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Use of barotrauma mitigation measures in the Gulf of Mexico grouper fisheries

Final Report

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Use of barotrauma mitigation measures in the Gulf of Mexico grouper fisheries

Final Report

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Executive summary

Introduction

- Reducing barotrauma-related bycatch and discard mortality of reef fish that are caught on hook and line and not kept is an important stock conservation priority. Fish venting and use of descending gear are equally effective measures to reduce barotrauma-related mortality.
- The project aimed to determine patterns of use of barotrauma mitigation measures and factors influencing the choice of measures in recreational, charter and commercial grouper fisheries in the Gulf of Mexico. The project also reviewed outreach strategies and materials in light of these results.
- In addition to reviews of prior information, the project designed and implemented an internet survey of reef fishers in Florida. The survey covered fishing experience/behavior, experiences with barotrauma, awareness and use of mitigation methods, and attitudes, social norms and perceived control with regards to such methods.

Results

- In the Gulf, a large share of reef fishing activity occurs in relatively shallow waters, with 70% of recreational, 81% of charter and 65% of commercial activity occurring in waters less than 90 ft (15 fathoms) deep.
- The median proportion of fish discarded among commonly caught reef fish species (excluding goliath grouper which is illegal to keep) was 51% (range: 30%-63%) in the recreational sector, 54% (range: 30%-68%) in the charter sector, and 34% (range: 13%-60%) in the commercial sector.
- About 50-70% of reef fishers in the different sectors are aware of venting tools, while 30-50% are aware of both venting tools and descending gear. Some 70-85% of respondents have used venting tools but only 10-25% have used both venting tools and descending gear.
- Fishers from all sectors agreed that both venting tools and descending gear help fish return to depth and improve their survival, but feel that descending gear takes more time, is more difficult to use and is more expensive than venting tools.
- Fishers experienced social pressure to use venting tools but did not feel the same pressure to use descending gear.
- Fishers in all sectors felt confident in their ability to use both venting tools and descending gear (the latter slightly less so) and disagreed that they needed more training in the use of either.
- In all sectors and for both tools, perceived social norms were by far the strongest predictor of intention to use. Attitudes to the tools and perceived control have only a marginal influence on intention to use.
- Overall fishers were supportive of (re-) introducing a rule requiring possession or use of a barotrauma mitigation device. Only 26% of all respondents agreed (17%) or strongly agreed (9%) that possession of such a device should not be required.

- A wide range of information sources were used by fishers from all sectors, with other fishers (anglers and boat captains), websites, fishing magazines, tackle shops and state agencies being the most commonly used.

Outreach and policy implications

- Emphasize that venting and descending are equally effective (if done correctly).
- Describe pros and cons of each.
- Emphasizing barotrauma mitigation as a social norm is predicted to have the greatest impact on use of mitigation measures.
- Social norms can be promoted through opinion leaders, fisheries forums, and regulations.
- Since fishers are overly confident in their ability to use mitigation measures correctly, outreach aimed at promoting correct use must first question their confidence.
- Re-introduction of requirement to possess a barotrauma mitigation tool is likely to emphasize the social norm and is opposed by only a minority of fishers.

Introduction

Reducing barotrauma-related bycatch and discard mortality of reef fish that are caught on hook and line and not kept is an important stock conservation priority. Fish venting and use of descending gear are effective measures to reduce barotrauma-related mortality. However, following removal of the venting tool requirement for Gulf of Mexico reef fisheries in 2013, fishers are no longer required to possess or use any such tools (even though their use continues to be promoted). The level of use of barotrauma mitigation measures by recreational and commercial fishers has major implications for stock dynamics and high level of use results in higher allowable catches.

Despite the importance of barotrauma mitigation measures to the Gulf of Mexico grouper fisheries, there is currently very limited information on the level of use of different measures, the factors determining use (or non-use) of the various potential measures by fishers, and the effectiveness of information campaigns intended to promote use of such measures. This project addressed these information gaps and aimed to provide improved estimates of barotrauma mitigation practices for use in stock assessments and strengthening outreach and information campaigns targeted at fishing stakeholders.

Project aims

1. To determine patterns of use of barotrauma mitigation measures in recreational and commercial grouper fisheries in the Gulf of Mexico.

2. To determine factors influencing the choice of barotrauma mitigation measures among recreational and commercial grouper fishers in the Gulf of Mexico.

3. To review and enhance outreach strategies and materials in the light of results from deliverables (1) and (2) to promote use of effective barotrauma mitigation measures.

Project activities

Review activities

Brief technical reviews were carried out on the effectiveness of alternative barotrauma mitigation measures in increasing survival, information from prior surveys related to use of barotrauma mitigation measures, and barotrauma mitigation–related outreach and extension messages.

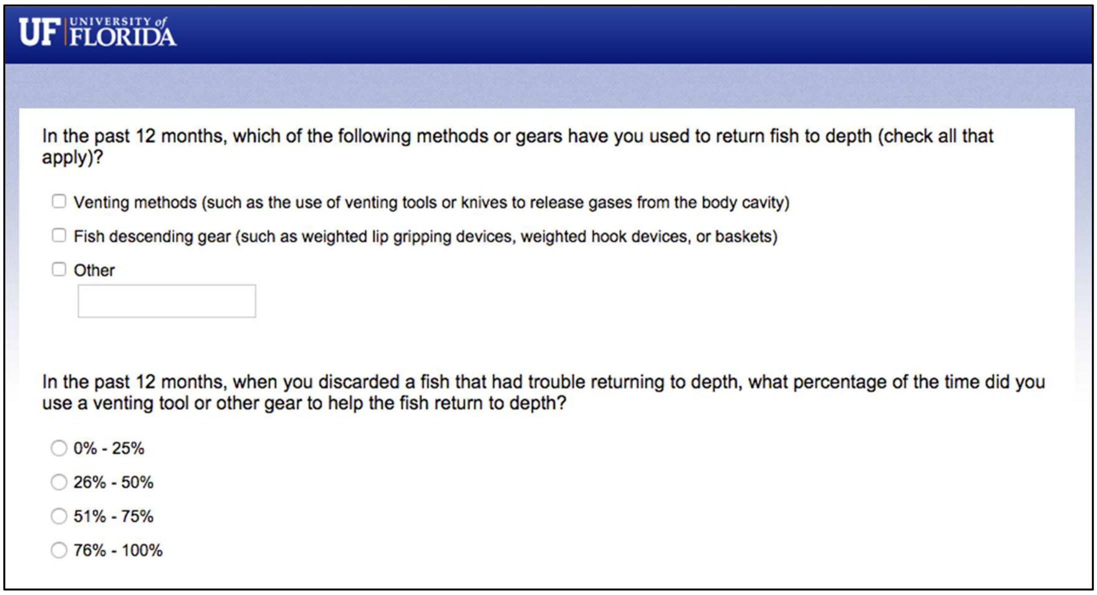
Design and implementation of a new barotrauma mitigation survey

Following synthesis and review activities, the project team decided to undertake a further survey in order to fill important data gaps and to develop a more sophisticated understanding of fisher behavior with respect to the use barotrauma mitigation measures.

The purpose of the survey was to gain a better understanding of fishers' use and perceptions of barotrauma mitigation devices including fish venting tools and descending devices. The survey was sent to three samples of fishers operating in the Gulf of Mexico: recreational reef anglers, charter captains and commercial fishermen. Through the survey, the project gained a better understanding of fishers' experiences with barotrauma, use of barotrauma mitigation devices, and perceptions of barotrauma mitigation. The survey used the Theory of Planned Behavior to predict and explain fishers' intentions and behavior regarding the use of barotrauma mitigation measures.

The first part of the survey aimed to characterize respondents' experiences with barotrauma and discards while also obtaining descriptive information regarding relevant fishing behavior. While the first question aimed to capture all of the ways each respondent identifies as a fisheries stakeholder, the rest of the survey requested them to respond according to their sampled identity (i.e., answer as a commercial fisherman, a recreational angler, or a charter captain) in order to explore differences in behavior and attitudes among these groups. The following questions referred to basic fishing characteristics and aimed to characterize the individual's frequency and method of fishing. Respondents were then asked to describe the percentage of time they spend fishing at different depth strata, which is assumed to influence their likelihood of encountering barotrauma. The following questions then asked respondents to identify both the frequency with which they catch certain reef species (in order to generally characterize their catch composition) as well as the perceived percentage of each species that they discard (in order to get a rough estimate of discard rate). They were also asked to identify their reason for discarding each species in order to distinguish whether discards occur because of regulation or because of personal preference. Respondents were then asked a series of questions regarding their own experiences with barotrauma and their knowledge and use of barotrauma mitigation devices (Figure 1) such as venting tools and descending gear, as well as their perceptions of the use of such gear by other fishers. Together this will give an idea of the frequency of use of barotrauma mitigation devices by the different stakeholder groups. In addition, respondents were asked about the use of such tools historically (i.e., when required by law) in order to explore whether they perceive that a change in use has occurred following the regulation change.

The next series of questions focused on items from the Theory of Planned Behavior (Ajzen 1991). The Theory of Planned Behavior is one of the most influential and widely used social psychological theories for predicting and explaining human behavior. The theory states that behavioral intent is formed by three variables: the attitude towards a behavior, the subjective norms, and the perceived behavioral control (Figure 2).


In the past 12 months, which of the following methods or gears have you used to return fish to depth (check all that apply)?

- Venting methods (such as the use of venting tools or knives to release gases from the body cavity)
- Fish descending gear (such as weighted lip gripping devices, weighted hook devices, or baskets)
- Other

In the past 12 months, when you discarded a fish that had trouble returning to depth, what percentage of the time did you use a venting tool or other gear to help the fish return to depth?

- 0% - 25%
- 26% - 50%
- 51% - 75%
- 76% - 100%

Figure 1: Example screen of the barotrauma survey

Generally, the more favorable the attitude and the subjective norm and the greater the perceived behavioral control, the stronger the intent of the individual to perform the behavior. Considering many behaviors pose difficulties of execution that may limit volitional control, behavior is the product of behavioral intent and perceived behavioral control. We applied this theory to predict behavior and intent to use barotrauma mitigation devices, taking into consideration fisher attitudes toward barotrauma mitigation, perceived social pressure regarding the use of barotrauma devices, and perceived control over the use of barotrauma devices. Therefore, the survey consisted of a series of question blocks to identify respondents' attitudes toward venting tools and descending gear, social norms associated with use of such devices, and their perceived control with regards to venting tools and descending gear, as well as their intent to use either in the future. In addition, respondents were asked about their attitudes toward barotrauma mitigation in general (for example, do they agree that returning a fish to depth will help its survival?), about their beliefs regarding regulatory requirement of such devices, and about their sources of information about fishing.

Multiple regression analysis was used to examine the effectiveness of the Theory of Planned Behavior in predicting intention to use barotrauma tools. Specifically, we assessed the relative contributions of attitudes, subjective norms and perceived behavioral control to the prediction of intentions.

The final part of the survey consisted of a series of demographics questions to characterize the respondent population. This included questions about date of birth, gender, and ethnicity, as well as questions about education, income, and zip code.

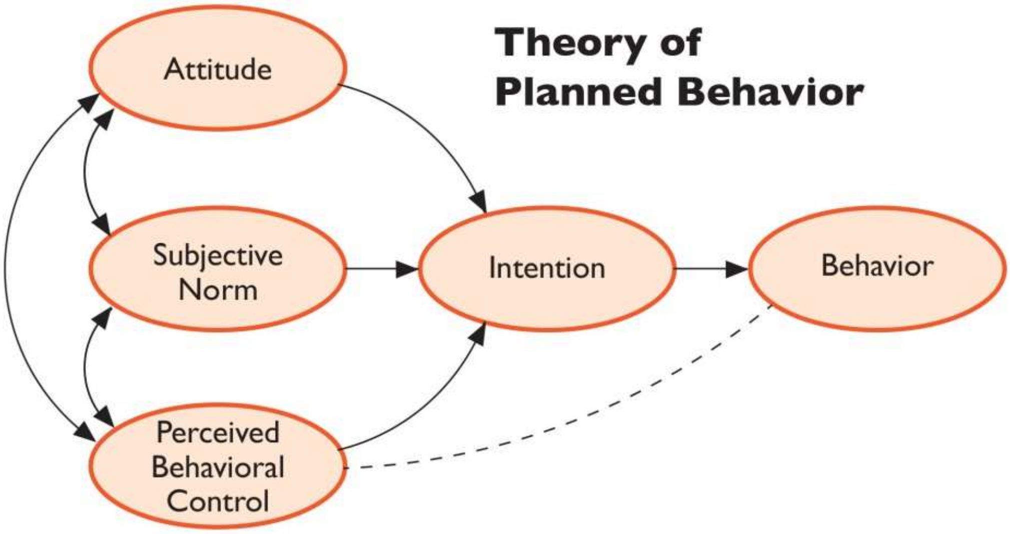


Figure 2: Theory of Planned Behavior

Respondents were contacted by email and invited to complete the survey (Dillman et al. 2009). The populations, samples and responses for the different fishing stakeholder groups were: a panel of recreational "reef fishers" who had self-identified as such in a previous survey (sample 2,162; responses: 573; response rate: 22%); commercial fishing license holders with registered email addresses (population and sample: 3938; responses: 270; response rate 7%); charter fishing license holders with registered email addresses (population and sample: 1245; responses: 146; response rate 12%). Respondents included fishers who fished primarily in the Gulf as well as some who fished primarily in the Atlantic. While these groups differed in some aspects (such as the depth profile of their fishing activities), many of their characteristics were indistinguishable. In the analysis, therefore, Gulf and Atlantic fishers were separated where relevant but otherwise combined.

Outreach and extension webinar

A webinar was held with selected extension agents and specialists from Florida Sea Grant to discuss the outreach and extension implications of survey results. Florida Sea Grant has a very active barotrauma mitigation outreach program and runs the website catchandrelease.org, a widely used source of barotrauma-related information.

Results

Reviews of prior information

Effectiveness of barotrauma mitigation measures

The effectiveness of barotrauma mitigation measures in general (and of venting in particular) has been subject to considerable scientific debate. However, recent and ongoing studies in the Gulf show that, when carried out correctly, venting and descending measures have clear and equal survival benefits (Drumhiller et al 2014 and Curtis et al. 2015 for red snapper; A. Collins, Florida Sea Grant, pers. comm. for gag grouper (ongoing MARFIN award NA13NMF4330168 to the Florida Fish and Wildlife Conservation Commission)).

Prior surveys relevant to barotrauma mitigation

An observer program on federally permitted commercial reef fishing vessels in the Gulf provides information on discard rates (25% in the vertical line and 47% in the bottom longline fisheries) and occurrence of barotrauma symptoms (35% in the vertical line and 46% in the bottom longline fisheries) in the period 2006-2009 (Scott-Denton et al. 2011). No quantitative information on the frequency of venting was provided.

Scyphers et al. (2013) assessed participation rates in and perceptions of venting in the recreational reef fisheries of the Northern Gulf of Mexico, where fisheries primarily target red snapper. They found that 67% of recreational anglers use venting tools, but provide no quantitative information on the frequency of occurrence of barotrauma symptoms or venting. The survey also asked respondents to identify the ideal needle insertion location on a red snapper. Results show that only about 50% of respondents could identify a broadly correct location.

Florida Sea Grant conducted a survey of Florida saltwater anglers regarding barotrauma mitigation in 2014 (Hazell et al. 2015). A total of 739 completed surveys were received. The survey solicited information regarding 1) anglers' basic fishing patterns and avidity, 2) awareness of the conditions associated with barotrauma, 3) the use of methods to mitigate the effects of barotrauma, 4) reasons why certain mitigation methods are not utilized, 5) confidence in the use of certain mitigation methods, 6) preferred methods to learn more about how to properly utilize barotrauma mitigation methods, and 7) some basic demographics about the survey respondents. The information gathered by the survey will hopefully provide guidance in the development of outreach programs to better inform Florida saltwater anglers of methods to reduce release mortality associated with barotrauma, while also assisting state and federal fishery managers in the development of barotrauma-related management strategies that are more effective and encourage/inspire(?) a high level of compliance.

The survey found that most respondents fishing in deeper waters have noticed the conditions associated with barotrauma. However, one-third of the respondents were unable to properly identify the organ often protruding from a "floater's" mouth, indicating a strong need for outreach and education. Of the respondents who do attempt to use a barotrauma mitigation tool, 92% use venting tools, while only 9% utilize a descending device. Of those who use a venting tool, almost one half of the respondents were unable to describe the proper manner to use the tool. Although most respondents were confident that the use of such tools does help released fish to survive, those who do not expressed strong reasons for not utilizing venting tools and descending devices. Again, an educational opportunity exists to address these concerns by anglers.

Barotrauma-related outreach and extension

The review of barotrauma-related outreach and extension focused on web-based information and leaflets commonly available to fishers. A diversity of resources is available. Some resources deal with both venting tools and fish descending devices (e.g. http://catchandrelease.org/, http://takemefishing.org/fishsmart/). Others focus primarily on venting (e.g https://www.flseagrant.org/fisheries/venting/ or the educational information provided by the Gulf Council on http://gulfcouncil.org/resources/education_faqs/index.php). Yet other resources focus more on descending devices and may implicitly or explicitly promote descending over venting, for example by referring to venting as an option available "when descending is not possible" or by stating that descending devices "result in less injury to the fish". Clearly, the outreach and extension messages regarding barotrauma mitigation can be confusing. None of the sources examined provide comprehensive guidance on the choices and their pros and cons, and none provide current scientific information on the effectiveness of the different measures.

Results of the new barotrauma mitigation survey

Fishing characteristics

Depth profiles of reef fishing activities are shown separately for the Gulf and Atlantic. In the Gulf in particular, a large share of reef fishing activity occurs in relatively shallow waters. In the Gulf, 70% of recreational, 81% of charter and 65% of commercial activity occurs in water less than 90 ft (15 fathoms) deep. For comparison, in the Atlantic, 58-68% of fishing activity occurs in less than 90 ft (Figure 3).

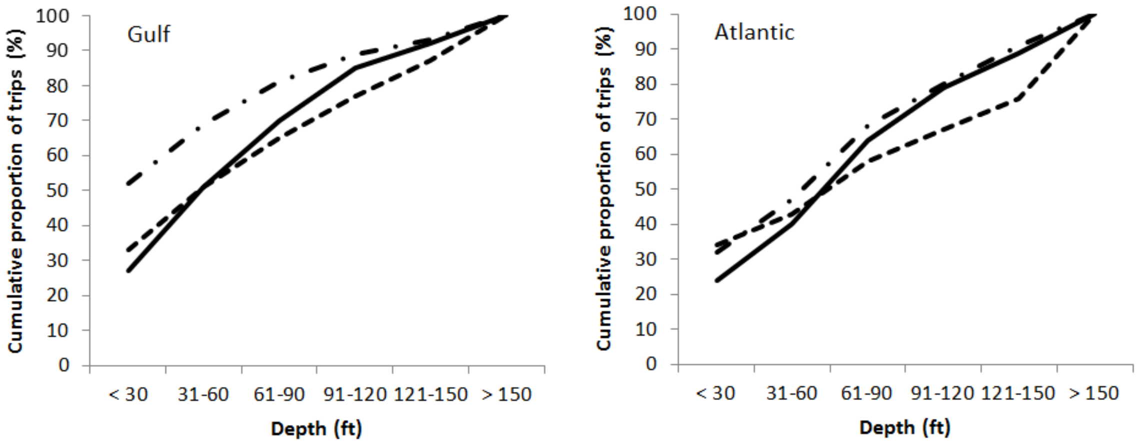


Figure 3: Fishing depth profiles (unweighted average of proportion of time spent fishing in different depth zones as reported by survey participants). Lines show depth profiles for the recreational sector (solid line), commercial sector (dashed line) and charter sector (dashed-dotted line).

The median proportion of fish discarded among commonly caught reef fish species (excluding goliath grouper which is illegal to keep) was 51% (range: 30%-63%) in the recreational sector, 54% (range: 30%-68%) in the charter sector, and 34% (range: 13%-60%) in the commercial sector. Discarding varied among species (Figure 4) in a similar manner in all sectors, with goliath grouper having the highest level of reported discards and vermillion, mangrove, mutton and yellowtail snappers the lowest. In both sectors, discards occurred primarily for regulatory reasons but some voluntary discarding was also reported, particularly in the recreational and charter sector.

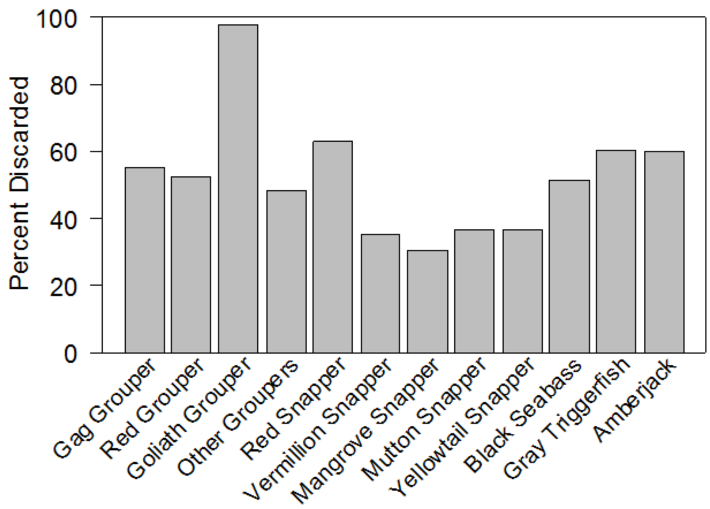


Figure 4: Discard rates by species in the recreational sector

Frequency of encounter of barotrauma-related symptoms

The majority of respondents (over 80%) reported seeing symptoms of barotrauma in only 0-25% of fish they discard (Figure 5). This is consistent with expectations based on the depth distribution of reef fishing activities.

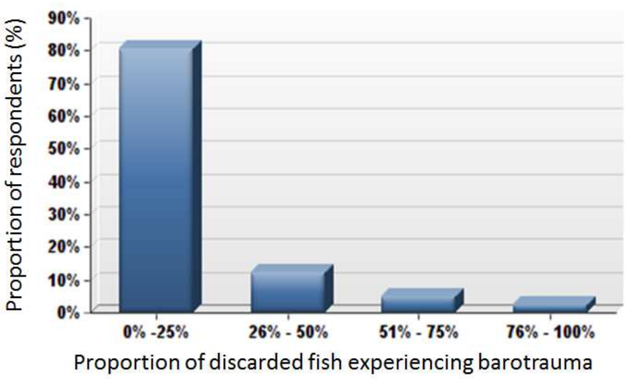


Figure 5: Reported frequency of discarded fish experiencing barotrauma

Use of barotrauma mitigation measures

Use of barotrauma mitigation measures (Figure 6) was assessed using three survey questions regarding (a) the respondent's own use of such measures, (b) their perception of the use of such measures by others in their own sector, and (c) their perception of use by others when possession of a venting tool was required. In all cases, the responses refer to the use of mitigation tools when needed, i.e. when a fish shows signs of barotrauma. Around 53-66% of fishers in all sectors reported using a barotrauma mitigation measure most of the time (75%-100% of the time when needed) while conversely, 17-28% reported rarely using such measures (0-25% of the time when needed), with the remainder reporting intermediate levels of use. Current perceived use by others is substantially lower, with only 17% of recreational and 23% of commercial fishers but 38% of charter captains perceiving use most of the time (75-100%). Respondents from all sectors perceived that use of mitigation measures had been more frequent when possession of a venting tool was required.

Questions on both self-reported use and perceived use by others were included in the survey to gauge the degree of over-reporting of barotrauma mitigation behaviors, for which there is a positive social norm. Perceived use by others of course need not be accurate and indeed, fishers in general have limited opportunity to observe the measures taken on other boats. Nonetheless, it is likely that self-reported use of barotrauma mitigation measures is biased upwards and that the true level of use is intermediate between the self-reported and perceived sector estimate.

It is noteworthy also that the respondents in all sectors perceived a decline in the use of mitigation measures when the venting tool requirement in federal and state water of the Gulf was removed (in 2013). This may reflect reduced social and enforcement pressure, but also a degree of confusion as to whether venting was in fact a positive action.

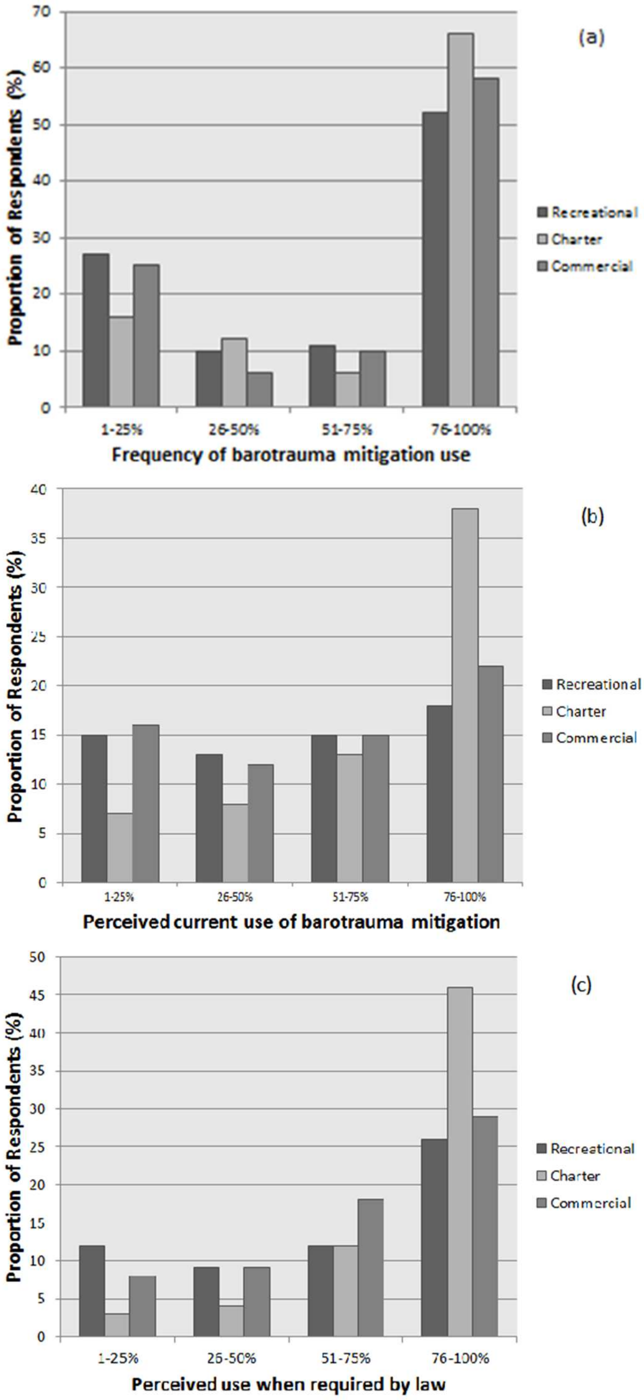


Figure 6: Use of barotrauma mitigation measures when needed: (a) self-reported use; (b) perceived current use by others in the sector, and (c) perceived use by others in the sector when possession of a venting tool was required (prior to 2013).

About 50-70% of reef fishers in the different sectors are aware of venting tools, while 30-50% are aware of both venting tools and descending gear (Figure 7). Very few fishers are aware only of descending gear. Awareness of descending gear is greatest in the charter sector. Use of barotrauma mitigation measures (Figure 8) is more strongly skewed towards venting than awareness, with 70-85% of respondents having used venting tools and only 10-25% both venting tools and descending gear.

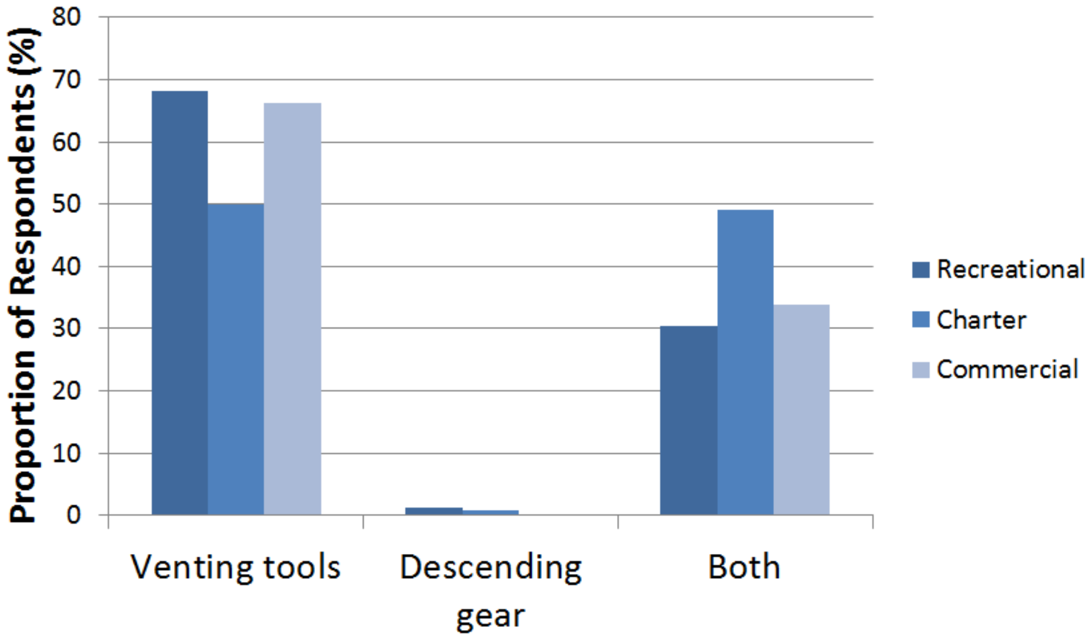


Figure 7: Awareness of venting tools and descending gear

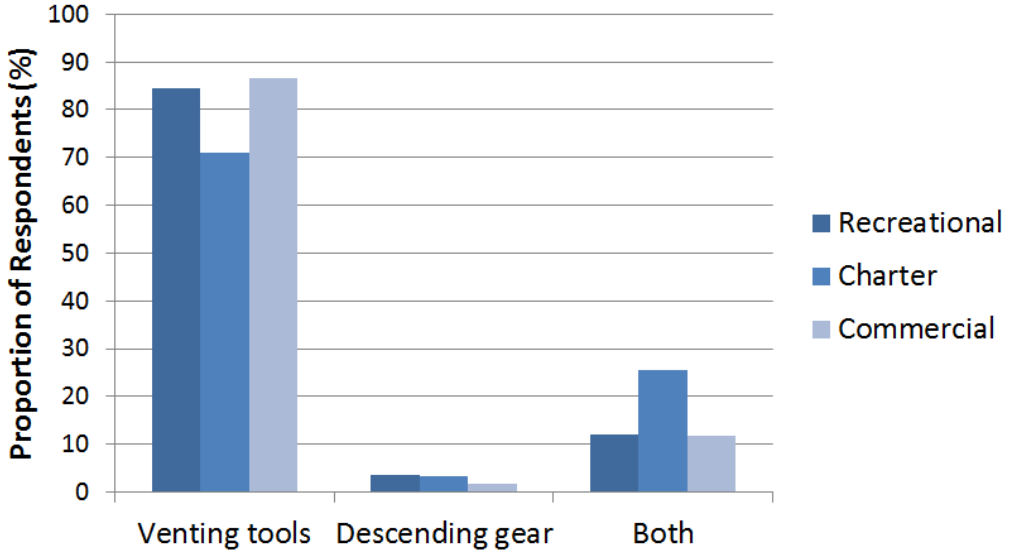


Figure 8: Use of venting tools and descending gear

Factors influencing barotrauma mitigation behaviors

Based on the Theory of Planned behavior, we hypothesized that barotrauma mitigation behaviors may be influenced by attitudes, social norms, and perceived control relating to fish venting tools and descending gears.

Fishers from all sectors agreed that both venting tools and descending gear help fish return to depth and improve their survival (Figure 9). However, fishers differed in their attitudes regarding the practicality and costs associated with the two types of mitigation devices, disagreeing that venting tools require a lot of time, are difficult to use, or are expensive, but being neutral on all these attributes for descending gear. Overall this indicates more positive attitudes to venting tools than to descending gear, based on the greater ease of use and the lower cost of the former.

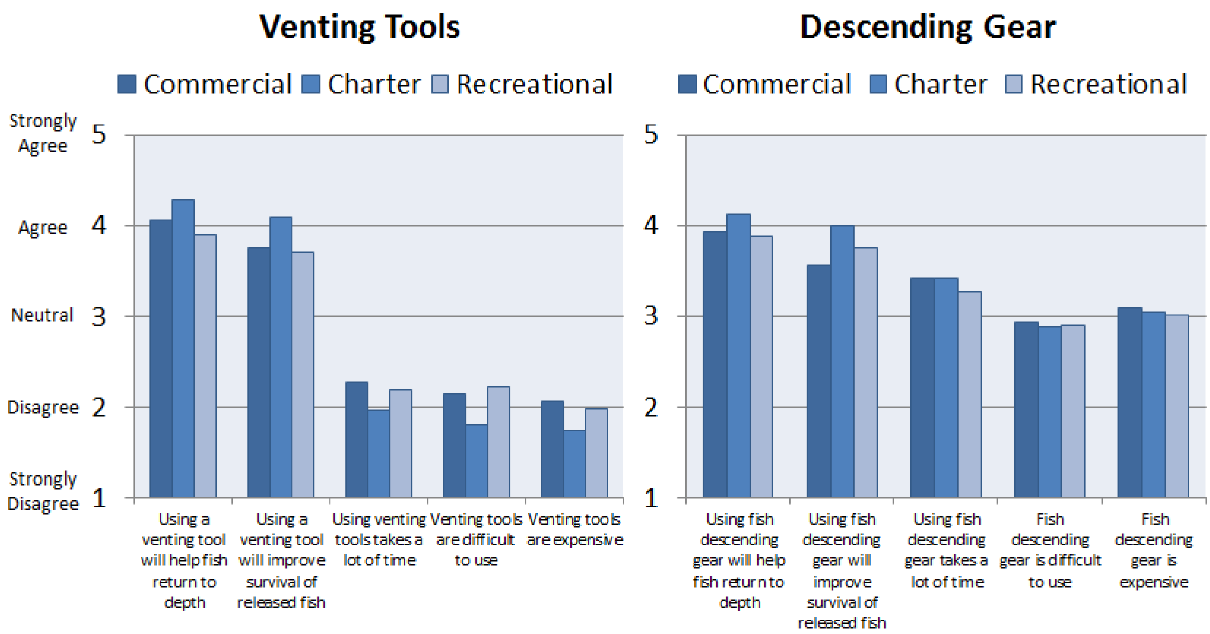


Figure 9: Responses to attitude -related questions for venting tools and descending gear

Fishers experienced implicit social pressure to use venting tools (responding in agreement with statements such as “other fishers expect me to use venting tools” etc.), but did not feel the same pressure to use descending gear (Figure 10). Note that fishers moderately disagreed that they feel social pressure when asked explicitly, even though their agreement with the other questions on venting tools shows that they feel such pressure implicitly. This suggests that fishers perceive a social norm to use venting tools but are not commonly asked by others to do so.

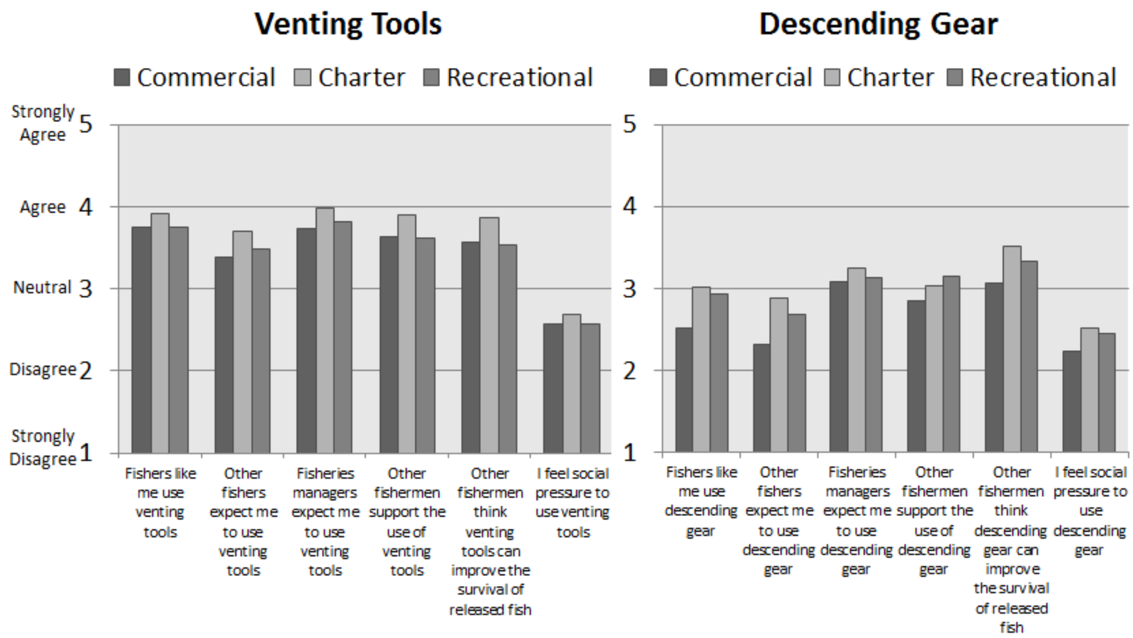


Figure 10: Responses to social norms-related questions for venting tools and descending gear

Fishers in all sectors felt confident in their ability to use both venting tools and descending gear (the latter slightly less so) and disagreed that they needed more training in the use of either (Figure 11). They neither agreed nor disagreed with an expectation of the provision of training in the use of either method by fisheries management.

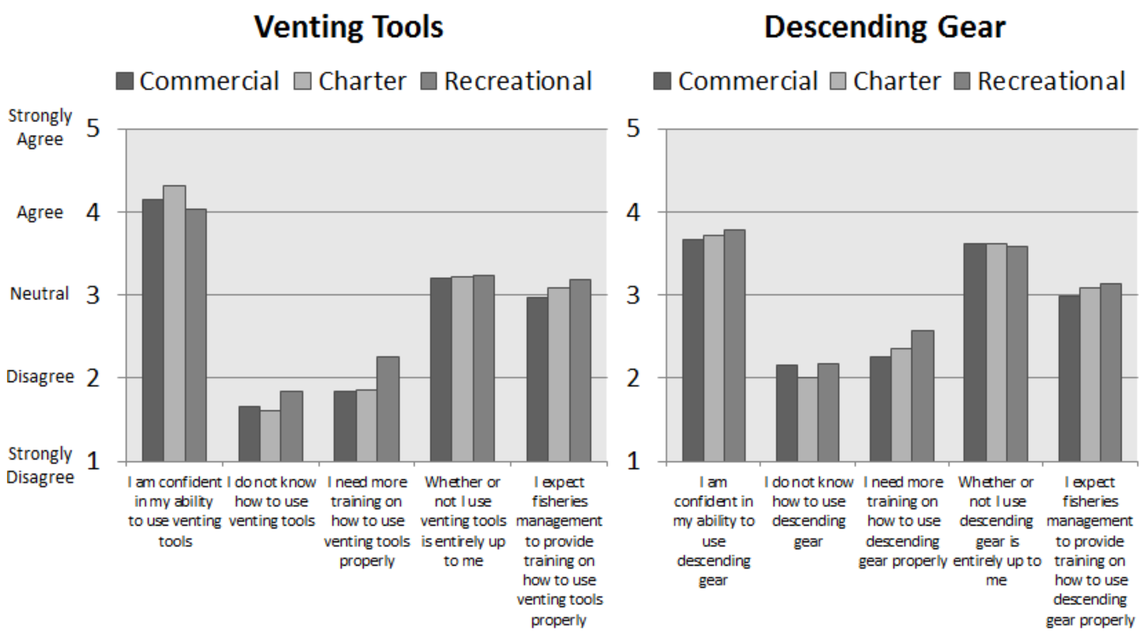


Figure 11: Responses to perceived control-related questions for venting tools and descending gear

Fishers who were familiar with both venting and descending gear showed a stronger intent to use venting tools than to use descending gear in the future (Figure 12).

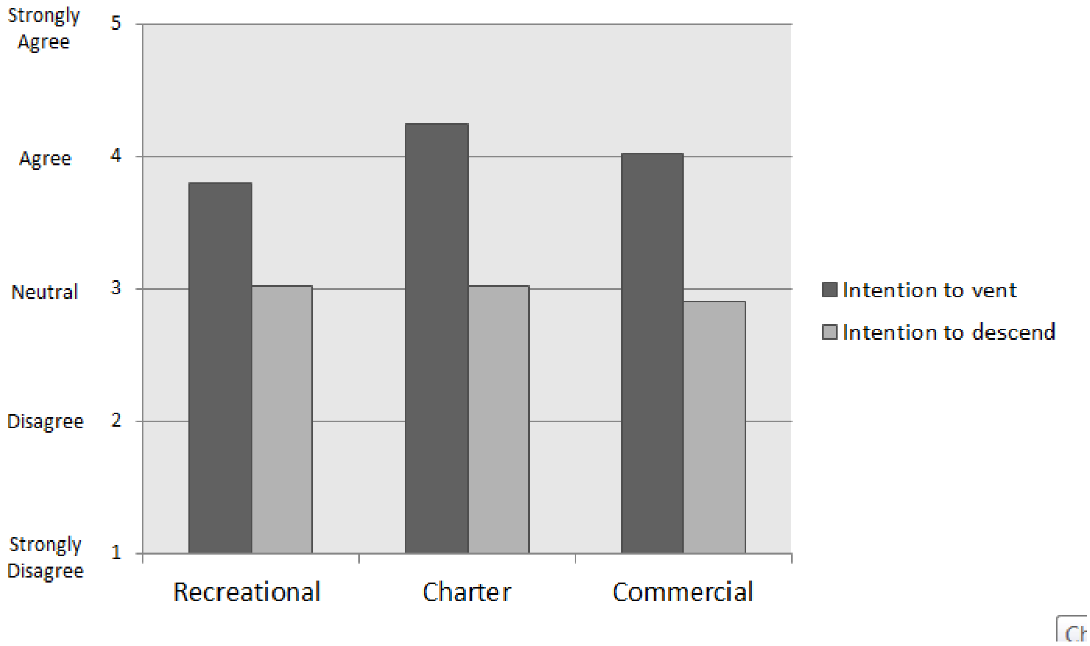


Figure 12: Intention to use venting tools or descending gear in the future, among fishers who are familiar with both

To evaluate the factors influencing use of barotrauma mitigation measures, multiple linear regression analyses were conducted using scales constructed for attitudes, social norms and perceived control as explanatory variables and intention to use a mitigation measure as a response variable. These analyses were conducted separately for venting tools and descending gear (Table 1). In all sectors and for both tools, perceived social norms were by far the strongest predictor of intention to use. Attitudes to the tools and perceived control have only a marginal influence.

Table 1. Factors influencing behaviors

Factor	FisherType	Beta	p	Outcome
Attitude: Venting Tools	Angler	0.212	<0.001*	Intention to Use: Venting Tools
	Charter	0.127	0.165	
	Commercial	0.129	0.111	
Norm: Venting Tools	Angler	0.469	<0.001*	
	Charter	0.497	<0.001*	
	Commercial	0.479	<0.001*	
Control: Venting Tools	Angler	0.082	0.022*	
	Charter	0.135	0.112	
	Commercial	0.265	<0.001*	

Factor	FisherType	Beta	p	Outcome
Attitude: Desc. Gear	Angler	0.312	<0.001*	Intention to Use: Desc. Gear
	Charter	0.249	0.034*	
	Commercial	0.379	0.001*	
Norm: Desc. Gear	Angler	0.380	<0.001*	
	Charter	0.516	<0.001*	
	Commercial	0.448	<0.001*	
Control: Desc. Gear	Angler	0.195	0.003*	
	Charter	0.184	0.059	
	Commercial	0.219	0.020*	

Attitudes to regulations

Overall fishers in all sectors were supportive of (re-) introducing rules that require possession or use of barotrauma mitigation devices (venting tools or descending gear) (Figure 13). Only 26% of all respondents agreed (17%) or strongly agreed (9%) with the statement that there should not be a regulation requiring possession. Respondents also agreed that regulations would increase the number of people using such tools and expected management to require the use of such tools in the future (Figure 13).

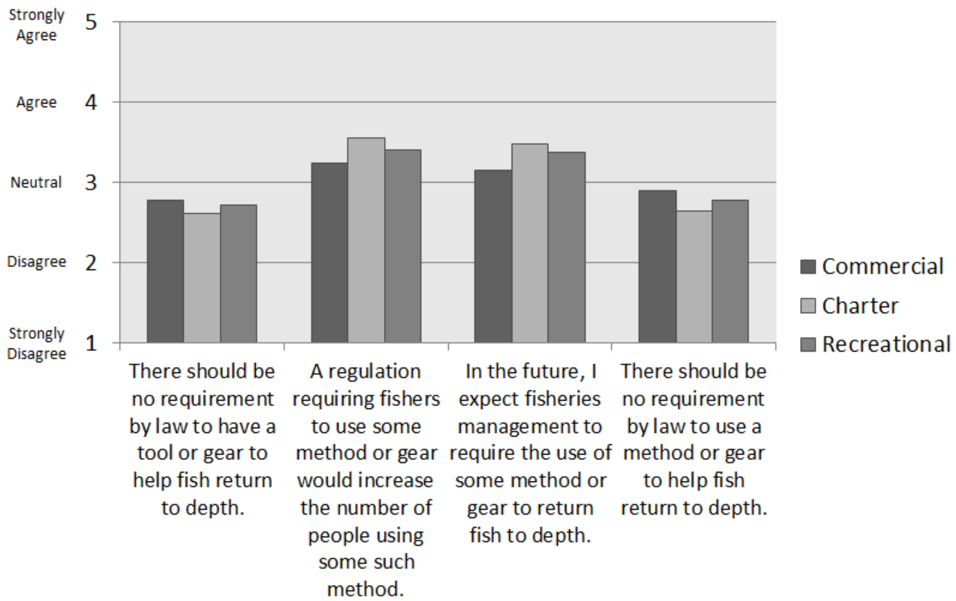


Figure 13: Attitudes to barotrauma-related regulations

Information sources used

A wide range of information sources were used by fishers from all sectors, with other fishers (anglers and boat captains), websites, fishing magazines, tackle shops and state agencies being the most commonly used (Figure 14). Social media, fishing workshops and forums, and federal fisheries management councils were least used.

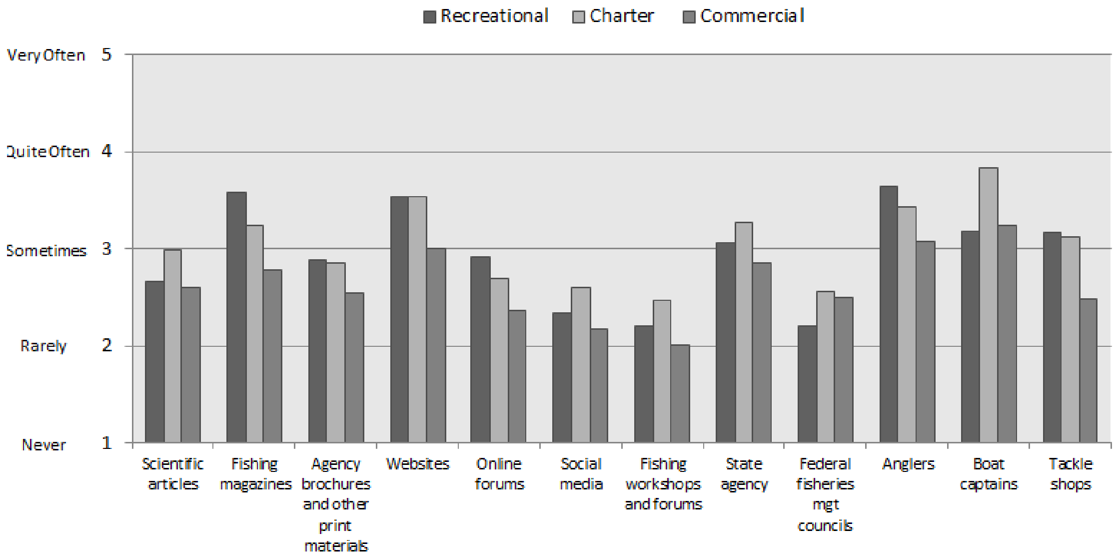


Figure 14: Fishing depth profiles (unweighted average of proportion of time spent fishing in different depth zones as reported by survey participants).

Outreach and extension webinar

Six Florida Sea Grant extension agents and specialists attended the outreach and extension webinar. The agents mentioned that, based on their personal experiences with fishers, the removal of the venting tool requirement and diverse outreach messages has led to some confusion about the appropriateness of venting, but that overall the practice remained firmly engrained. The agents and specialists suggested that the outreach messages should be reviewed and modified in light of the project results, in particular with respect to the factors influencing the intention to use venting and descending methods.

Outreach and policy implications

Outreach and extension

- Emphasize that venting and descending are equally effective (if done correctly).
- Describe pros and cons of each.
- Re-enforce barotrauma mitigation as a social norm. This is predicted to have the greatest impact on use of mitigation measures.
- Social norms can be promoted through opinion leaders, fisheries forums, and regulations.
- Since fishers are overly confident in their ability to use mitigation measures correctly and therefore unlikely to seek out this information, outreach aimed at promoting correct use must start by challenging the fisher's belief that they know the correct use.

Policy

- Re-introduction of a requirement to possess a barotrauma mitigation tool would re-enforce the social norm and is likely to lead to increased use. Such a measure would be opposed by only a minority (26%) of fishers (strongly opposed by only 9%).

Follow-up activities

- Provide summary report for publication and a presentation to the council.
- Undertake review and revision of Florida Sea Grant barotrauma-related extension messages and activities in the light of results.

Acknowledgements

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Marine Resource Education Program Final Report

The 2015 Marine Resource Education Program (MREP) Southeast Management Workshop was held September 22 – September 24, 2015, in Tampa, Florida. Thirty individuals participated in the workshop.

During the workshop, participants learned about how science is used by the Scientific and Statistical Committee and in the Council's development of Fishery Management Plans. They also received refreshers* about:

- Best available science vs. best possible science
- Fishery dependent and fishery independent data collection
- Stock assessment process
- Big picture overview of Council regions, the Southeast Regional Office, and Science Centers

*These topics were covered in depth during the April MREP Science Workshop.

Participants also got an overview of the Magnuson-Stevens Act, how and why the Councils came to be, and legislative affairs in the context of MSA reauthorization.

Other items covered during the three-day workshop include:

- Review of the Fishery Management Council Process
- Federal Fisheries Management
- SERO

Participants were also given a case study and role play assignments to study before participating as "Council members" in a mock Council session. The role play scenario began with an introduction to a hypothetical fishery decision to be made and participants had to follow the process all the way through to final action.

Finally, presenters provided information to participants on how to get involved in the Fishery Management process, and Council Executive Directors and the Regional Administrator held a roundtable discussion/question and answer session.

Throughout the three-day workshop, participants got answers to questions and had opportunities to network with other stakeholders from across all sectors.

Gulf Fisheries Regulation Query Tool

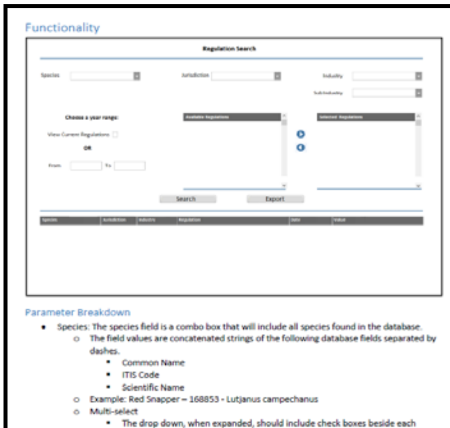
Final Report, December 2015

Introduction

Fisheries managers and academia often need historic regulatory information regarding the management of the Gulf's fisheries. Unfortunately, this information is often difficult to locate and interpret across the Gulf States. This void in available information causes the need for substantial location efforts as well the likely potential for varying interpretation and application among stakeholders.
To help solve this issue, GCR Inc. (GCR) was asked by the Gulf States Marine Fisheries Commission (GSMFC) to work on behalf of the Gulf of Mexico Fishery Management Council (Council) in creating an online, publicly available database query tool the presents gathered, uniformly interpreted, and formatted commercial and recreational regulatory information. This project consisted of three phases: scoping, development and data gathering. Each resulted in the transfer of a searchable database that can be easily updated and attached to the Council's website, providing stakeholders and the general public with exportable historic regulation information on key Gulf species.

Project Scoping

Upon receipt of a notice to proceed, GCR met with GSMFC to determine the existing regulatory information, identify potential contacts for gathering missing information, and set requirements for the eventual query tool. As there were very few examples of existing fishery regulation tools in existence, GCR worked closely with stakeholders to design a tool tailored for the Gulf of Mexico. In this scoping phase, GCR determined which species were critical, which regulations needed to be included, and which layout accounted for all possible data searches. Multiple solutions were vetted, but ultimately, a simple database that could be updated


Functionality

Regulation Search

Species | Jurisdiction | Industry | Sub-Industry

Choose a year range:
View Current Regulations
OR
From To

Available Regulations | Selected Regulations

Search | Export

Species	Jurisdiction	Industry	Regulation	Date	Value

Parameter Breakdown

- Species: The species field is a combo box that will include all species found in the database.
  - The field values are concatenated strings of the following database fields separated by dashes.
    - Common Name
    - ITIS Code
    - Scientific Name
  - Example: Red Snapper – 168853 - Lutjanus campechanus
  - Multi-select
    - The drop down, when expanded, should include check boxes beside each

Systems Requirements Specification document.

over time was chosen. The scoping phase was concluded with the approval of a Systems Requirements Specifications (SRS) document, outlining the architecture of the tool.

Development

Once the SRS was approved by the Council, GCR built the query tool using .NET technologies and a SQL Server backend database. The application's database was designed to be easily updated using a GCR supplied Excel spreadsheet with specific formatting in conjunction with SQL SSIS import functionality. The application will be attached to the host site by the Council using Amazon Web Services.

Data Gathering

In parallel to the development activities, GCR identified, acquired, reviewed, and uniformly interpreted various fishery regulation information on the following top 15 Gulf species:

Species		**ITIS Code**	**Scientific Name**
Amberjack	Greater	168689	*Seriola dumerili*
Cobia		168566	*Rachycentron canadum*
Drum	Red	169290	*Sciaenops ocellatus*
Grouper	Black	167760	*Mycteroperca bonaci*
Grouper	Gag	167759	*Mycteroperca microlepis*
Grouper	Red	167702	*Epinephelus morio*
Grouper	Scamp	167763	*Mycteroperca phenax*
Hogfish		170566	*Lachnolaimus maximus*
Lobster	Spiny (Caribbean)	97648	*Panulirus argus*
Mackerel	King	172435	*Scomberomorus cavalla*
Mackerel	Spanish	172436	*Scomberomorous maculatus*
Snapper	Red	168853	*Lutjanus campechanus*
Snapper	Vermilion	168909	*Rhomboplites aurorubens*
Snapper	Yellowtail	168907	*Ocyurus chrysurus*
Triggerfish	Gray	173138	*Balistes capriscus*

The primary source for regulatory data was GSMFC law summaries. However, missing information was found in the Electronic Code of Federal Regulations (CFR) or on individual state fishery management websites.

	Species	Scientific Name	ITIS Code	Jurisdiction	Industry	Sub Industry	Regulation	Effective Date	Value
14	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Min Size Limit	1/1/2014	14" FL
15	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Permit Required	1/1/2014	Federal reef fish commercial vessel perm
16	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Trip Limit	1/1/2014	12 fish
17	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Season Closed	1/1/2014	6/1 - 7/31
18	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational		Min Size Limit	1/1/2013	14" FL
19	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational		Season Closed	1/1/2013	10/15 - 12/31, federal quota in effect
20	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational		Daily Bag Limit of Species	1/1/2013	20/person
21	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational		Daily Bag Limit of Aggrega	1/1/2013	20/person in reef fish aggregate of 20
22	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational	Charter Boats	Daily Bag Limit of Species	1/1/2013	2 day limit allowed on qualified multi-da
23	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational	Head Boats	Daily Bag Limit of Species	1/1/2013	2 day limit allowed on qualified multi-da
24	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Min Size Limit	1/1/2013	14" FL
25	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Commercial		Permit Required	1/1/2013	Federal commercial vessel permit for ree
26	Triggerfish, Gray	*Balistes capriscus*	173138	Louisiana	Recreational		Min Size Limit	1/1/2012	14" FL

A screen shot of the data pulled for the top 10 Gulf species populating the query tool.

Conclusion

This effort resulted in an application that incorporates an intuitive interface that a non-technical user will be able to easily navigate and use. This single screen application can be embedded in the existing Council website and users can search, filter, aggregate, and export all data attributes. Filter/searches will allow for a selection of combinations of the following fields:

- Species (common and scientific names)
- Year (single or range) or across a range of years
- Jurisdictions - Gulf states (one or more) and/or federal waters
- Commercial and/or recreational regulations

The end product, the Gulf of Mexico Fishery Management Council Fishery Regulation Search Tool, provides fishery managers, scientists, and academia with historic fisheries regulatory information in order to make timely, informed, and accurate decisions and projections regarding the current and future management of the Gulf's fisheries.

A screen shot of the Gulf regulation query tool, showing the users' choices for searching and filtering regulation data.

Name: Gabriela Stocks, Ph.D.
Task Title: Social Network Analysis of Red Snapper and Grouper-Tilefish IFQ Programs
Reporting Period: March 26-June 27, 2016

WORK ACCOMPLISHED—FINAL REPORT

All progress reports are cumulative and all inclusive. Since the last reporting period, three key analyses have been completed:

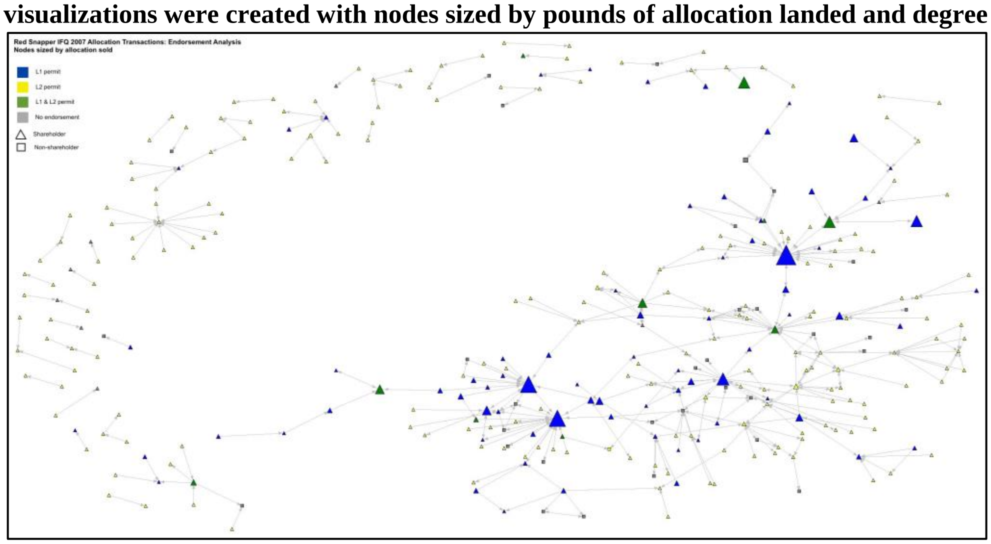
1. Red Snapper IFQ endorsement and Grouper-Tilefish IFQ endorsement proxy analyses
2. Red Snapper IFQ related accounts analysis
3. Red Snapper and Grouper-Tilefish IFQ sea lords analysis

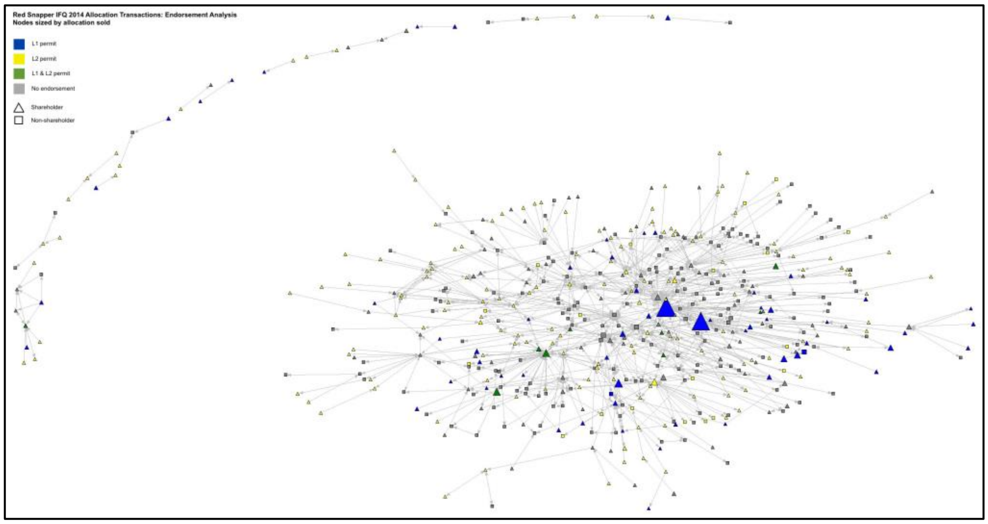
<u>1. Red Snapper IFQ endorsement and Grouper-Tilefish IFQ endorsement proxy analyses</u>

One of the key questions of interest to non-economic social scientist deals with equity and the effects of fisheries policies on smallholder fishermen. To this end, Dr. Ava Lasseter requested a network analysis of the roles of various scales of fishermen in IFQ allocation transactions over time.

The Red Snapper IFQ endorsement analysis used Class 1 (2000 lb trip limit) and Class 2 (200 lb trip limit) reef fish licenses prior to the IFQ program as the baseline for determining whether a fisherman could be classified as engaging in large- or small-scale fishing practices, respectively. These IFQ accounts were then tracked through time (2007-2014) to determine whether large- or small-scale fishermen were somehow advantaged later in the program's evolution, and whether new actors were gaining entry to the fishery. As can be seen in Figure 1, Class 1 permit holders played an important role in allocation transactions in 2007 and continued to do so in 2014. Most noteworthy about the 2014 network, however, is the number of new entrants to the fishery (represented by grey nodes), which indicates that original Class 1/Class 2 license holders do not have a monopoly on Red Snapper allocation.

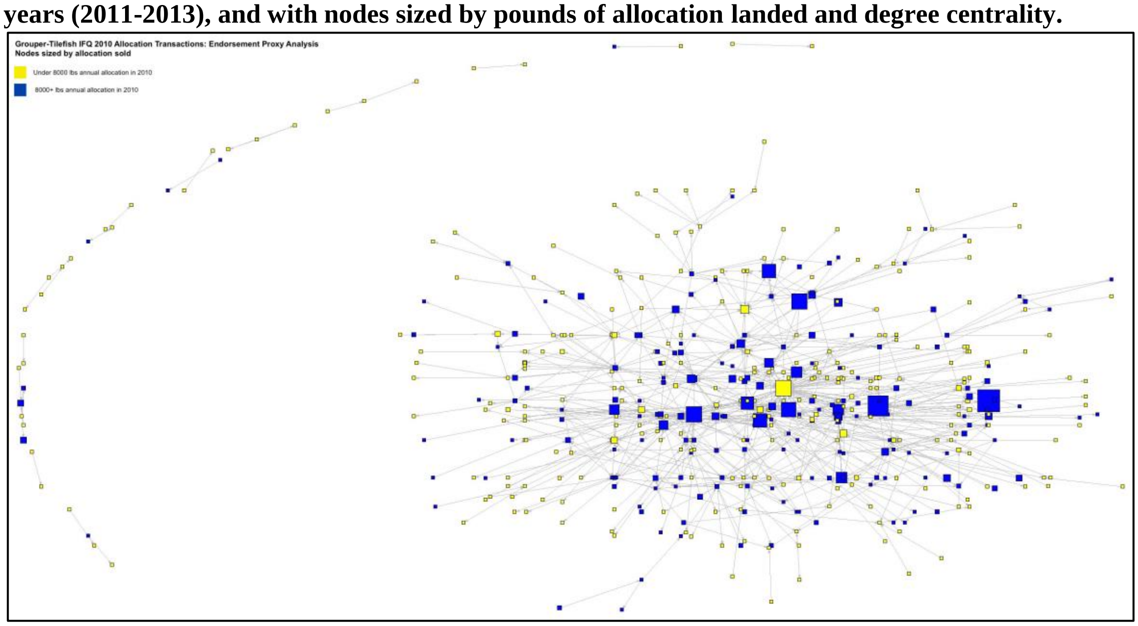
Figure 1: 2007 and 2014 Red Snapper IFQ allocation transaction networks with Class 1/Class 2 endorsement data. Nodes are colored by license status (blue = Class 1 license holder, yellow= Class 2 license holder, green = both Class 1 and Class 2 licenses, grey = no license), shaped by shareholder status, and sized by pounds of allocation sold. Similar visualizations were created with nodes sized by pounds of allocation landed and degree centrality.

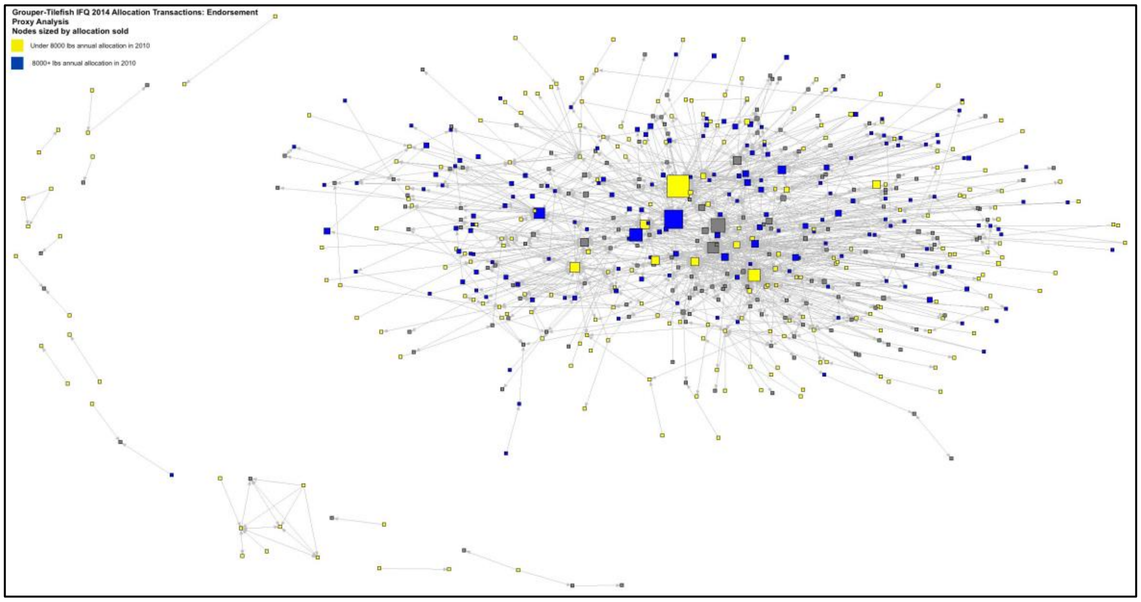




Because the Grouper-Tilefish IFQ program did not use similar licenses to determine the initial distribution of shares, a proxy was developed for the purposes of this analysis: fishermen with a cumulative quota allocation in 2010 of greater or less than 8000 pounds across all five categories of the Grouper-Tilefish IFQ program. These fishermen were then tracked over the length of the program (2010-2014). As can be seen in Figure 2, larger-scale fishermen (represented by blue nodes) played an important role in allocation transactions in 2007 and continued to do so in 2014. However, some fishermen who employed relatively small-scale fishing practices in 2010 (represented by yellow nodes) had become important actors by 2014. And, as in the Red Snapper analysis, new entrants to the fishery (represented by grey nodes) were also abundant, some of which transacted significant amounts of allocation.

Figure 2: 2010 and 2014 Grouper-Tilefish IFQ allocation transaction networks with endorsement proxy data. Nodes are colored by cumulative allocation in 2010 (yellow = less than 8000 lbs of cumulative allocation, blue = at least 8000 lbs of cumulative allocation) and sized by pounds of allocation sold. Similar visualizations were created for interim years (2011-2013), and with nodes sized by pounds of allocation landed and degree centrality.





2. Red Snapper IFQ related accounts analysis

IFQ participants and NMFS staff have suggested that the behavior of IFQ participants has changed over time. In particular, there is anecdotal evidence that IFQ participants are increasingly expanding their business operations and affiliations with other IFQ participants, and may not be acting individually in both leasing transactions and fishing practices. Understanding more about "related accounts" in the IFQ programs is therefore important because it may shed light on how fishermen (and others) are negotiating and adapting their livelihood strategies to changing circumstances and opportunities. IFQ accounts are considered related if they have an entity in common, as recorded in the NMFS/SERO Permit Information Management System.

In a prior report, the networks of related accounts in both IFQ programs combined (Figure 3) and the networks of related accounts specific to Grouper-Tilefish IFQ allocation transactions (Figure 4) were discussed. For the current reporting period, a set of networks of related accounts specific to Red Snapper IFQ allocation transactions was generated (Figure 5). In each of these analyses, it is clear that the number of related accounts has increased over time. This is especially clear in the case of the Red Snapper IFQ (Figure 5), which began with only a handful of related accounts in 2007.

Figure 3: 2007 and 2014 related IFQ accounts networks. The number of related accounts has increased over time.

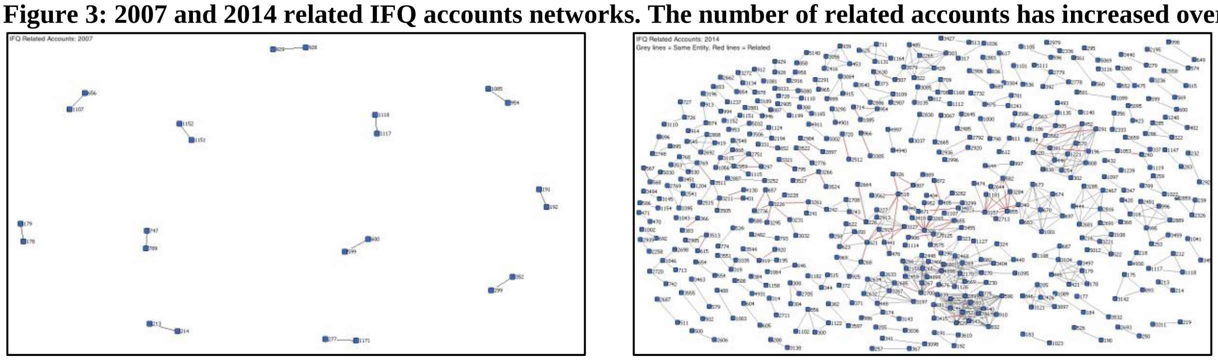


Figure 4: 2010 and 2014 Grouper-Tilefish IFQ related accounts networks. Nodes are colored by state.

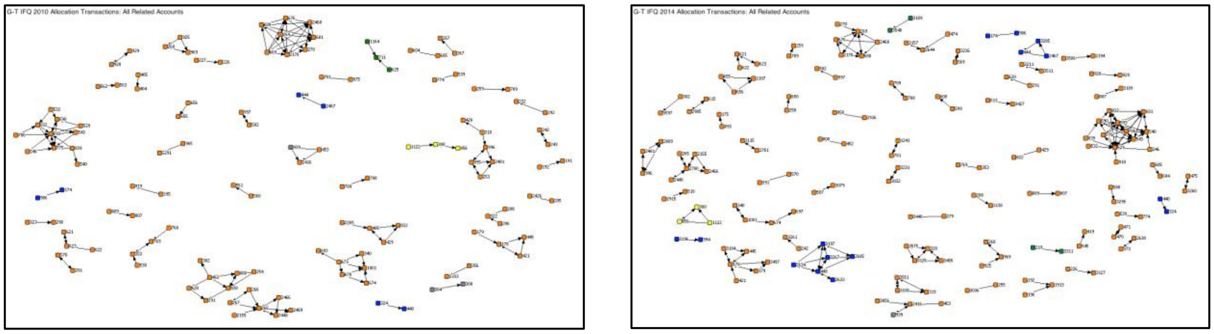
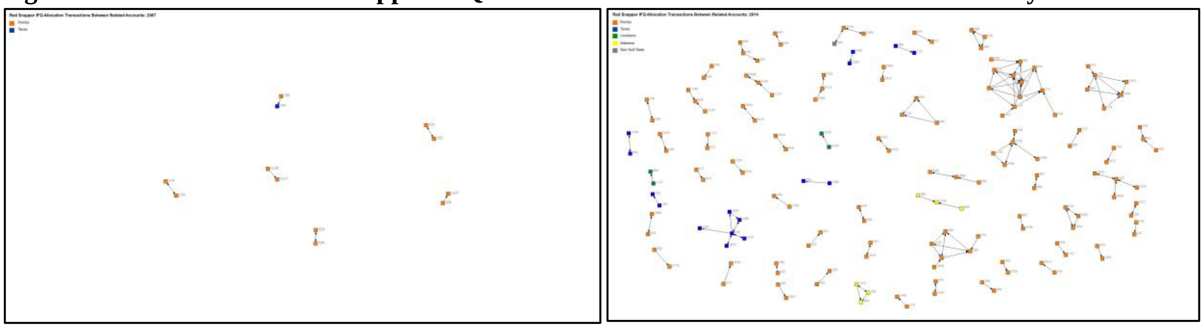


Figure 5: 2010 and 2014 Red Snapper IFQ related accounts networks. Nodes are colored by state.



3. Red Snapper and Grouper-Tilefish IFQ sea lords analysis

A key focus of the current network analysis project has been the identification of "sea lords", loosely defined as IFQ participants that transact large quantities of annual allocation but report little to no landings. For the purposes of this analysis, we operationalized "little to no landings" as accounts or groups of related accounts that landed less than 50% of their annual cumulative allocation (i.e., allocation given based on shares + allocation purchased from other program participants) in a given year. The network graphs generated in the first reporting period, representing annual networks of allocation transactions in both the Grouper-Tilefish and Red Snapper IFQ Programs, formed the basis for this analysis.

This analysis is an extension of the analyses discussed in section 2 of this report. Using related accounts data in combination with Red Snapper and Grouper-Tilefish IFQ allocation transaction networks allows us to aggregate allocation transactions and landings for related nodes, thus reducing the complexity of the network graph and facilitating the identification of groups of nodes or individual nodes that may be functioning as Sea Lords.

This analysis occurred in two steps. First, as described in section 2 of this report, network graphs of related accounts for each year of the Red Snapper and Grouper-Tilefish IFQ programs were generated. For each year, clusters of related accounts were identified with a unique ID number and their allocation transactions and landings were aggregated.

Second, the new clusters of related accounts were used to replace individual nodes in the networks of Red Snapper and Grouper-Tilefish allocation transactions. Again, this allows for a clearer visualization of the most powerful actors in the networks. Figure 6 represents the Red Snapper 2007 and 2014 allocation transaction networks. Figure 7 represents the Grouper-Tilefish 2010 and 2014 allocation transaction networks. Sea Lords, if they exist, may be represented by large triangular nodes. These are either individual actors or clusters of related actors who sold relatively large amounts of allocation to other account holders and who landed relatively little of their annual allocation.

In Figure 6, (Red Snapper network), a visible reduction in the number of individual “sea lords” (represented in red) between 2007 and 2014 is apparent. Such a reduction is not as apparent in Figure 7 (Grouper-Tilfish network), but that could be because the number of related account clusters was high from the beginning of the program, likely due to the social learning that had occurred in the Red Snapper IFQ program during the prior three years.

Figure 6: 2007 and 2014 Red Snapper allocation transaction network with related account clusters. Nodes are colored by related account status (blue = related account cluster, red=individual IFQ accounts), shaped by reported landings (squares = landed at least 50% of cumulative allocation, triangles = landed <50% of cumulative allocation), and sized by allocation sold to unrelated accounts.

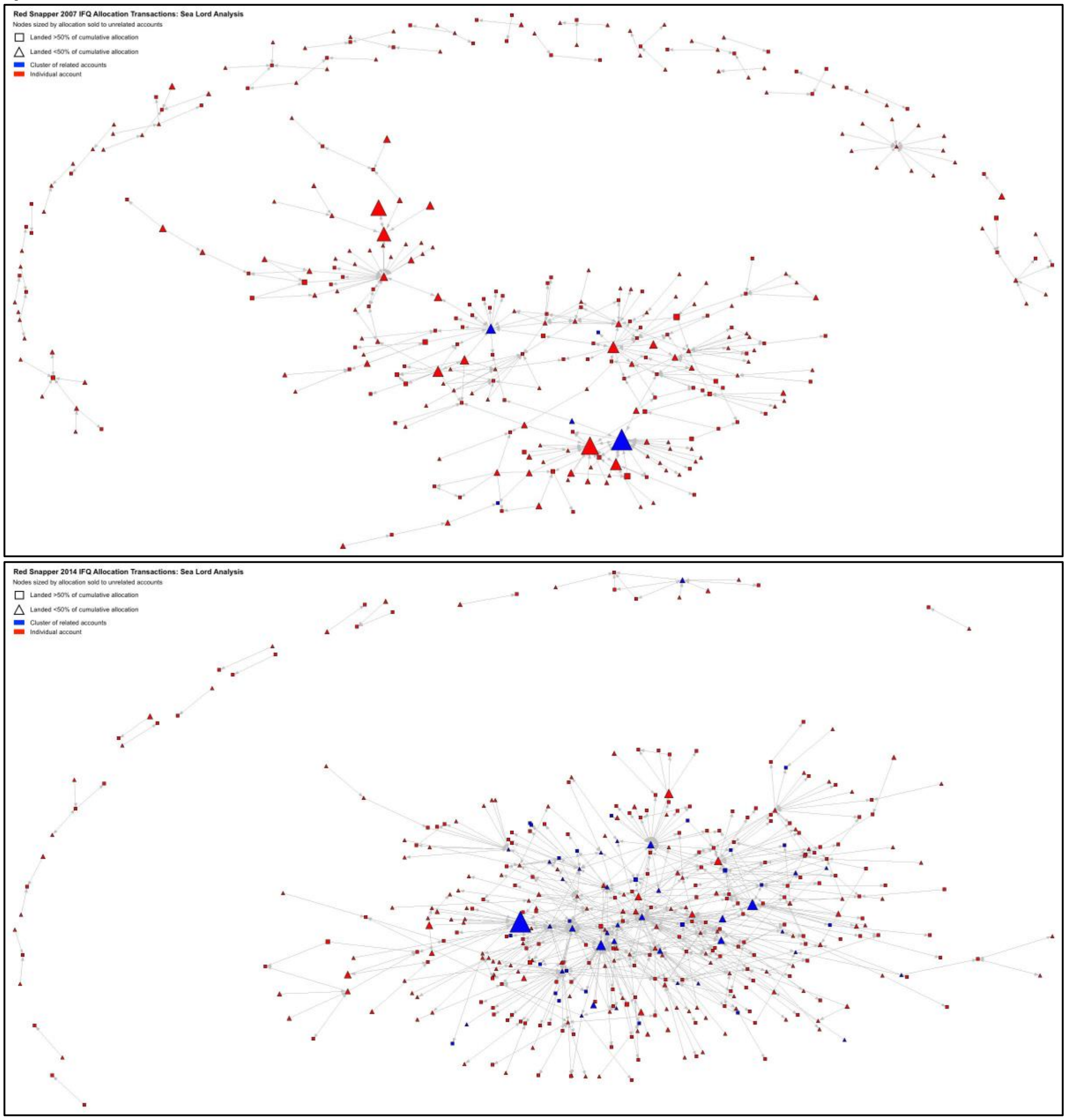
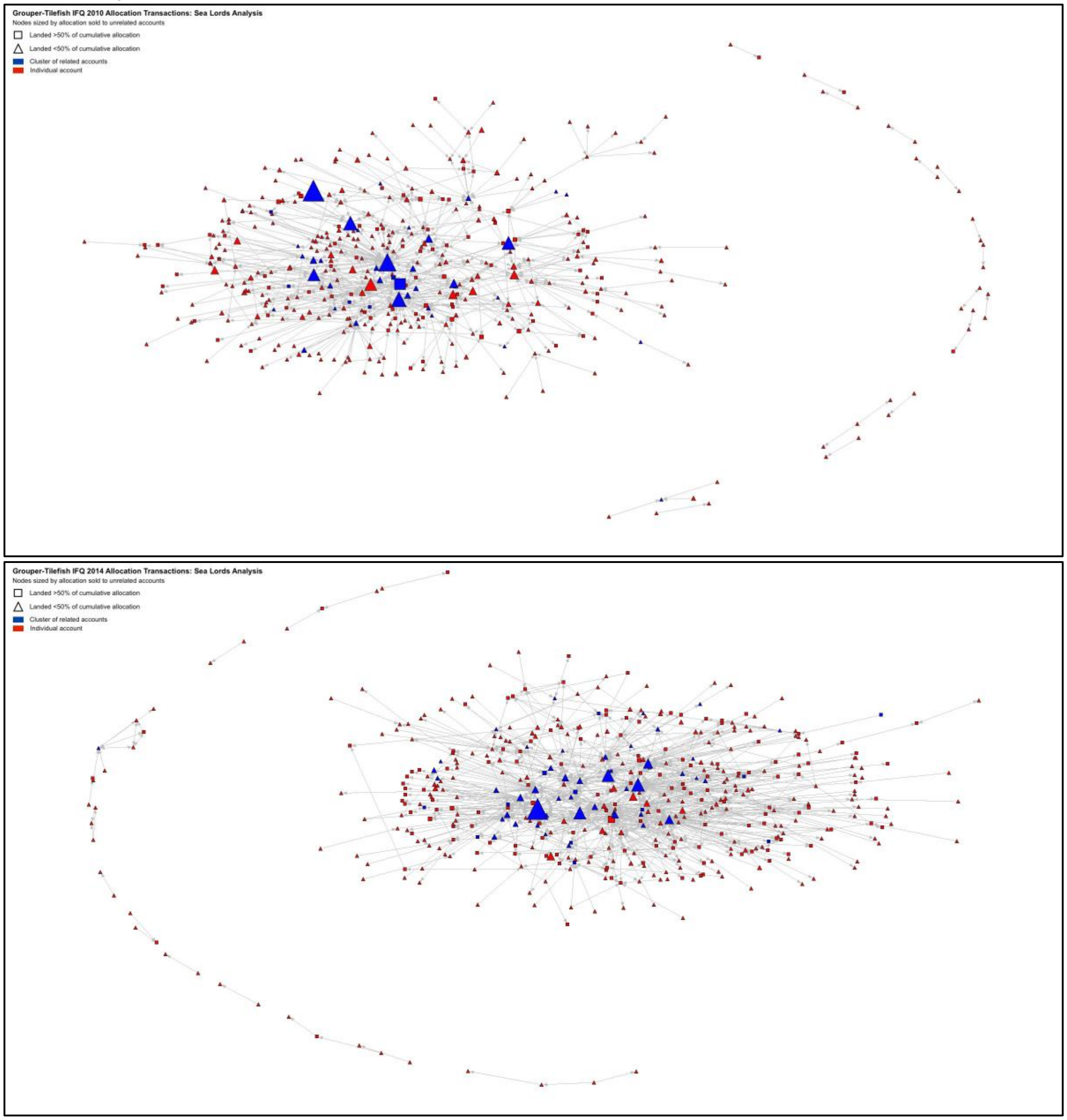
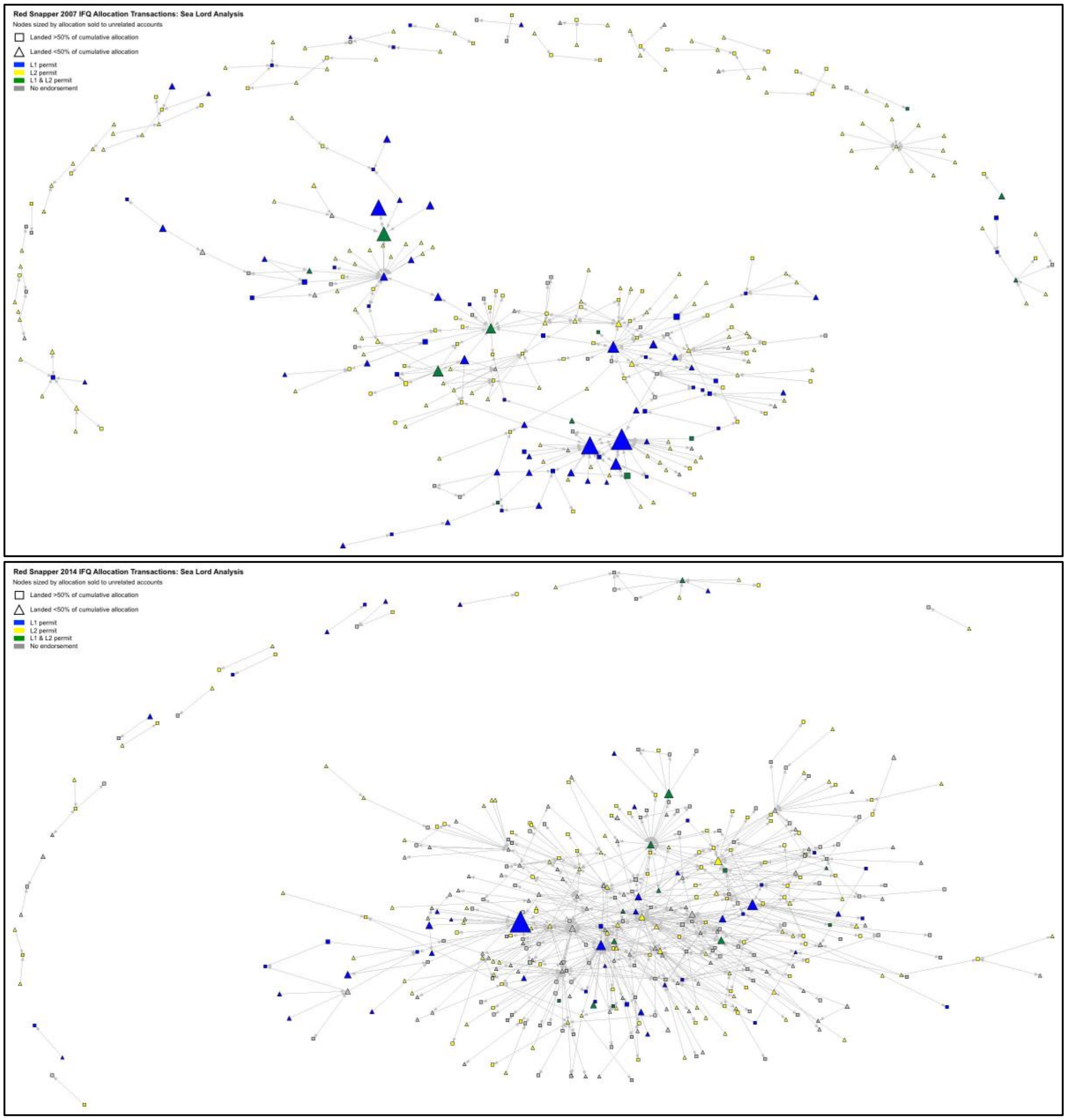


Figure 7: 2010 and 2014 Grouper-Tilefish allocation transaction network with related account clusters. Nodes are colored by related account status (blue = related account cluster, red=individual IFQ accounts), shaped by reported landings (squares = landed at least 50% of cumulative allocation, triangles = landed <50% of cumulative allocation), and sized by allocation sold to unrelated accounts.



An additional step was taken with the Red Snapper IFQ sea lords analysis - the integration of Class 1/Class 2 license data. Figure 8 represents the 2007 and 2014 Red Snapper IFQ allocation transaction networks. It appears that Class 1 license holders (i.e., large-scale fishermen) continue to play an important role in allocation transactions over time.

Figure 8: 2007 and 2014 Red Snapper allocation transaction network with related account clusters and Class 1/Class 2 license data. Nodes are colored by license status (blue = Class 1 license holder, yellow= Class 2 license holder, green = both Class 1 and Class 2 licenses, grey = no license), shaped by reported landings (squares = landed at least 50% of cumulative allocation, triangles = landed <50% of cumulative allocation), and sized by allocation sold to unrelated accounts.



Final Report

Technical Efficiency and Social Network Analysis of Gulf of Mexico Commercial IFQ Fisheries

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Executive Summary

- The commercial fleets harvesting red snappers, red groupers, and deep-water groupers in the Gulf of Mexico are all dominated by a small number of vessels that account for the majority of landings (referred to as “large harvesters”). In all three fisheries roughly 10-20% of the fleet accounts for 70-95% of the landings per year.

- Large harvesters, on average, had higher technical efficiency scores than the rest of the fleet both prior to and following IFQ implementation for the Gulf of Mexico commercial red snapper, red grouper, and deep-water grouper fisheries.

- IFQ implementation affected technical efficiency differently across fleets. For the red snapper and red grouper fleets, vessel-level technical efficiencies increased for large harvesters but fell for the rest of the fleet following IFQ implementation.

- Quota trading (of both share and allocation) and in the landings markets (IFQ landings sales from fishers to dealers) are minimally dense with very limited numbers of edges (transactions) relative to total network sizes.

- Social network analysis (SNA) using modularity maximization techniques found that the quota markets were highly segmented as characterized by numerous sub-markets with relatively few trades connecting these sub-markets.

- SNA employing modularity maximization techniques also found that the landings markets are highly segmented; most fishers only sell their IFQ landings to a single dealer in a given year. These dealers form the hub of fishing communities.

- IFQ fishers are much more likely to trade quota (share and allocation) with another member of their fishing community (the group of fishers they share a dealer with) than fishers they are not connected to through a shared dealer.

- Quota trading networks are not segmented based on IFQ participant harvest levels. Large harvesters tend to trade both with other large harvesters and the rest of the fleet.

- Large harvesters tend to be important to quota trading markets as measured by Eigenvector Centrality indicating that, generally, their trading opportunities are not limited relative to other market participants.

Technical Efficiency and Social Network Analysis of Gulf of Mexico Commercial IFQ Fisheries

Overview

With respect to evaluating the impacts of IFQ (individual fishing quota) implementation in Gulf of Mexico reef fish commercial fisheries, the objectives of this study were: 1) to determine the mechanics of how participants trade quota and how the dockside market (fishers selling their fish to dealers) influences trading in the quota markets by conducting social network analysis (SNA) of IFQ trading in the Gulf of Mexico Reef Fish IFQ fisheries; 2) examine changes in fleet efficiency pre- and post-IFQ; and 3) analyze IFQ trading relative to vessel level technical efficiencies (TEs) using SNA metrics to evaluate how market segmentation may have impacted efficiency gains from IFQ implementation.

The results are divided into three sections. The first section presents the TE analysis and provides a background on the stochastic distance frontier (SDF) modeling framework, the results of the SDF analysis, the resulting vessel-level TEs and how they were impacted by IFQ implementation. The second section presents the social network analysis of the quota and landings trading markets, including the SNA metrics associated with trading market characteristics and how they have changed through time. In addition, this second section evaluates the overlap between the networks to analyze how IFQ trading is accomplished by fishers. The third section evaluates IFQ trading based on vessel-level TEs using SNA metrics to determine if market segmentation has impacted technical efficiency gains.

Analysis was performed on three of IFQ species groups: red snapper (RS), red grouper (RG), and deep-water groupers (DWG). Preliminary analysis of SNA and TE results indicated that due to similarities in fishing behaviors among vessels, quota ownership, and trading patterns among IFQ participants, that results of separate analysis of other shallow water grouper (OSWG) and gag grouper (GG) would be highly correlated with red grouper; similarly, tilefish (TF) would be highly correlated with DWG. Thus, focus was placed on RG (as opposed to OSWG and GG) and DWG (as opposed to TF), due to the relative sizes of the fisheries and IFQ markets in terms of pounds harvested and quota and allocation traded (NMFS 2015a, 2015b).

Technical Efficiency (TE) Analysis

TE Methods and Procedures

A stochastic distance function (SDF) was used to estimate production efficiency of commercial fishing vessels in the Gulf of Mexico reef fish fishery. The potential impact of the implementation of the individual fishing quota (IFQ) system on fleet efficiency if also assessed.

Previous literature has shown commercial fishing to be characterized by substantial variability in production due to random factors and fishing operation cannot readily adjust production accordingly (Solis et al. 2014a). Stochastic frontier analysis (SFA) is a parametric approach to analyzing the production efficiency of commercial fishing operations and is the preferred methodology since uncertainly is accounted for in the empirical model. Commercial fishing is a multi-species venture where inputs are often similar and common between targeted species. An output-oriented SDF was adopted to evaluate the production efficiency in a multioutput framework. Following Kumbhaker, Wang, and Horncastle (2015), the multioutput distance function (ODF) for the SFA model is expressed as:

(1) $$D_0(y,x) = min\{\theta | (y/\theta)\ \epsilon\ \rho(x)\}$$

where $\mathrm{D}_0(\mathrm{y},\mathrm{x})$ represents the distance away from the frontier and assumed homogeneous of degree one in outputs, and $\rho(\mathrm{x})$ is a set of feasible output vectors for each input vector x. If $\mathrm{D}_0(\mathrm{y},\mathrm{x}) = 1$, output y lies on the boundary of the production frontier; if $\mathrm{D}_0(\mathrm{y},\mathrm{x}) < 1$, then output y lies off the boundary and within the feasible production region.

The empirical relationship between inputs and outputs is estimated using a translog functional form based on the results of a generalized likelihood ratio test compared to the Cobb-Douglas specification. The model is specified as follows:

(2)
$$lnD_{0i} = \beta_0 + \sum_{m=1}^{M} \beta_m lny_{mi} + 0.5 \sum_{m=1}^{M} \sum_{n=1}^{M} \beta_{mn} lny_{mi} lny_{ni} + \sum_{l=1}^{L} \beta_l lnx_{li} + 0.5 \sum_{l=1}^{L} \sum_{k=1}^{L} \beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L} \sum_{m=1}^{M} \beta_{lm} lnx_{li} lny_{mi}$$

where y_{mi} and x_{li} represent the quantity of output m and input l for vessel $\mathrm{i} = 1,2,3, \ldots \mathrm{n}$, respectively. The following conditions were imposed to ensure the ODF is well-behaved: (1) homogeneity of degree one in outputs, and (2) symmetry of the parameters. Homogeneity was imposed by normalizing the function by an arbitrary output (Coellli and Perelman 1999) and symmetry of the parameters by setting $\beta_{\mathrm{mn}} = \beta_{\mathrm{nm}}$. In addition, all input and output variables (y_{ji} and x_{ji}) were normalized by their geometric mean. Equation 2 is then re-specified as:

(3)
$$ln\frac{D_{0i}}{y_{1i}} = \beta_0 + \sum_{m=1}^{M} \beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5 \sum_{m=1}^{M} \sum_{n=1}^{M} \beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L} \beta_l lnx_{li} + 0.5 \sum_{l=1}^{L} \sum_{k=1}^{L} \beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L} \sum_{m=1}^{M} \beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right)$$

Equation 3 can be rewritten as:

(4)

$$-lny_{1i} = \beta_0 + \sum_{m=1}^{M} \beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5 \sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L} \beta_l lnx_{li} + 0.5 \sum_{l=1}^{L}\sum_{k=1}^{L} \beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M} \beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right) - lnD_{0i}$$

Substituting $-\mathrm{lnD}_{0i} = -\mathrm{u}_i$ introduces the stochastic frontier into the model and captures the effects of inefficiency in the production process. An error term is added to account for random disturbances and denoted by v_i. The estimated output-oriented stochastic distance function is specified as:

(5)

$$lny_{1i} = \beta_0 + \sum_{m=1}^{M} \beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5 \sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L} \beta_l lnx_{li} + 0.5 \sum_{l=1}^{L}\sum_{k=1}^{L} \beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M} \beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{j=1}^{J} \beta_j C_j + v_i + u_i$$

where v_i is random error term, u_i captures differences in efficiency, and C_j is a set of control variables designed to account for external factors affecting vessel production.[1] External factors include changes in management, stock levels, fishing area, and temporal changes in efficiency due to technology change. Our analysis employs a random effects time-varying efficiency model that utilizes unbalanced panel data with observations on N firms over T time periods. The use of panel data allows for the analysis of temporal variables such as IFQ implementation. By using a flexible time-varying model we allow for vessel level changes in technical efficiency through time. The basic panel data production function is outlined below:

(6)

$$lnY_{it} = x'_{it}\beta + v_{it} + u_{it}$$

The model was estimated using maximum likelihood based on the likelihood function presented by Kumbhaka, Wang, and Horncastle (2015) assuming u_{it} follows a truncated normal distribution.

Following the estimation of the output-oriented stochastic distance function, vessel level technical efficiency scores were calculated to identify the level of production efficiency and

[1] The left side of the equation was transformed from $-lny_{1i}$ to lny_{1i} as outlined in Coelli and Perelman (1999) for ease of parameter interpretation.

evaluated before and after IFQ implementation. Technical efficiency scores were then compared to assess the impact of IFQ implementation on fleet performance. Technical efficiency scores were calculated as follows:

(7) $$TE_{it} = E[exp(-u_{it})|v_{it} - u_{it}]$$

Technical efficiency scores are bounded between 0 and 1 with a score of 1 indicating that a vessel lies on the production frontier is producing the maximum amount of inputs given its inputs.

TE Data and Model Specification

TE Data

National Marine Fisheries Service Logbook data were used to perform the technical efficiency analysis. The data includes trip-level information on landings, fishing effort, and vessel characteristics. The data used covered 10 years of fishing (2005-2014) and included all Gulf of Mexico trips where reef fish species were landed. The data used was bounded to the five years prior to implementation of the Grouper-Tilefish IFQ program (2005-2009) and the five years after (2010 to 2014). Observations with missing data on landings or inputs were removed from the data set. Trip-level data was aggregated into annual vessel-level observations.

Models were run for red snapper (RS), red grouper (RG), and deep-water groupers (DWG).[2] For all models, only vessels that harvested at least 1000 pounds of fish during the year were included in the analysis. In addition, in an effort to focus on the fishery associated with each model run, only vessels that harvested at least 200 pounds of the fish being analyzed in the model (RS, RG, or DWG) during the year were included in the analysis. These restrictions were designed to limit the impact of part-time fishers and vessels focused on other fisheries that harvest small amounts of IFQ species; examples of these groups include: charter boats that occasionally take commercial fishing trips, semi-retired fishers that harvest small amounts of IFQ species, and large operators focused on other fisheries that have incidental catches of IFQ species.

TE Model Specification

The empirical models (RS, RG, and DWG) each included four outputs, three inputs, and a set of control variables. The four outputs were specified as total annual landings with the species composition varying by model as outlined in Table 1. Output levels were measured in pounds gutted weight.

[2] Although the RS IFQ program began in 2007, the same years (2005-2014) of data were used in all three models (RS, RG, DWG) for continuity and without loss of information (i.e., a model was run using RS data back to 2000 but the results were similar to those presented here).

Table 1. Output variables in the production frontier models

Output	Model: RS	Model: RG	Model: DWG
y1	Red snapper (RS)	Red grouper (RG)	Deep-water grouper (DWG)
y2	Other mid-depth snappers (OMDS)	Other shallow-water groupers (SWG)	Tilefish (TF)
y3	All other reef fish (DWG + SWG + TF)	All other reef fish (RS + OMDS + DWG + TF)	All other reef fish (RS + OMDS + SWG)
y4	All other landings	All other landings	All other landings

Note: For each model, the y1 variable was used to impose homogeneity.

The three input variables were: crew (x1), number of fishing days (x2), and vessel length (x3). Crew size and fishing days were measured as annual totals. The control variables included: a dummy for IFQ management (0 prior to IFQ), linear and quadratic time trends (t and t^2, t measured in years), and a fishing area dummy used to account for productivity across regions as shown in Figure 1. The areas were based on NMFS logbook partitions and fishing pressure by area. The RS and RG models had a RS spawning stock biomass index variable and a RG spawning stock biomass index variable, respectively.[3] These variables were included as proxies for abundance which has been used previously in the literature to account for differences in catch rates through time (Solís et al. 2014a; Felthoven and Morrison Paul 2004). Spawning stock biomass data was not available for DWG for 40% of the analysis period so this variable was not included in the DWG model. Descriptive statistics for the three models are presented in Table 2. Of interest is the landings statistics for the DWG model. DWG is harvested at greater depths than RS and RG which limits participation to larger vessels usually using longline gear that harvest more fish. Although these vessels are the major harvesters of DWG, as the results display, their targeting is directed predominately at other species (namely SWG species including RG).

[3] The RS stock index was taken from a 2013 update to the SEDAR stock assessment of Gulf of Mexico Red Snapper (SEDAR 2015a). The measure used was $SSB/SSB_{FSPR26\%}$, and the 2014 value was interpolated assuming a linear trend between the 2013 value and 2015 estimate. The RG stock index was taken from SEDAR 42 (SEDAR 2015b) and the measure used was SSB/MSST. The 2014 value was interpolated assuming a linear trend between the 2013 value and the 2019 estimate.

Figure 1. Map of fishing areas used in stochastic production frontier analysis

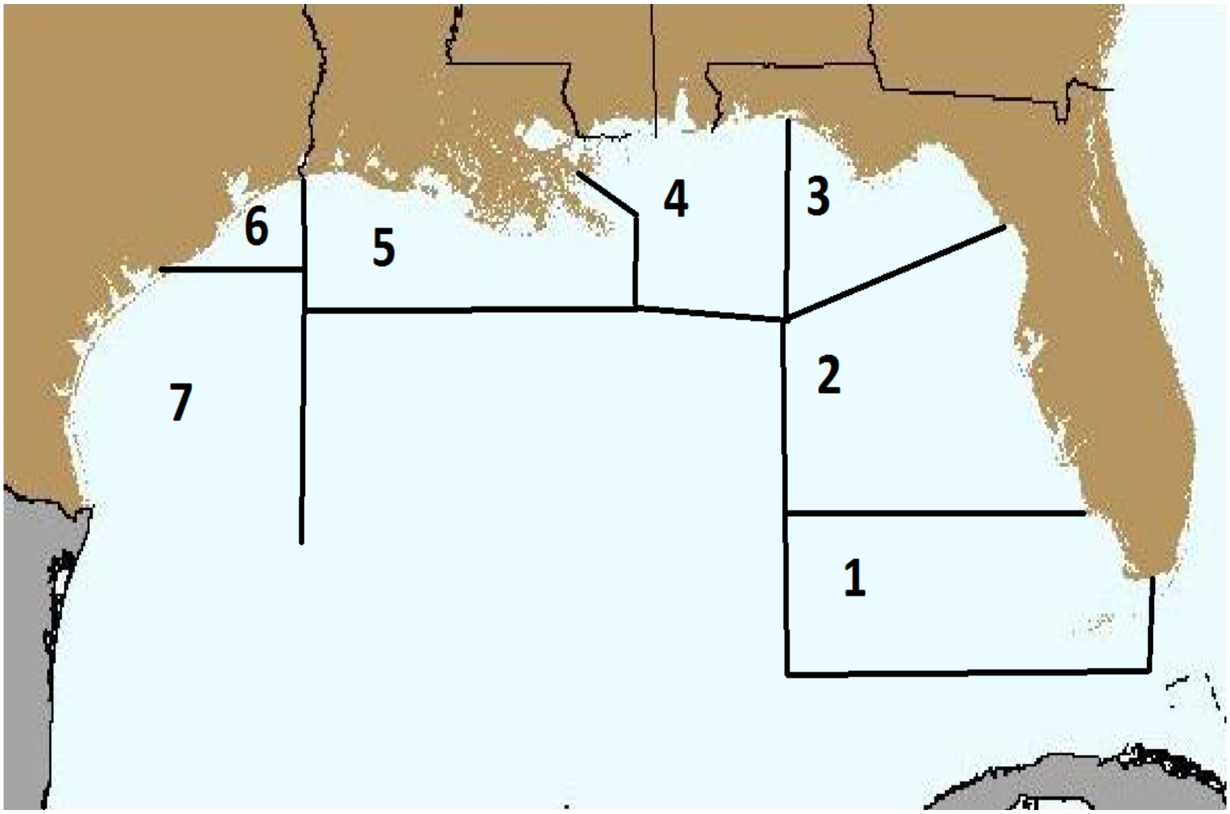


Table 2. Descriptive statistics for the variables used in the technical efficiency analysis by model

		Model					
		RS		RG		DWG	
Variable	Units	Mean	SD	Mean	SD	Mean	SD
y1	Lbs	11,259.50	24,525.02	12,353.00	18,611.42	6,670.02	10,905.06
y2	Lbs	5,776.12	13,206.61	3,191.20	4,773.98	3,108.71	9,782.01
y3	Lbs	14,132.70	24,730.76	8,318.78	17,850.91	41,005.29	39,142.66
y4	Lbs	3,781.12	5,824.72	3,224.35	5,337.97	5,418.59	7,086.22
Crew	crew/trip * trips	42.75	37.07	34.60	25.63	49.75	35.48
Fishing days	Days	67.21	52.52	70.58	53.06	102.16	52.31
Vessel length	Feet	40.04	9.85	38.45	8.30	44.86	9.26
IFQ	dummy	0.77	N/A	0.39	N/A	0.38	N/A
AREA:							
1: FL Keys	dummy	0.03	N/A	0.05	N/A	0.05	N/A
2: SW FL	dummy	0.29	N/A	0.55	N/A	0.41	N/A
3: FL Big Bend	dummy	0.27	N/A	0.31	N/A	0.13	N/A
4: FL Pan.-MS	dummy	0.17	N/A	0.06	N/A	0.14	N/A
5: LA	dummy	0.13	N/A	0.02	N/A	0.16	N/A
6: SE TX	dummy	0.08	N/A	>0.01	N/A	0.08	N/A
7: S TX	dummy	0.03	N/A	>0.01	N/A	0.03	N/A
RS Stock	SSB/SSBFSPR26%	0.35	0.15	N/A	N/A	N/A	N/A
RG Stock	SSB/MSST	N/A	N/A	1.44	0.31	N/A	N/A

Note: N/A indicates the statistic is not applicable to the variable. Area 1 is the base.

TE Results

Stochastic Production Frontier Estimates

The parameter estimates from the stochastic production frontier models are presented in Table 3. Parameter estimates of the first-order terms (ly2, ly3, ly4, lx1, lx2, and lx3) have the expected sign for all three models demonstrating monotonicity at the geometric mean, that is, non-decreasing in outputs and decreasing in inputs in accordance with economic theory. The statistical significance of the λ estimate for all three models indicates that technical inefficiency is present and validates the use of a production frontier rather than a production function. In addition, the fact that the λs are greater than one for all three models indicates that skill is more important than random shocks in explaining production variation across vessels (Solís et al. 2014b).

Table 3. Parameter estimates of the stochastic distance frontier models

	Model					
	RS		RG		DWG	
Variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-1.060***	0.239	8.711***	0.249	-0.043	0.179
ly2	-0.155***	0.009	-0.194***	0.011	-0.042***	0.013
ly3	-0.435***	0.008	-0.177***	0.008	-0.573***	0.012
ly4	-0.104***	0.011	-0.287***	0.009	-0.140***	0.012
ly22	-0.030***	0.003	-0.065***	0.005	-0.004	0.003
ly33	-0.077***	0.002	-0.042***	0.002	-0.094***	0.005
ly44	-0.042***	0.004	-0.056***	0.003	-0.047***	0.006
ly23	0.022***	0.003	0.030***	0.004	0.035***	0.006
ly24	0.002	0.005	0.006	0.006	-0.009	0.006
ly34	0.028***	0.004	0.017***	0.003	0.043***	0.010
lx1	0.448***	0.026	0.483***	0.024	0.497***	0.040
lx2	0.726***	0.028	0.816***	0.024	0.671***	0.045
lx3	1.304***	0.064	1.127***	0.064	1.241***	0.089
lx11	-0.315***	0.037	-0.338***	0.033	-0.429***	0.059
lx22	-0.214***	0.042	-0.242***	0.031	-0.164***	0.055
lx33	-0.627***	0.237	-0.235	0.265	-3.349***	0.412
lx12	0.640***	0.069	0.867***	0.055	0.654***	0.101
lx13	-0.200	0.161	-0.442***	0.167	0.332	0.209
lx23	0.441***	0.165	0.832***	0.150	-0.021	0.186
lyx21	0.025***	0.007	0.015	0.010	0.006	0.010
lyx22	-0.020***	0.007	0.001	0.009	0.009	0.009
lyx23	-0.049***	0.017	-0.088***	0.031	0.044*	0.023
lyx31	-0.006	0.008	-0.020***	0.005	0.078***	0.014
lyx32	-0.019**	0.009	0.009**	0.005	-0.108***	0.013

	Model					
	RS		RG		DWG	
Variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
lyx33	0.035*	0.019	-0.033**	0.016	0.067**	0.031
lyx41	0.016	0.010	0.012	0.007	-0.005	0.015
lyx42	0.005	0.010	-0.030***	0.007	0.025**	0.012
lyx43	-0.108***	0.026	-0.026	0.024	-0.046	0.037
Area 2	0.069	0.093	0.128***	0.042	0.103*	0.063
Area 3	0.198**	0.093	0.096**	0.045	0.028	0.066
Area 4	0.054	0.097	-0.137**	0.059	-0.038	0.067
Area 5	0.448***	0.098	-0.163**	0.076	0.241***	0.068
Area 6	0.418***	0.102	0.138	0.167	0.254***	0.077
Area 7	0.374***	0.112	-0.016	0.203	0.260***	0.090
T (year)	-0.008	0.047	-0.068***	0.026	0.002	0.032
t^2 (year^2)	-0.008***	0.002	0.003***	0.001	0.001	0.002
IFQ	0.246***	0.061	0.025	0.044	0.193***	0.049
Stock	3.935***	0.696	0.236***	0.047	N/A	N/A
σ_μ	0.781**	0.359	0.386***	0.035	0.532***	0.069
σ_ν	0.410***	0.024	0.365***	0.047	0.263***	0.028
$\lambda = \sigma_\mu / \sigma_\nu$	1.904***	0.342	1.059***	0.068	2.020***	0.064
Model statistics:						
Log-likelihood	-2,158.948		-2,410.654		-784.064	
# of obs.	2,949		3,506		1,440	
# of vessels	710		822		407	

Notes: Right-hand-side outputs are normalized by y1 (e.g., ly2 = ly2 – ly1). Single, double and triple asterisks denote statistical significance of $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively. N/A indicates that the coefficient was not estimated for that model.

By normalizing by the geometric mean and summing the parameter coefficients on the input variables (lx1, lx2, and lx3) we are able to measure returns to scale (Coelli et al. 2005). The returns to scale are 2.478, 2.426, and 2.409 for the RS, RG, and DWG models, respectively. Increasing returns to scale have previously been found in similar analysis on fisheries (Solís et al. 2014b; Felthoven et al. 2009). Asche et al. (2009) argued that increasing returns to scale can be caused by overcapacity in the fishing fleet. The parameter estimates on the fishing area variables indicate that fishing productivity generally varies by fishing area. The parameters for stock effect and IFQ were all positive indicating that higher stock levels and IFQ management led to increases in landings. In the next subsection we cover the vessel level TE scores and how they were impacted by IFQ management.

Technical Efficiency Scores

TE scores were estimated for each vessel in years they were active and met the requirements for inclusion in the data set. TE scores were calculated using the method outlined in Jondrow et al. (1982). The TE scores (pre- and post-IFQ) for the three models are presented in the top half of Table 4 below. The results indicate that average TE scores were unaffected by IFQ management; scores actually fell for all three models. The means presented in Table 4 are for all vessels, vessel level analysis comparing the pre and post IFQ TE scores of those vessels that fished in both periods was performed using a paired t-test of difference in means and are shown in the bottom half of table 4. The paired sample shows similar TE scores (with a larger drop in DWG TE scores post IFQ implementation) to the values presented in Table 4; however, the difference in pre- and post-IFQ TE scores for RG and DWG were statistically significant.

Table 4. Pre- and post-IFQ TE scores by fishery and for both all vessels and for vessels fishing both pre- and post-IFQ implementation (paired vessels)

Fishery and Data	Pre-IFQ	Post-IFQ	Difference in Means (P value)
All Vessels:			
Red snapper	0.743	0.742	0.832
Red grouper	0.618	0.618	0.967
Deep-water grouper	0.671	0.669	0.773
Paired Vessels:			
Red snapper	0.748	0.742	0.276
Red grouper	0.605	0.594	0.041
Deep-water grouper	0.662	0.640	0.043

Note: The difference in means was tested with a two-sided t-test.

The initial findings that TE scores fell after IFQ implementation was surprising. In an effort to determine if these results were indicative of the entire fleet, we performed further analysis where the fleet was subdivided into large harvesters and small harvesters. Vessels were categorized as large harvesters in years which they accounted for at least 0.25% of the total catch for the species group being modeled in the analysis (RS, RG, or DWG depending on the model). Figure 2 presents both the percentage of fishers that qualify as large harvesters and the percentage of the harvest landed by the large harvesters by year. As the figure displays, large harvesters generally accounted for 10-20% of all harvesters and 70-90% of the pounds harvested (of the species in question).[4] These subgroups were then used to evaluate if IFQ management impacted TE of large harvesters differently than TEs of small harvesters.

[4] This figure and these estimates were based on raw NMFS logbook data (not the model data) so small harvesters (<200 lbs of the species per year and <1000 lbs of total catch per year) have not been removed.

Figure 2. Large harvester's percentage of fishers and catch by species group and year

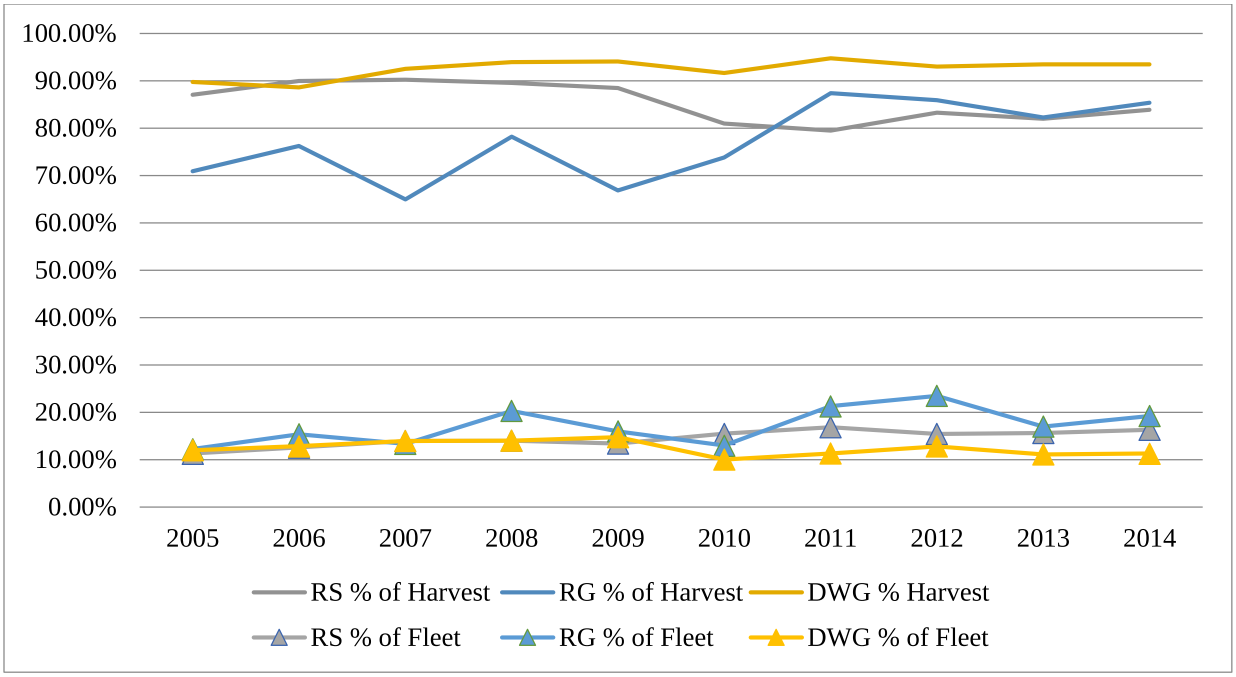


Table 5 presents the TE scores by group for the entire period. As the scores indicate, large harvesters were significantly more efficient than small harvesters for all three fisheries analyzed.

Table 5. TE Scores by fishery and harvest group

Fishery	Large	Small	Difference in Means (P value)
Red snapper	0.786	0.726	0.832
Red grouper	0.661	0.601	0.967
Deep-water grouper	0.721	0.621	0.043

Note: The difference in means was tested with a two-sided t-test.

Next, the analysis was run comparing the two groups for both the pre- and post-IFQ periods separately and to evaluate how average TE scores for the two harvester types changed after IFQ implementation; this information is presented in Table 6. While DWG TE scores showed no significant change in pre- and post-IFQ scores, the data from the RS and RG fisheries indicates that large harvesters became more efficient (i.e., higher TE scores after IFQ implementation) and small harvesters became less efficient (i.e., lower TE scores after IFQ implementation).

Table 6. Pre- and post-IFQ TE scores by fishery and harvest group

Harvest group and Fishery	Pre-IFQ	Post-IFQ	Difference in Means (P value)
Large harvesters:			
Red snapper	0.760	0.794	0.000
Red grouper	0.652	0.672	0.002
Deep-water grouper	0.721	0.721	0.967
Small harvesters:			
Red snapper	0.737	0.723	0.013
Red grouper	0.606	0.593	0.005
Deep-water grouper	0.621	0.621	0.958

Note: The difference in means was tested with a two-sided t-test.

These results indicate that large harvesters in the RG and RS fisheries were able to increase TE after IFQ implying that constraints associated with past seasonal management was limiting the efficiency of large fishers. With regards to small harvesters (RG and RS) our results indicate that IFQ management actually decreased vessel level TE as opposed to increasing it as might be expected given the removal of seasonal closures.

Social Network Analysis (SNA)

Social network analysis provides an ideal framework for analyzing quota and landings trading markets and examining how trading occurs in these markets, how the markets evolve over time, and the roles participants assume in newly created quota markets. The study of networks, while relatively new to the resource economics field, is common in many academic disciplines including mathematics, physics, computer science, biology, sociology, and anthropology. Networks have been used to study such diverse topics as: the interconnection of websites on the internet, design of food webs in nature, international trade flows, and disease transmission in humans. At its most basic, a network simply measures some form of connection between objects. Network graphs consist of a group of points, often referred to as vertices or nodes, connected by lines between them, referred to as edges or links. The vertices represent actors or objects (people, animals, computers, websites, chemicals, companies, etc.) and the edges represent the nature of the connections between the vertices (friendships among individuals, predator-prey relationships in nature, intranet connections between computers, hyperlinks between internet sites, bonds in chemical compounds, transactions between companies, etc.) (Newman 2010).

Although network graphs (composed of vertices and edges) are fairly basic, the techniques used to analyze them are quite diverse and often mathematically rigorous. Network analysis includes a number of different forms of research. For example, analysis can focus on network structure (the size and shape of the system being studied), vertices in the network (which actors in the network are most important), edges in the network (what connections are key to the network), network dynamics (how the network changes through time), spatial dynamics (how does location affect the network), and comparison between networks (how do different networks compare over space and time and how do they interact).

In this report we analyze networks based on quota trading (share and allocation) and landings (fishers selling fish dockside to dealers) markets. These networks are analyzed on an annual basis to see how they change through time. The quota trading markets are separated by species group (RS, RG, and DWG) while the landings networks include all IFQ species. SNA metrics related to network structure and segmentation are analyzed. In addition, this analysis looks at connections between the two networks (quota trading and landings) to help determine how IFQ participants trade quota. The rest of this section is as follows. The next section describes the data used in the analysis. The following section analyzes the quota trading networks (quota and allocation), and an analysis of the landings networks. The last section evaluates the overlap between the landings and quota networks.

SNA Data

The data used in this analysis was collected from the National Marine Fisheries Service (NMFS) and includes data from 2007-2014. The data includes the buyer and seller, amount transacted, and date of transaction for all IFQ share, allocation, and landings transactions. For the landings market, pounds traded represented the amount of fish transacted (rather than quota) and the buyer is a registered dealer purchasing the fish dockside.

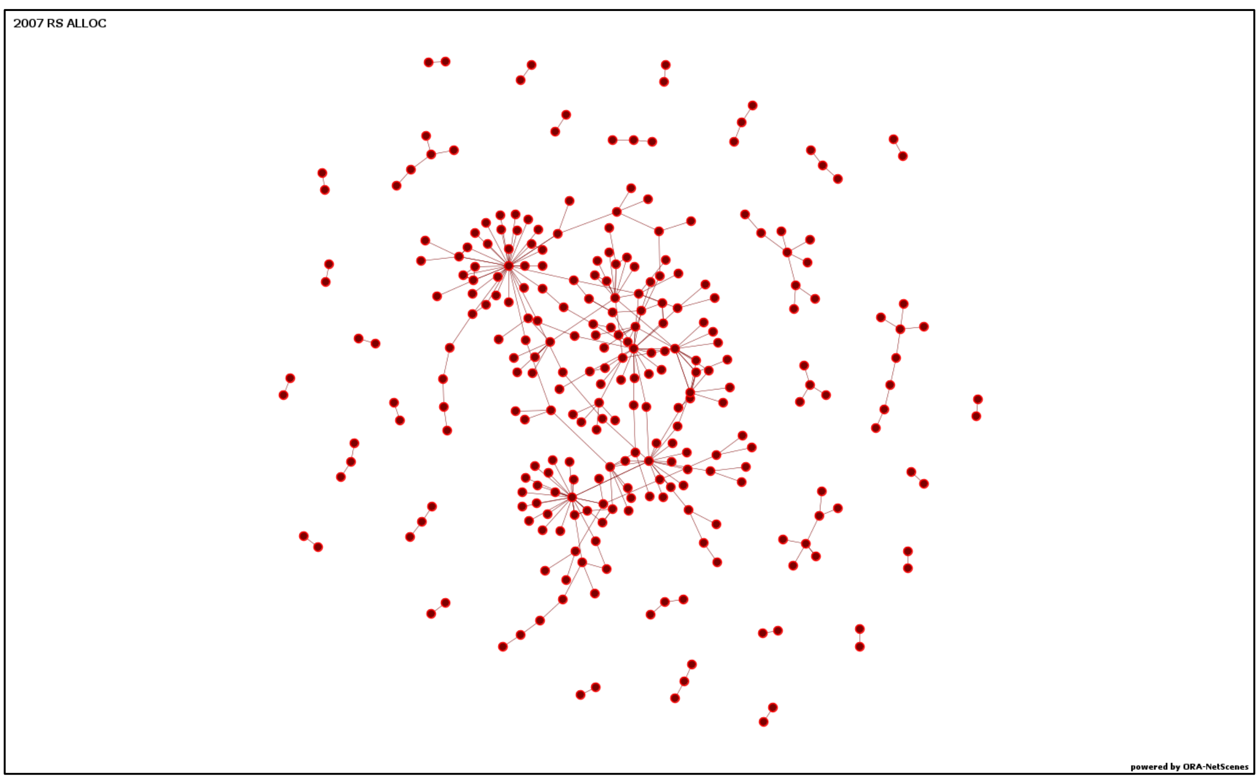
Prior to performing network analysis on the quota lease and landings markets, the data had to be reconstructed in a number of ways. The first change was that unique fishing firms or entities had to be identified. The raw data from the NMFS had two separate account identifiers. The first identifier, IFQ ID, was a unique identifier of each IFQ account. This identifier was used from 2007 to 2009 and allowed the same entities to control multiple accounts (have multiple IFQ IDs). The problem with this identifier was that it made it difficult to determine whether trades were truly independent transactions or simply a single fishing firm transferring quota among its vessels. In 2010 these accounts were consolidated (retroactively for data purposes) for each unique entity into a second identifier, Entity ID. Although the Entity ID consolidated the separate IFQ ID accounts for each participant, it still did not accurately distinguish all economic entities (fishing firms) for the purpose of determining what transactions were independent. For example, if a fishing firm with multiple vessels incorporated each vessel it was possible that each vessel would get a unique Entity ID when they were controlled by the same firm.

The problem of identifying unique firms was rectified by comparing the ownership and management teams of each Entity ID account (provided by NMFS) to all other Entity ID accounts with the goal of combining overlapping Entity IDs. For the purposes of this analysis, for a transaction to be considered to have occurred between two independent entities, the two parties to the trade had to have less than 50% ownership overlap. For instance, if Firm 1 was owned equally by individuals A and B and traded with Firm 2 solely owned by individual B, the trade was deemed to not be independent (i.e., not at "arm's length") and the transaction was not included in the analysis. After accounting for this overlap the dataset used included 1,726 share transactions, 21,367 allocation transactions, and 94,373 landings transactions.

SNA of Trading Markets

The first two markets analyzed were the share (IFQ sale) and allocation (IFQ lease) transactions. Separate networks were developed for each IFQ species groups. Networks were created based on annual trading (evaluating only trading during a given year) to account for the seasonal nature of quota (i.e., that quota and allocation poundage are based on the total quota for the fishery which is set annually). The quota and allocation networks were unimodal, consisting of only one type of node (IFQ account holders). An edge in the network represented a sale of quota or allocation from one IFQ account holder (seller) to another (buyer). A graph of a share network (without isolates, or those IFQ participants that did not trade allocation) for the first year of the red snapper IFQ program is presented in Figure 3. The graph depicts a major component, or largest subset of connected nodes surrounded by smaller minor components.

Figure 3. Red snapper allocation trading network in 2007



In addition to basic network measures such as number of nodes (IFQ participants) and number of edges (number of trading relationships), the network analysis evaluated network density and modularity. Network density is the number of edges (transactions) in a network given as a proportion of the total number of edges possible given the number of nodes (participants) in the network. The following formula for network density (D) uses *m*, the number of edges, and *n*, the number of nodes[5]:

(8) $$D = 2m/(n(n-1))$$

Modularity measures the level of segmentation in a social network. Evaluating segmentation within the trading networks can provide insights into how localized trading. SNA algorithms divide networks into communities of nodes based on the pattern of edges between them (Newman 2010). The algorithms attempt to locate communities in a manner such that trades within communities are maximized and trades between communities are minimized.

In this analysis, the Newman Spectral Optimization Algorithm (NSOA) is used to maximize the modularity of a network (Newman 2006). Assortative mixing, which modularity is based on, occurs when groups within a network are mostly connected to members of their own group and connections between groups are rare. In social networks assortative mixing can occur based on gender, age, race, or geographic location (Newman 2010). Modularity (Q) is a measure between -1 and 1 that measures the level of assortative mixing:

(9)

$$Q = \frac{1}{2m}\sum_{ij}\left(A_{ij} - \frac{k_i k_j}{2m}\right)\delta(c_i c_j)$$

In equation 9, *m* is the number of edges in the network, A_{ij} is 1 if vertices *i* and *j* are connected and 0 otherwise, k_i is the degree of vertex i, k_j is the degree of vertex j, $\delta(c_i c_j)$ is the Kronecker delta, c_i is the type or class of vertex *i*, and c_j is the type or class of vertex *j* (Newman 2010). The NSOA arranges the vertices into communities (c) in a manner that maximizes the modularity of the network. The Q value is positive when there are more edges between vertices of the same type than would be expected if connections were random, and is negative when there are less of these same edges than would be expected if connections were random. While modularity maximization can provide insights into how segmented a network is it does not provide any evidence on what is leading to that segmentation. Determining what is leading to segmentation is discussed later.

The SNA metrics for the share and allocation networks for the red snapper, red grouper, and deep-water grouper trading markets are presented in Table 7. For each network the number of groups created by the NSOA in maximizing modularity is presented under the modularity score. Some of the general trends that emerge from the results are that density and modularity are higher for the share networks than the landings networks. The greater densities are due to smaller networks (fewer IFQ participants trade shares than allocation) and the higher modularities are the result of share networks being less connected networks.

[5] This formula is for an undirected network. Undirected networks focus only on whether there is a connection between two nodes and not the direction of the connection.

Table 7. Share and allocation network metrics by fishery and year

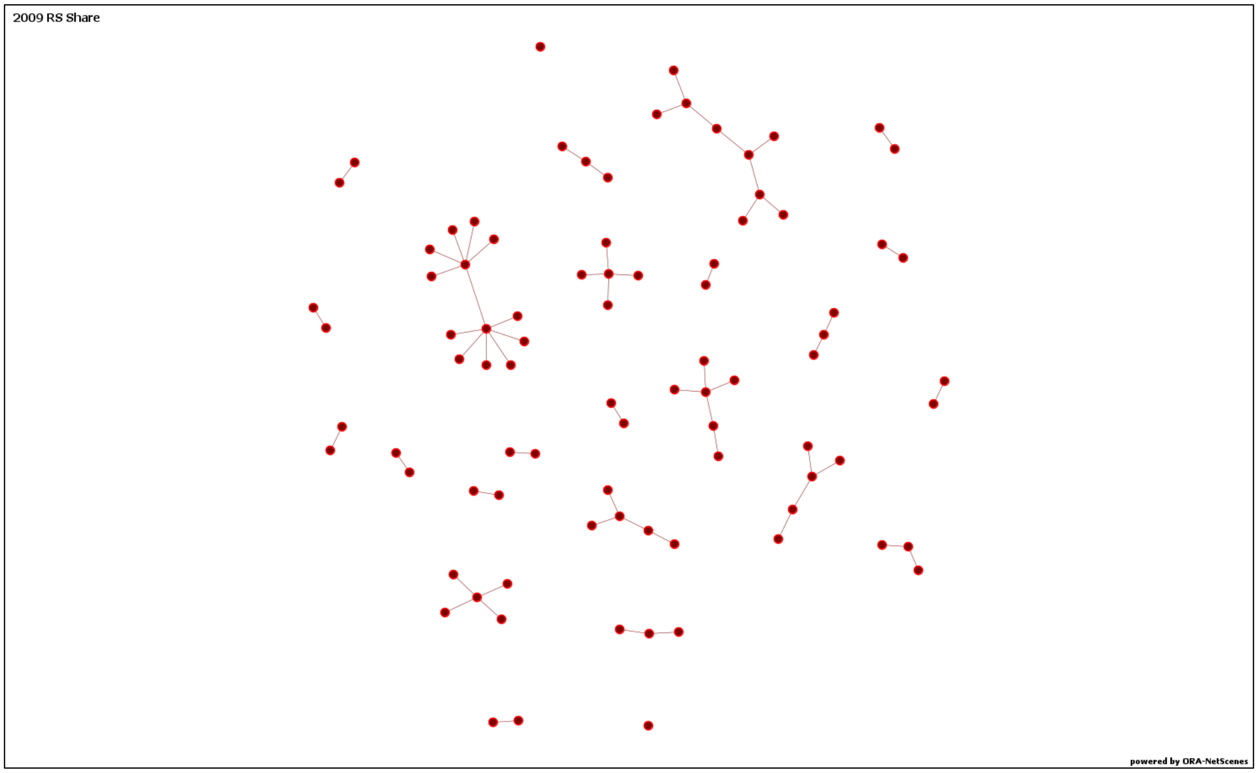
Measure	2007	2008	2009	2010	2011	2012	2013	2014
Red Snapper								
Share:								
Nodes	118	68	86	93	69	89	67	97
Edges	79	39	61	58	50	54	42	77
Density	0.011	0.017	0.017	0.014	0.021	0.014	0.019	0.017
Modularity	0.934	0.955	0.904	0.908	0.786	0.923	0.798	0.877
Groups	39	29	23	29	19	29	17	28
Allocation:								
Nodes	276	240	277	351	364	382	380	406
Edges	309	262	344	564	624	677	753	783
Density	0.008	0.009	0.009	0.009	0.009	0.009	0.011	0.010
Modularity	0.858	0.818	0.811	0.751	0.746	0.785	0.763	0.774
Groups	29	38	29	21	24	22	26	31
Red Grouper								
Share:								
Nodes	N/A	N/A	N/A	203	147	147	102	103
Edges	N/A	N/A	N/A	182	111	128	91	95
Density	N/A	N/A	N/A	0.009	0.010	0.012	0.018	0.018
Modularity	N/A	N/A	N/A	0.866	0.883	0.838	0.780	0.766
Groups	N/A	N/A	N/A	37	38	33	25	25
Allocation:								
Nodes	N/A	N/A	N/A	345	412	407	368	397
Edges	N/A	N/A	N/A	416	620	758	617	758
Density	N/A	N/A	N/A	0.007	0.007	0.009	0.009	0.010
Modularity	N/A	N/A	N/A	0.837	0.789	0.748	0.767	0.734
Groups	N/A	N/A	N/A	46	39	26	33	27
Deep-water Grouper								
Share:								
Nodes	N/A	N/A	N/A	140	106	89	61	64
Edges	N/A	N/A	N/A	110	68	55	32	45
Density	N/A	N/A	N/A	0.011	0.012	0.014	0.018	0.022
Modularity	N/A	N/A	N/A	0.872	0.909	0.892	0.859	0.791
Groups	N/A	N/A	N/A	31	32	31	21	17
Allocation:								
Nodes	N/A	N/A	N/A	230	262	274	228	240
Edges	N/A	N/A	N/A	243	308	342	265	337
Density	N/A	N/A	N/A	0.009	0.009	0.009	0.010	0.012
Modularity	N/A	N/A	N/A	0.809	0.785	0.786	0.807	0.739
Groups	N/A	N/A	N/A	38	28	30	26	26

Note: N/A indicates the measures are not applicable since the ITQ program was not yet implemented.

Focusing on the allocation networks, a general trend of decreased modularity is noticeable. This finding is correlated to generally increasing number of trading relationships and indicates that these markets are becoming less segmented. This trend was most prevalent in the red snapper allocation network. In 2010, when the Grouper-Tilefish IFQ program began, there was a drastic increase in the number of IFQ participants (nodes) and the number of trading relations (edges). These increases were due to Grouper-Tilefish IFQ participants deciding to take part in the RS IFQ program as well. As trading grew the allocation networks became more connected leading to lower modularity scores.

Figure 4 depicts the 2009 red snapper share network which is made up of a number of smaller components and lacks a large major component. This leads to higher modularity as the NSOA divides these into separate groups and with no ties between them modularity values are higher.

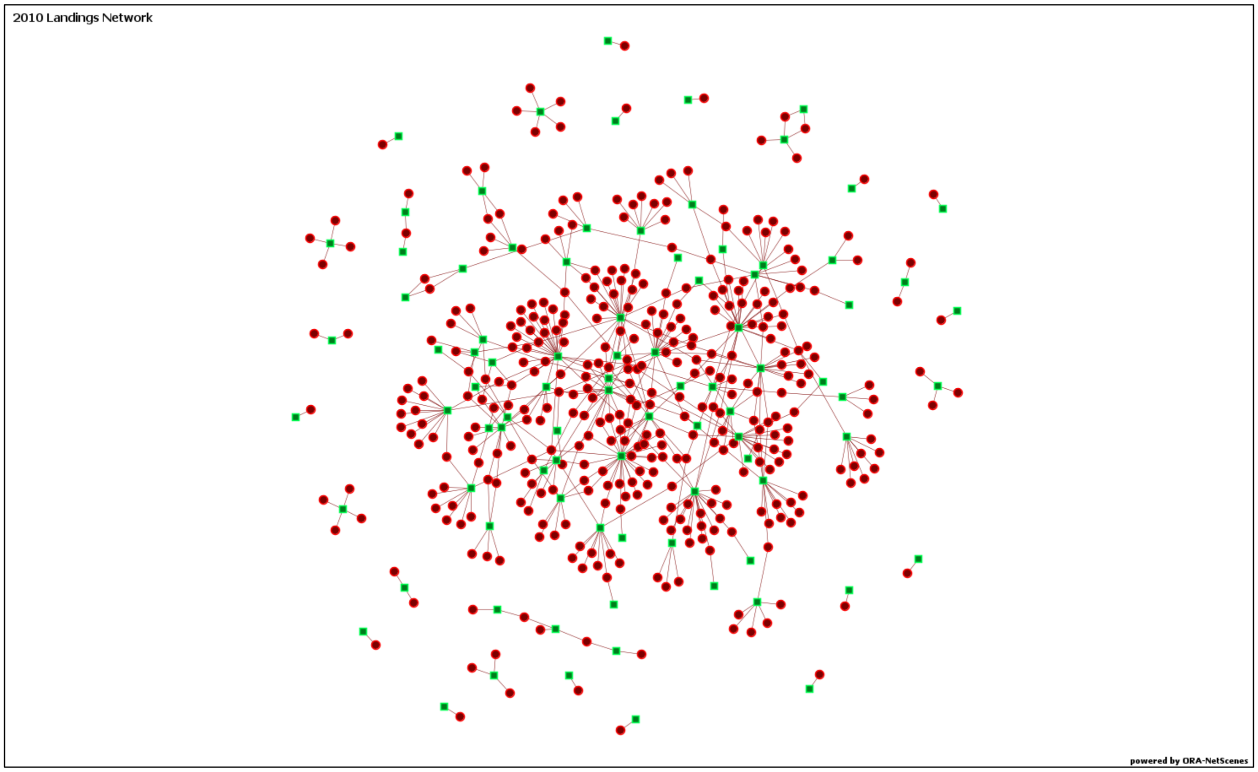
Figure 4. Red snapper share trading network in 2009



SNA of Landings Markets

Transactions in the landings market involve fishers (IFQ participants) selling IFQ species to registered IFQ brokers (processors, wholesalers, and retailers). The landings network is a bi-modal network with two distinct types of nodes (fisher nodes and dealer nodes) with edges (fish transactions) only occurring between different node types. A landings network graph is displayed in Figure 5. The green nodes are IFQ dealers and the red nodes are IFQ fishers and edges between nodes implying the fisher sold fish to the dealer. The landings networks were not separated by IFQ species types since it was assumed, and verified by analysis, that fishers, generally, sell all of their landings to a single dealer for a given trip.

Figure 5. Landings network graph in 2010 (red = fishers, green = dealers)



The network metrics calculated for the landings networks were: number of fisher nodes, number of dealer nodes, number of edges, network density, modularity, and edges per fisher. The formula for network density of a bimodal network is presented in equation 10 where *m* is the number of edges, *l* is the number of type 1 nodes (fisher), and *n* is the number of type 2 nodes (dealers).[6]

(10) $$D^{bimodal} = m/(l*n)$$

The network metrics are presented in Table 8. Similar to the results from the quota networks the landings networks are minimally dense with fishers, on average, trading with just over one dealer per year. The modularity scores were all above 0.9 indicating a highly segmented network. This was to be expected given the tendency for fishers to only transact with one dealer[7].

[6] This formula is for an undirected network. Undirected networks focus only on whether there is a connection between two nodes and not the direction of the connection.

[7] Prior to modularity maximization dyads and triads were removed from the landings networks. Dyads and triads are minor components with only two or three nodes, respectively. Generally, dyads represent IFQ fishers that are also

Table 8. Landings network SNA metrics by year

Metric	2007	2008	2009	2010	2011	2012	2013	2014
Fisher nodes	266	255	249	378	372	373	358	372
Dealer nodes	75	67	66	89	97	97	97	119
Edges	339	302	303	504	469	470	455	491
Bimodal density	0.017	0.018	0.018	0.015	0.013	0.013	0.013	0.011
Modularity	0.927	0.940	0.934	0.926	0.938	0.935	0.941	0.946
Groups	29	32	35	38	39	39	42	45
Edges/Fisher	1.274	1.184	1.217	1.333	1.261	1.260	1.271	1.320

The assumption that fishers do not sell different species to different dealers was backed up by the fact that edges per fisher did not increase significantly and modularity did not fall following the implementation of the Grouper-Tilefish IFQ program in 2010.

Overlap Between Networks

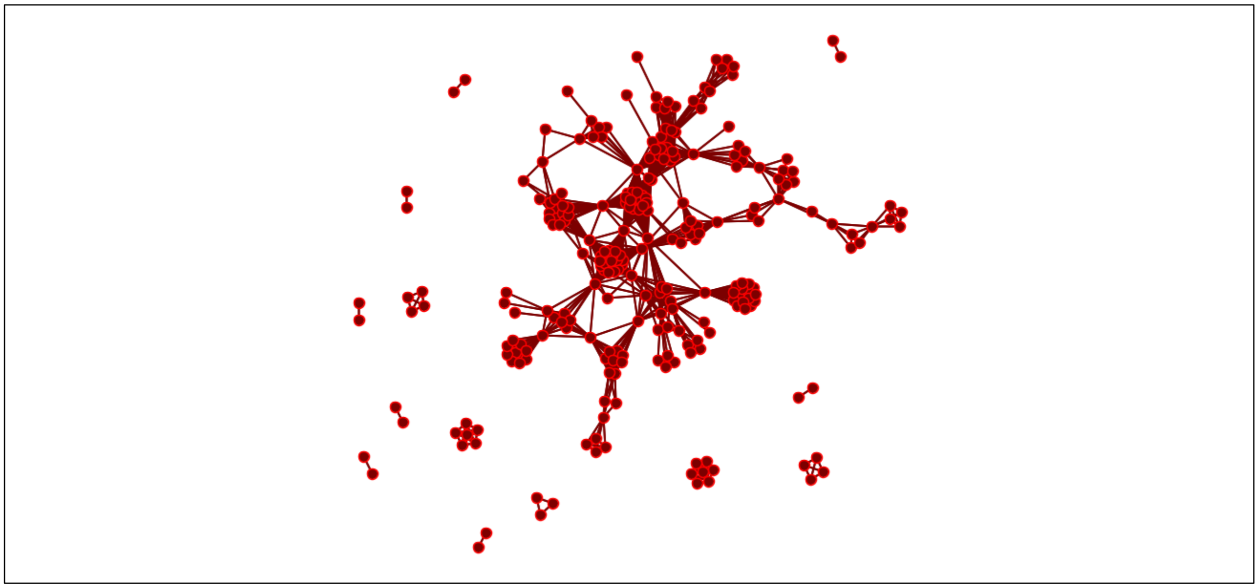
One of the major goals of this research was to evaluate quota trading network mechanics; namely, how, and where, do IFQ participants find trading partners? Ideally we would be able to survey all IFQ participants and ask them this question as well as where they go for information on quota markets that would allow us to determine their information sharing networks. Lacking this data, our analysis led to the landings networks. Since fishers show a great deal of fidelity to the dealers they sell fish to with very few fishers selling to multiple dealers in a given year (Ropicki and Larkin 2014), we decided to evaluate quota trading relative to landings network relationships. The basic premise of this analysis is that dealers might serve as the base of fishing communities with fishers using the same dealer tied together in a 'fishing community', and these fishing communities might be sub-networks where IFQ participants go to trade quota and share information on quota markets (Ropicki and Larkin 2014).

To test the idea that trading occurs through 'fishing communities', the landings networks were transformed into uni-modal networks that only contain fishers. Landings networks can be represented by adjacency matrices (A_{ij}) where i is a fisher and j is a dealer and the matrix entry a_{ij} is 1 if they traded and zero if they did not. By multiplying a landing network adjacency matrix by its transpose (A_{ji}) we get a network (A_{ii}) with only fisher nodes where an edge between two fishers indicates they shared a dealer we defined these networks as shared dealer networks.

own a registered dealer entity and sell their landings to themselves. Triads were removed on the assumption that they most likely involved two fisher nodes that were affiliated, but did not surpass the 50% ownership threshold for combining the entities outlined earlier in the report, trading with themselves (selling fish to themselves).

Figure 6 presents a visualization of a shared dealer network. These networks are extremely dense (large numbers of connections relative to landings markets). As an example if we assume a basic landings network with one dealer and 10 fishers all connected to the dealer we have a network with 11 nodes (1 dealer and 10 fishers) and 10 edges. However, when we multiply that network by its transpose we get a network with 10 nodes (all fishers) and 45 edges since all fishers are connected in this simplified network (all used the same dealer).

Figure 6. Shared dealer network in 2007



Once the shared dealer networks were created they were compared to the quota and allocation networks using the Jaccard Index. The Jaccard index (J) calculates the similarities between sample sets as the size of the intersection divided by the size of the union (Hanneman and Riddle, 2005):

(11)

$$J(A,B) = \frac{|A \sqcap B|}{|A \sqcup B|}$$

For our purposes, the two networks intersect if the same two IFQ participants were connected in both networks (quota and shared dealer) and the union is all pairs that are in both networks, the union of the networks implies that this analysis only involves trades between IFQ participants that fished.

Once the Jaccard index (observed correlation) is calculated, a quadratic assignment procedure (QAP) is run to test for statistical significance. To do this, the observed correlation is compared to 2,500 pairs of matrices with the same number of nodes and edges but where the data is known to be independent. Independence is achieved by taking one of the two matrices and randomly rearranging the rows and columns; this is because the changes are random the new matrix is independent of the original (Borgatti et al. 2013).

The results of the overlap analyses for red snapper, red grouper and deep-water groupers are presented in Table 9. The results presented include the Jaccard index value for the network (Observed Correlation), the average Jaccard index value for the randomly generated networks (Average Random Correlation), and the p-value measures the probability of observing the Jaccard index (Observed Correlation) if the two networks were randomly designed with the same number of edges and connections. These statistics are reported for both the share and allocation networks. In addition, for the allocation networks the percentage of total trading relationships covered by the analysis is included for the allocation networks.[8] The results indicate that fisher to fisher trades through 'fishing community' connections are much more common than would be expected if trading were random, this finding provides strong evidence that IFQ participants do look within their 'fishing communities' when looking to trade quota.

Table 9. Red snapper network overlap measures by fishery and year

Measure	2007	2008	2009	2010	2011	2012	2013	2014
Red Snapper								
Share:								
Obs. corr.	0.005	0.002	0.005	0.002	0.002	0.001	0.001	0.002
Avg. ran. corr.	0.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
P-value	<.001	<.001	<.001	<.001	<.001	0.001	0.003	<.001
Allocation:								
Obs. corr.	0.041	0.042	0.049	0.044	0.055	0.056	0.068	0.071
Avg. ran. corr.	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.001
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
% trading rel.	56.0%	59.2%	64.0%	73.6%	76.3%	72.8%	67.1%	68.3%
Red Grouper								
Share:								
Obs. corr.	N/A	N/A	N/A	0.006	0.002	0.006	0.004	0.005
Avg. ran. corr.	N/A	N/A	N/A	0.001	<.001	0.001	<.001	<.001
P-value	N/A	N/A	N/A	<.001	<.001	<.001	<.001	<.001
Allocation:								
Obs. corr.	N/A	N/A	N/A	0.026	0.05	0.06	0.053	0.062
Avg. ran. corr.	N/A	N/A	N/A	0.002	0.002	0.003	0.003	0.003
P-value	N/A	N/A	N/A	<.001	<.001	<.001	<.001	<.001
% trading rel.	N/A	N/A	N/A	64.2%	69.4%	75.7%	68.7%	73.7%

[8] Since we are comparing shared dealer networks to quota trading networks trades involving IFQ participants that did not fish are not included in the analysis. This metric was included to show that fisher to fisher trades represent the majority of trading relationships in the allocation markets.

Measure	2007	2008	2009	2010	2011	2012	2013	2014
Deep-water Grouper								
Share:								
Obs. corr.	N/A	N/A	N/A	0.004	0.001	0.002	0.001	0.002
Avg. ran. corr.	N/A	N/A	N/A	0.001	<.001	<.001	<.001	<.001
P-value	N/A	N/A	N/A	<.001	<.001	<.001	0.030	<.001
Allocation:								
Obs. corr.	N/A	N/A	N/A	0.016	0.025	0.025	0.022	0.026
Avg. ran. corr.	N/A	N/A	N/A	0.001	0.001	0.002	0.001	0.002
P-value	N/A	N/A	N/A	<.001	<.001	<.001	<.001	<.001
% trading rel.	N/A	N/A	N/A	63.4%	67.5%	69.3%	64.9%	63.8%

Note: N/A indicates the measures are not applicable since the ITQ program was not yet implemented.

The Jaccard index values are low due to the nature of the two networks being analyzed. The shared dealer network is fairly dense given the way it is formed while the quota networks, as noted above, contain few edges and are minimally dense. The disparity between the densities of the two networks leads to the low values the statistical significance is the more important measure for analysis.

Fleet Segmentation Analysis (FSA)

The TE analysis presented in the first section of this paper displayed a statistically significant difference between the TE of vessels harvesting large amounts of quota and the rest of the fleet. This difference was found during both the pre- and post-IFQ periods. Past work on Gulf of Mexico commercial reef fisher technical efficiency and fleet capacity (i.e., Solis et al. 2014a, Weninger and Waters 2003, Weninger 2008) indicated large potential gains in fleet technical efficiency and the potential for large reductions in overcapacity. However, reductions in fleet size and overcapacity have been limited in these fisheries; after modest initial drops in the number of vessels harvesting IFQ species following IFQ implementation, vessel participation has generally started to increase (NOAA 2015a, 2015b).

According to economic theory, reductions in overcapacity from IFQ management are accomplished through more efficient harvesters placing a higher value on quota and buying out their less efficient counterparts. In this analysis we examine the quota trading markets using SNA to examine if the market structure could potentially be limiting fleet consolidation (i.e., any observed discrepancies with economic theory pertaining to rights-based management are reflecting inefficiencies in the trading markets due to the presence of social networks and not incorrect theories). This fleet segmentation analysis (FSA) is accomplished by computing a number of network metrics relative to the parts of the fishing fleet outline in the TE section of this report (large harvesters and other vessels).

FSA Data

The data used for this analysis are a combination of the logbook data used for the TE analyses and the IFQ trading and landings data used for the SNA analyses. Data analysis for this portion of the research involved linking the NMFS logbook data (vessel-based) with the IFQ dataset (owner-based). This reconciliation of the two datasets required using the NOAA Fisheries Vessel Documentation Database (http://www.st.nmfs.noaa.gov/st1/CoastGuard/VesselByName.html) to reconcile vessels to their owners. Once vessels were associated with IFQ accounts, the IFQ accounts were coded to identify fleet segments based on landings (as either large harvesters or others) and SNA was conducted on the quota networks for the three IFQ species groups analyzed previously (i.e., RS, RG, and DWG).

FSA Methods and Procedures

The major objective of this portion of the research was to determine if the quota markets were segmented in a manner that was inhibiting trade between the two fishing groups (large harvesters and other fishers). Two SNA metrics were used to evaluate quota trading between the two groups. The first metric was modularity. In the previous section, modularity was maximized to evaluate market segmentation; in this section, modularity was used on pre-defined groups (large harvesters and others) to measure assortative mixing. High trading network modularity values would indicate that large harvesters tended to trade only with other large harvesters and other IFQ participants tended to only trade amongst themselves. The second metric analyzed was Eigenvector Centrality (EC), which is a node-level metric that measures the connectedness of a node and its position in the network under the basic assumption that a node is important if it is linked to other important nodes. EC is calculated for node i as follows:

(12)

$$EC_i = \lambda \sum_j x_{ij} EC_j$$

where λ is a proportionality constraint, x_{ij} is one if node i is connected to node j and 0 otherwise, and ECj is the Eigenvector Centrality of node j (Borgatti et al. 2013). EC values were calculated to see if large harvesters, on average, were well connected in the networks. It was assumed that better connected nodes would have greater access to other potential trading partners.

FSA Results

The results are presented in Table 10 by fishery and year. The modularity scores were generally around zero with no discernable time trends. This finding implies that quota trading is not segmented based on fisher type; in other words, larger harvesters are roughly as likely to trade with other fishers as they are amongst themselves. Average EC values for large harvesters were generally higher than for other IFQ participants in the allocation networks.[9] The tendency for large harvesters, on average, to have important positions in the trading networks would seem to indicate that their ability to trade quota is not limited.

Table 10. TE-based social network metrics by fishery and year

Measure	2007	2008	2009	2010	2011	2012	2013	2014
Red Snapper								
Share:								
Nodes: large	16	11	14	20	13	16	9	16
Nodes: other	102	57	72	73	56	73	58	81
Modularity	0.057	0.047	0.110	0.140	0.062	-0.037	-0.073	0.055
Avg. EC: large	0.033	0.031	0.030	0.033	0.055	0.032	0.077	0.022
Avg. EC: other	0.021	0.033	0.050	0.031	0.049	0.030	0.039	0.033
Allocation:								
Nodes: large	57	55	52	51	50	45	48	49
Nodes: other	219	185	225	300	314	337	332	357
Modularity	0.084	0.115	0.111	0.095	0.124	0.133	0.090	0.046
Avg. EC: large	0.037	0.041	0.043	0.040	0.053	0.054	0.053	0.019
Avg. EC: other	0.006	0.005	0.005	0.008	0.005	0.004	0.005	0.009
Red Grouper								
Share:								
Nodes: large	N/A	N/A	N/A	28	23	31	20	27
Nodes: other	N/A	N/A	N/A	175	124	116	82	76
Modularity	N/A	N/A	N/A	0.041	-0.021	0.007	0.075	-0.084
Avg. EC: large	N/A	N/A	N/A	0.056	0.011	0.015	0.049	0.037
Avg. EC: other	N/A	N/A	N/A	0.016	0.022	0.021	0.023	0.015
Allocation:								
Nodes: large	N/A	N/A	N/A	47	65	69	61	67
Nodes: other	N/A	N/A	N/A	298	347	338	307	330
Modularity	N/A	N/A	N/A	0.081	0.084	0.038	0.110	0.055
Avg. EC: large	N/A	N/A	N/A	0.055	0.021	0.004	0.006	0.040
Avg. EC: other	N/A	N/A	N/A	0.008	0.007	0.011	0.012	0.003
Deep-water Grouper								
Share:								
Nodes: large	N/A	N/A	N/A	14	9	9	9	13
Nodes: other	N/A	N/A	N/A	126	97	80	52	51
Modularity	N/A	N/A	N/A	0.030	0.025	0.026	0.079	-0.148

[9] Although EC values for the share markets are included in the tables they are more heavily influenced by outliers than the allocation EC values due to the smaller sizes of the share markets.

Measure	2007	2008	2009	2010	2011	2012	2013	2014
Avg. EC: large	N/A	N/A	N/A	0.075	0.041	0.063	0.044	0.056
Avg. EC: other	N/A	N/A	N/A	0.023	0.027	0.030	0.044	0.045
Allocation:								
Nodes: large	N/A	N/A	N/A	27	33	37	33	31
Nodes: other	N/A	N/A	N/A	203	229	237	195	209
Modularity	N/A	N/A	N/A	0.084	0.040	0.020	-0.015	-0.054
Avg. EC: large	N/A	N/A	N/A	0.060	0.072	0.034	0.042	0.067
Avg. EC: other	N/A	N/A	N/A	0.006	0.007	0.007	0.012	0.009

Note: N/A indicates the measures are not applicable since the ITQ program was not yet implemented.

Summary and Conclusions

The objectives of this study were to: 1) examine changes in fleet efficiency pre- and post-IFQ, 2) to determine how participants trade quota (where do they find trading partners) and how the landings market (fishers selling their fish to dealers) influences trading in the quota markets by conducting social network analysis (SNA) of IFQ trading in the Gulf of Mexico Reef Fish IFQ fisheries, and 3) analyze IFQ trading relative to vessel level technical efficiencies (TEs) using SNA metrics to evaluate how market segmentation may have impacted efficiency gains from IFQ implementation. Analysis was performed on the red snapper, red grouper, and deep-water grouper fisheries and IFQ programs. Data used in this analysis came from both NMFS logbook and IFQ program data.

Technical efficiency analysis was performed using output-oriented stochastic distance frontiers. Trip-level data from NMFS logbooks were aggregated into annual observations (2005-2014) at the vessel level. Preliminary analysis found that the fleets analyzed could be subdivided into a small group (10-20% of the fleet) of large-volume harvesters (accounting for 70-90% of landings) and the rest of the fleet. The large harvesters were found to be more efficient both before and after IFQ implementation. Changes in vessel efficiencies following IFQ implementation varied among the fleets (red snapper, red grouper, and deep-water groupers). For the red snapper and red grouper fleets, the large harvesters became more efficient following IFQ implementation while all other vessels became less efficient. TE scores for vessels in the deep-water grouper fleet fell but the findings were not statistically significantly.

Social network analysis was performed on the NMFS IFQ data. Three different trading markets (share, allocation, and landings) were analyzed using SNA. All three networks were found to be highly segmented consisting of a number of loosely connected sub-markets. The landings market was marked by high dealer fidelity among fishers as most fishers used only one dealer in a given year. It is possible that this finding (landings market segmentation) reflects fishing community structure where single dealers connected to numerous fishers (most of whom were connect to no other dealers) served as the backbone of fishing communities where fishers exchange quota. This idea was tested by measuring network overlap between the quota and shared dealer networks using a Jaccard index and quadratic assignment procedures. The results indicated the IFQ participants are much more likely to trade quota with fishers they share a dealer with.

Lastly, the quota trading networks were analyzed relative to the distinct fleet segments (large harvesters and all other fishers) determined in the first section of the paper. The objective of this analysis was to determine if quota trading markets were functioning in a manner that limited opportunities for the two groups to trade. The results showed that large harvesters commonly trade with both other large harvesters and other IFQ participants – the market was not segmented. In addition, we found that, on average, large harvesters held important positions within quota trading markets relative to other participants.

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