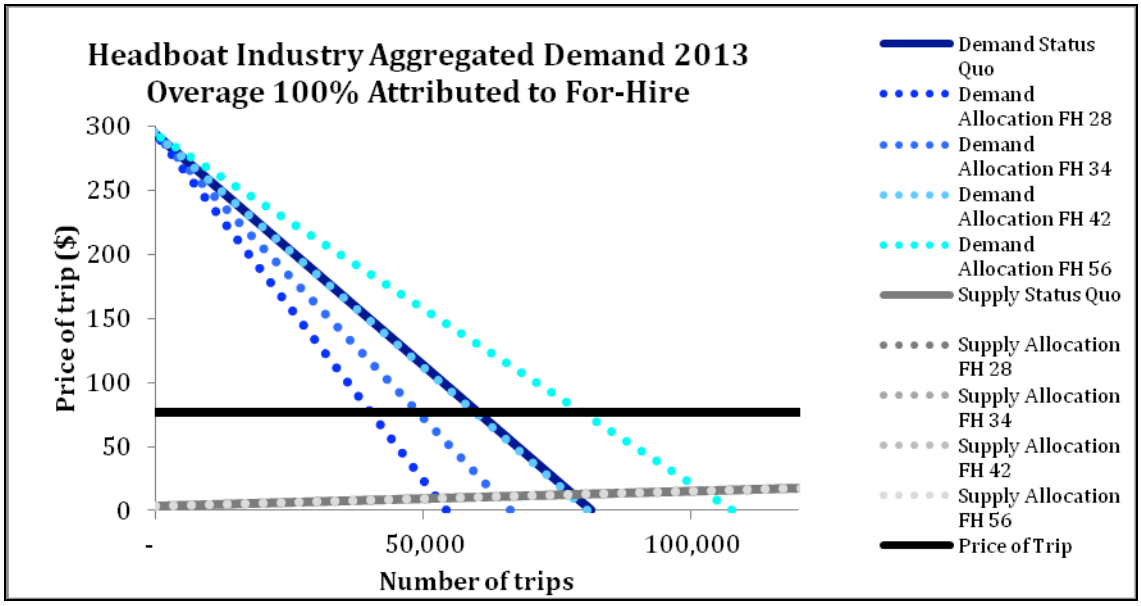

Figure 49. Aggregated demand in 2013 for headboat industry with 100% of overages attributed to for-hire anglers

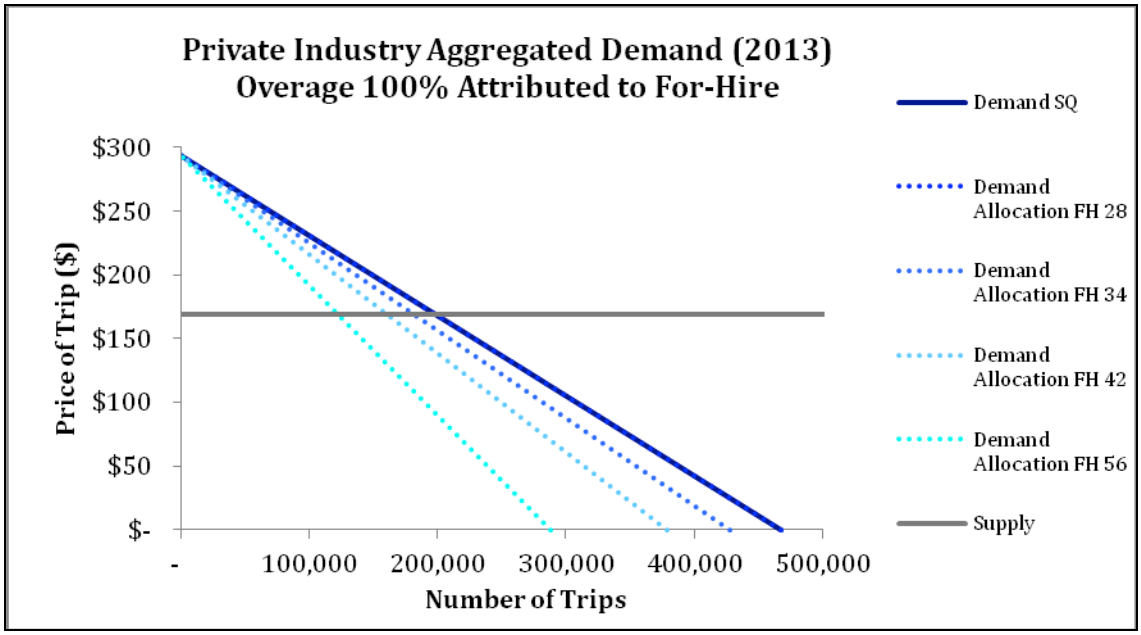

Figure 50. Aggregated demand in 2013 for private anglers with 100% of overages attributed to for-hire anglers