# Final Report

# Network Analysis of Quota Trading in the Gulf of Mexico IFQ Fisheries

By

***Andrew Ropicki***
Assistant Professor, Food and Resource Economics
University of Florida
aropicki@ufl.edu

***Jordan Moor***
PhD Student, Food and Resource Economics
University of Florida
jordanmoor@ufl.edu

***Frank Asche***
Professor, Fisheries and Aquatic Sciences
University of Florida
frank.asche@ufl.edu

October 21, 2021

*The authors would like to thank the*
*Gulf of Mexico Fishery Management Council for their support*

**Executive Summary**

- This project evaluated allocation, share, and landings trading in the Gulf of Mexico IFQ programs from 2007 through 2019. Analysis was subdivided by year and species groups (shallow water grouper, red snapper, deep water grouper and tilefish, and All IFQ Species). Five networks (allocation, share, landings, shared dealer, and fishing community) were analyzed for most year and species group combinations – several hundred networks were created and analyzed.
- Data used included transaction data (share, allocation, and landings) and account ownership data.
- Analysis focused on arms-length transactions between independent shareholder accounts (defined as accounts that did not share all owners) which were determined by analysis of IFQ shareholder account ownership data.
- Dealer affiliated shareholder accounts (shareholder accounts that also were tied to dealers allowed to purchase IFQ landings dockside) were identified through internet searches of dealer entities to determine ownership overlap with shareholder accounts.
- Quota trading is predominately achieved through allocation trading and the percentage of shareholder accounts trading allocation has risen since IFQ implementation. By 2019, at least 93% of all active accounts (those trading share, allocation, or landing fish) traded allocation across species groups.
- Most shareholders landing fish sell their catch to only one dealer in a given year indicating a high level of dealer fidelity among fishers. This is despite a 53% and 60% increase in the number of active shareholder and dealer accounts since program implementation, respectively.
- While dealer affiliated shareholder accounts make up only 9% to 16% of all active shareholder accounts by year and species group they account for, on average, 36% and 33% of allocation purchased and sold, respectively, and 28% of share purchased and 18% of share sold.
- Allocation trading is accomplished primarily within dealer-centric fishing communities (71% of all allocation pounds traded).
- Between fishing community allocation trading (29% of all allocation pounds traded) was modeled using annual fishing community networks. These networks were extremely dense and showed that almost all (~96%) of fishing communities are connected in some way and between community trading is dominated by a core group of highly connected fishing communities.
- Allocation trading relationships are highly correlated with: 1) shared dealer network relationships, 2) previous years trading relationships, 3) proximity (same county), and 4) a shareholders dealer affiliated status.

- Allocation prices for red snapper, red grouper, and gag grouper are cointegrated (move similarly through time), but only red snapper allocation prices are perfectly cointegrated across regions.

# Network Analysis of Quota Trading in the Gulf of Mexico IFQ Fisheries

## Overview

A primary goal of the Gulf of Mexico (GOM) reef fish individual fishing quota (IFQ) programs was to reduce overcapacity in the fisheries. With catch shares management more efficient harvesters are expected to place a higher value on quota and buy out their less efficient counterparts leading to decreased capacity (Squires et al. 1998). However, for this to occur quota trading markets must function effectively; buyers and sellers must be able to find each other with relative ease, participants must have similar access to market trading data and opportunities, and no participants should be able to exert undue influence on quota or dockside markets. Understanding the mechanics of interactions among IFQ participants (fishers and dealers) in both quota (share and allocation) and landings (fishers selling to registered dealers) markets can provide valuable information on how these markets function and how market functionality is impacting management goals and other socioeconomic outcomes important to fishery managers. Network analysis provides a technique to evaluate the quota and landings markets both spatially and temporally to examine a number of socioeconomic issues important to fishery managers.

Network analysis provides a suitable framework for analyzing quota and landings trading markets and examining how trading occurs in these markets, how the markets evolve over time, and the role of dealers in allocation trading markets. 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). 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).

Network analysis has become a commonly used tool to examine natural resource management issues. Previous research has evaluated the importance of network structure on communication and collaboration in a resource management setting (Bodin et al 2006; Olsson et al 2004; Olsson et al. 2007) and highlighted the ability of network metrics to explain collaboration levels in management (Bodin and Crona 2009; Sandström 2008). In the fisheries space network analysis has been used to examine the role of fisher information sharing in co-managed fisheries (Barnes et al 2019) and incidental catch avoidance (Barnes et al. 2016), the potential for cross fishery spillover effects (Addicot et al. 2018), seafood trade flows (Gephart and Pace 2015), and characterizing the connectivity of fisheries (Fuller et al. 2017). Network analysis research analyzing quota trading has included research describing the network structure (van Putten et al. 2011), evaluating how network structure and fisher network position impact quota trading prices (Ropicki and Larkin 2014; Innes et al. 2014), and the development of quota trading networks (Vasta 2019).

While past network analysis applied to fisheries management research has analyzed how fisher characteristics impacts quota prices (Ropicki and Larkin 2014) and the impacts of management changes on fishery participation (van Putten et al. 2011; Addicott et al. 2018), this research is unique in that it evaluated the mechanics of trading and both network and group interactions and node (individual) level analysis. With respect to evaluating the impacts of IFQ implementation in Gulf of Mexico reef fish commercial fisheries, the objectives of this study were: 1) develop and analyze quota trading and landings networks for each year and species group of the Gulf of Mexico IFQ fisheries, 2) to determine how the Gulf of Mexico IFQ fisheries quota and landings markets are connected using network analysis techniques, 3) evaluate how the Gulf of Mexico IFQ markets have changed since implementation, 4) examine the role of dealers in the Gulf of Mexico IFQ markets, and 5) evaluate market cointegration of allocation subnetworks to determine if these subnetworks represent individual allocation markets or are part of an integrated allocation network.

The report is divided into three sections. The first section provides a background on the data utilized in this analysis and how it was employed to develop networks. The section includes information on data cleaning and analysis steps as well as network development and design choices. The second section includes results of the analysis subdivided by topic area and includes discussion of the networks developed and their attributes, analysis of network overlap, and temporal changes in networks. The final section provides a summary of research findings.

## Networks Analyzed and Data Used

In this report we analyze five main types of networks (share, allocation, landings, shared dealer, and fishing community) that involve either IFQ fishers, or IFQ fishers and dealers in the case of landings networks. Share and allocation networks describe share and allocation trading relationships (edges) between IFQ shareholder accounts (nodes), the landings networks describe landed IFQ fish sold dockside to registered dealers. Shared dealer networks are created from landings networks but include only IFQ shareholder accounts and an edge occurs when two IFQ fishers sold IFQ landings to the same registered dealer. Fishing community networks grouped fishers into dealer-centric communities to examine how much allocation is traded within these communities and how allocation is traded between these communities. Networks were created and analyzed on an annual basis to see how they change through time. Additionally, allocation and share poundage (share is generally priced by current year poundage when trading) are determined on a yearly basis and each individual year represents a new good being traded.

Trading data (share, allocation, and dockside landings) and account ownership information was provided by the National Marine Fisheries Service Southeast Regional Office through a non-disclosure agreement. Data was gathered for all program years through 2019. 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 pounds of fish transacted (rather than quota) and the buyer is a registered dealer purchasing the fish dockside. Additional data gathered included account ownership information for each IFQ shareholder account by year including percentage ownership by entity.

Prior to performing network analyses, the data had to be reconstructed in a several ways. The first change was that unique fishing firms or entities had to be identified. Numerous owners hold multiple IFQ shareholder accounts and movement of share and allocation between these accounts are simply shuffling of quota and do not represent arms-length transactions between independent entities. For these network analyses the goal was to evaluate how IFQ participants interact in the fishery which required a focus on arms-length transactions and accounts that were co-owned had to be combined. The National Marine Fisheries Service provided information on account ownership by year with each ownership entity or person having a unique ID number. Using this data an algorithm was created in Microsoft Excel to measure the percentage ownership overlap between all accounts. For the purposes of these analyses IFQ accounts were combined if they had the same owners and all share and allocation transactions between these accounts were not included in the analyses[1]. This delineation created a stringent definition of shared ownership (all owners in common between two accounts), future research might be possible using lesser requirements such as requiring 50% ownership overlap for instance. Additionally, the algorithm created could be used by NMFS and the GMFMC in general IFQ data analysis, percentage account overlap could be included in all trading data providing a check on "trade reason" data that is gathered from trading parties. All information provided in the remainder of the report employs the shared ownership account structure.

Another way the data was augmented prior to analysis was determining which IFQ shareholder accounts were affiliated with dealer accounts. A dealer account only allows the account holder to purchase fish dockside and does not allow for any form of quota trading, to trade quota the dealer must also have a shareholder account. Since one of the goals of this project was to determine the role of dealers in the share and allocation markets it was important to determine which shareholder accounts were affiliated with dealer accounts. Unfortunately, ownership data on dealer accounts was not available so the algorithm used to determine shareholder account overlap could not be used. Dealer account overlap was determined by evaluating shared addresses and or entity/personal names of shareholder and dealer account holders. Additionally, internet searches of all dealer accounts were performed using business search databases attempting to determine entity ownership which was then compared to the shareholder account ownership information. This process, while less methodical than the shareholder overlap determination algorithm, identified numerous dealer-connected shareholders and is believed, by the researchers, to have been accurate.

[1] This is to say if two accounts were owned by entities A, B, C, and D they were combined. We did not require the percent owned by A, B, C, and D to match exactly – only that they were the same entities.

Annual networks were created based on four different quota species groupings: 1) all IFQ species, 2) shallow water grouper (SWG - red, gag, and other shallow water grouper species), 3) red snapper (RS), and 4) deep water grouper and tilefish (DWGTF). These network delineations were determined by preliminary analysis of how account activity in the different species groups overlapped. Annually between 2010 and 2019, on average, 71% of all accounts that were actively involved (landed fish or traded share or allocation) with at least one SWG species group (red, gag, or other shallow water grouper) were actively involved in all three indicating a high degree of overlap. Over the same time period, 91% of IFQ accounts that were active in one of the three SWG species groups were active in at least two of the groups. The DWGTF combination was used because almost all accounts active in the tilefish IFQ program were also active in the deep water grouper IFQ program. Between 2010 and 2019, on average, 97% of IFQ accounts active in the tilefish program (either through landings or share/allocation trading) were also active in the deep water grouper program[2]. Table 1 includes a breakdown of account overlap by year and species group for both SWG and DWGTF.

**Table 1. IFQ shareholder account species activity overlap by year (SWG and DWGTF).**

| **SWG** | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| **RG, GG, & OSWG** | 73% | 72% | 75% | 71% | 72% | 72% | 70% | 69% | 66% | 66% |
| **RG/GG ONLY** | 12% | 11% | 11% | 9% | 9% | 9% | 8% | 7% | 9% | 9% |
| **RG/OSWG ONLY** | 2% | 3% | 2% | 6% | 4% | 3% | 3% | 3% | 4% | 3% |
| **GG/OSWG ONLY** | 6% | 4% | 5% | 6% | 6% | 6% | 8% | 5% | 6% | 9% |
| **RG ONLY** | 3% | 5% | 3% | 4% | 5% | 5% | 5% | 8% | 8% | 8% |
| **GG ONLY** | 2% | 2% | 1% | 1% | 1% | 1% | 2% | 3% | 2% | 3% |
| **OSWG ONLY** | 2% | 2% | 3% | 3% | 3% | 3% | 3% | 4% | 4% | 3% |
| | | | | | | | | | | |
| **DWGTF** | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| **DWG & TF** | 52% | 60% | 55% | 54% | 61% | 57% | 54% | 53% | 54% | 56% |
| **DWG ONLY** | 46% | 40% | 43% | 44% | 38% | 42% | 43% | 45% | 43% | 42% |
| **TF ONLY** | 2% | 0% | 1% | 2% | 1% | 2% | 3% | 2% | 3% | 2% |

With four network types (allocation, share, landings, and shared dealer) and four network delineations (All IFQ Species, SWG, RS, and DWGTF) created for each year of IFQ management through 2019, 172 networks were created[3]. Shareholder and dealer accounts were included in networks if they were considered active in the year being analyzed. For a shareholder account to be considered active it had to either land fish, trade quota (share or allocation), or be involved in some combination of the three activities. For a dealer account to be considered active they had to buy fish dockside. Activity was specific for the species group being analyzed, RS activity did not lead to inclusion in the SWG networks and vice versa; however, activity with any IFQ species led to inclusion in the all IFQ species network. This network inclusion strategy led to many

[2] It is important to note that the tilefish fishery is a subset of the deep water grouper based on participation. While tilefish program participants are overwhelmingly involved in the deep water grouper program, the opposite can't be said. Only 57% of deep water grouper program participants were also involved in the tilefish program.

[3] For the period from 2007 to 2009 red snapper was the only IFQ species meaning the All IFQ Species and RS networks are identical for those years.

shareholder account isolates in each network. Isolates are network entities that are not connected to other nodes in the network (shareholders in the landings and shared dealer networks that did not land fish and shareholders in the allocation and share networks that did not trade quota); however, this approach did lead to equally sized networks in terms of the number of participants which allowed for adding and combining networks with different types of ties. Network analysis was performed on all of these networks, but due to the large number of networks only several of the visualizations are included in the report.

### *Shareholder Account Types by Year*

The analysis of active accounts allowed for the easy classification of accounts by activity type. Shareholder accounts were divided into seven different categories ( 1) landings only, 2) allocation only, 3) share only, 4) landings and allocation, 5) landings and share, 6) allocation and share, and 7) landings, allocation, and share). This information is included in Table 2 by year (2010-2019) for each of the species groups. Interestingly, more accounts are involved in allocation trading then landing fish in all years for All IFQ Species groups. On average across All IFQ Species groups, 92% of active accounts trade allocation versus only 61% that land fish[4]. Share trading is rarer as only 30% of accounts trade share in an average year across All IFQ Species groups.

[4] The DWGTF category was an outlier as only 46% of active participants landed fish in an average year.

Table 2. Active shareholder account types by year and species group (2010-2019).

| **All IFQ Species** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Landings Only | 7% | 4% | 3% | 3% | 1% | 2% | 2% | 3% | 2% | 2% |
| Allocation Only | 13% | 20% | 19% | 21% | 20% | 20% | 21% | 21% | 21% | 26% |
| Share Only | 1% | 1% | 1% | 1% | 1% | 2% | 1% | 1% | 2% | 0% |
| Landings and Allocation | 31% | 39% | 39% | 43% | 45% | 44% | 45% | 48% | 50% | 49% |
| Landings and Share | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Allocation and Share | 21% | 15% | 15% | 12% | 13% | 13% | 15% | 13% | 12% | 10% |
| Landings, Allocation, and Share | 27% | 21% | 22% | 20% | 20% | 18% | 16% | 15% | 13% | 13% |
| Number of Accounts | 615 | 619 | 622 | 579 | 606 | 632 | 644 | 647 | 645 | 616 |
| **SWG** | | | | | | | | | | |
| Type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Landings Only | 16% | 7% | 5% | 7% | 5% | 6% | 7% | 9% | 8% | 6% |
| Allocation Only | 11% | 19% | 18% | 20% | 21% | 20% | 21% | 22% | 22% | 24% |
| Share Only | 1% | 1% | 1% | 1% | 0% | 2% | 2% | 1% | 2% | 1% |
| Landings and Allocation | 26% | 39% | 42% | 45% | 47% | 44% | 46% | 47% | 50% | 51% |
| Landings and Share | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Allocation and Share | 21% | 15% | 13% | 10% | 10% | 12% | 10% | 9% | 9% | 8% |
| Landings, Allocation, and Share | 25% | 18% | 20% | 17% | 17% | 17% | 14% | 11% | 9% | 9% |
| Number of Accounts | 531 | 552 | 547 | 506 | 527 | 550 | 544 | 546 | 545 | 519 |
| **RS** | | | | | | | | | | |
| Type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Landings Only | 9% | 7% | 5% | 4% | 4% | 3% | 3% | 3% | 2% | 2% |
| Allocation Only | 17% | 22% | 21% | 22% | 19% | 21% | 20% | 19% | 18% | 24% |
| Share Only | 1% | 0% | 2% | 0% | 1% | 1% | 0% | 1% | 1% | 1% |
| Landings and Allocation | 50% | 53% | 53% | 56% | 56% | 58% | 58% | 58% | 60% | 57% |
| Landings and Share | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Allocation and Share | 9% | 8% | 10% | 7% | 8% | 8% | 9% | 9% | 9% | 7% |
| Landings, Allocation, and Share | 12% | 10% | 10% | 10% | 11% | 9% | 9% | 10% | 10% | 9% |
| Number of Accounts | 435 | 441 | 463 | 447 | 475 | 496 | 508 | 517 | 523 | 521 |
| **DWGTF** | | | | | | | | | | |
| Type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Landings Only | 13% | 9% | 6% | 10% | 7% | 6% | 9% | 9% | 7% | 3% |
| Allocation Only | 17% | 29% | 31% | 35% | 36% | 38% | 41% | 43% | 42% | 52% |
| Share Only | 2% | 2% | 2% | 2% | 0% | 5% | 2% | 3% | 1% | 2% |
| Landings and Allocation | 19% | 26% | 32% | 30% | 30% | 29% | 28% | 34% | 32% | 31% |
| Landings and Share | 1% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| Allocation and Share | 34% | 24% | 19% | 12% | 15% | 14% | 14% | 9% | 12% | 7% |
| Landings, Allocation, and Share | 15% | 11% | 9% | 10% | 12% | 8% | 6% | 4% | 5% | 4% |
| Number of Accounts | 312 | 338 | 346 | 305 | 298 | 313 | 306 | 280 | 294 | 296 |

## IFQ Markets Network Analysis

### *Share and Allocation Networks*

Separate networks were created for each type of quota (share and allocation) traded. Four separate groups of networks were analyzed (All IFQ Species, SWG, RS, and DWGTF). Networks were created based on annual trading to account for the seasonal nature of quota, share poundage is determined by the total quota each year and trades are determined by pounds of quota. Similarly, allocation expires at the end of each year and is reset in accordance with share poundage for the next year. The quota and allocation networks are unimodal, consisting of only one type of node (IFQ account holders). An edge in the network represented a sale of share or allocation from one IFQ account holder (seller) to another (buyer). A graph of the 2017 All IFQ Species share network is provided in Figure 1. Isolates (shareholder accounts that traded allocation and/or landed fish but did not trade share and edge direction (arrow on edges pointing from the seller to the buyer) have been removed for clarity. Additionally, dealer affiliated nodes have been colored blue. The graph depicts a series of minor components with a smaller major component (large group of connected shareholders). This network structure is due to the limited amount of share trading performed.

Figure 1. 2017 All IFQ Species share trading network.

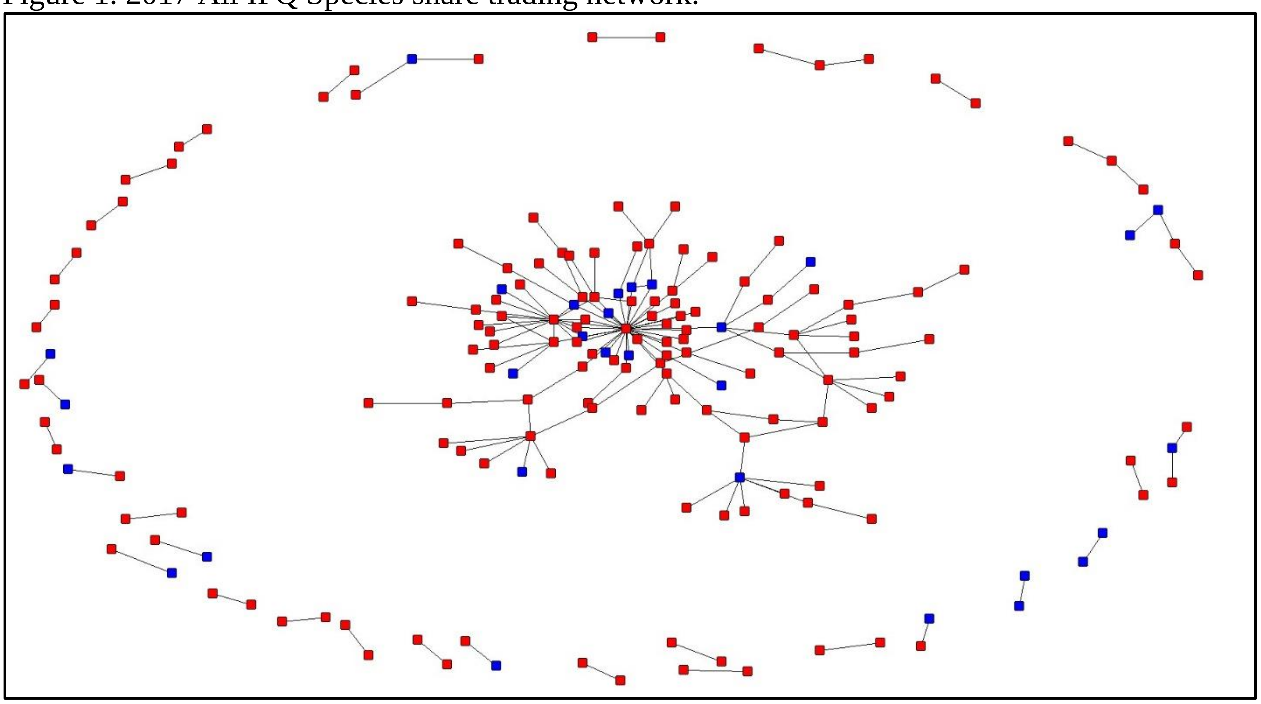
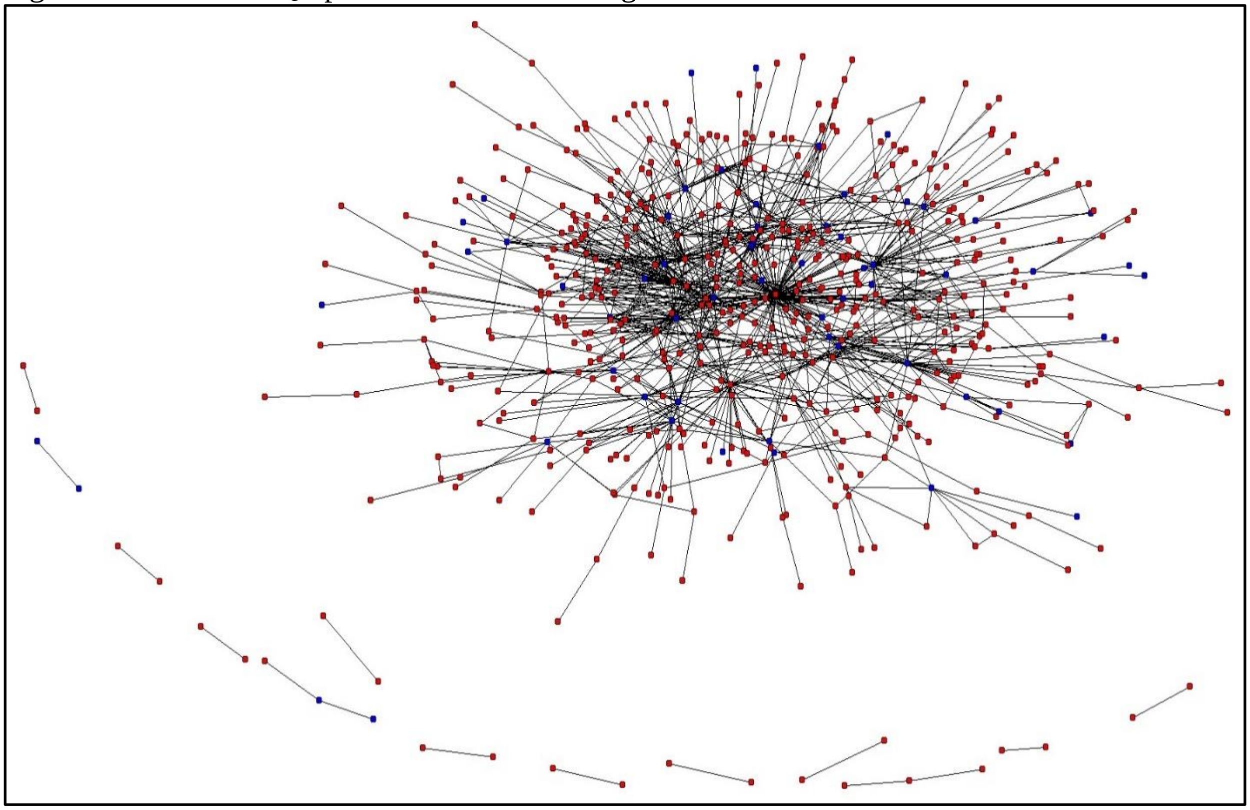


Figure 2 is a graph of the 2010 RS allocation network. Similar to the share network, isolates (shareholder accounts that landed RS or traded RS share but did not trade RS allocation) and tie/edge directions have been removed for clarity, and dealer affiliated nodes are colored blue. Because allocation trading is more frequent the graph is dominated by a larger major component (large group of connected nodes) surrounded by a series of minor components.

Figure 2. 2010 All IFQ Species allocation trading network.



***Landings and Shared Dealer Networks***

The landings network is a bimodal network consisting of two types of nodes (shareholder and dealer accounts) that can only connect to the other node type. Edges in this network represent fishers selling their IFQ landings to registered dealers. Figure 3 is a graph of the 2014 All IFQ Species landings network. Blue squares are registered dealers and the red circles are shareholder accounts that sold landings, isolates (shareholder accounts that traded quota but did not land IFQ species) and edge directions have been removed for ease of viewing.

Figure 3. 2014 All IFQ Species landings network.

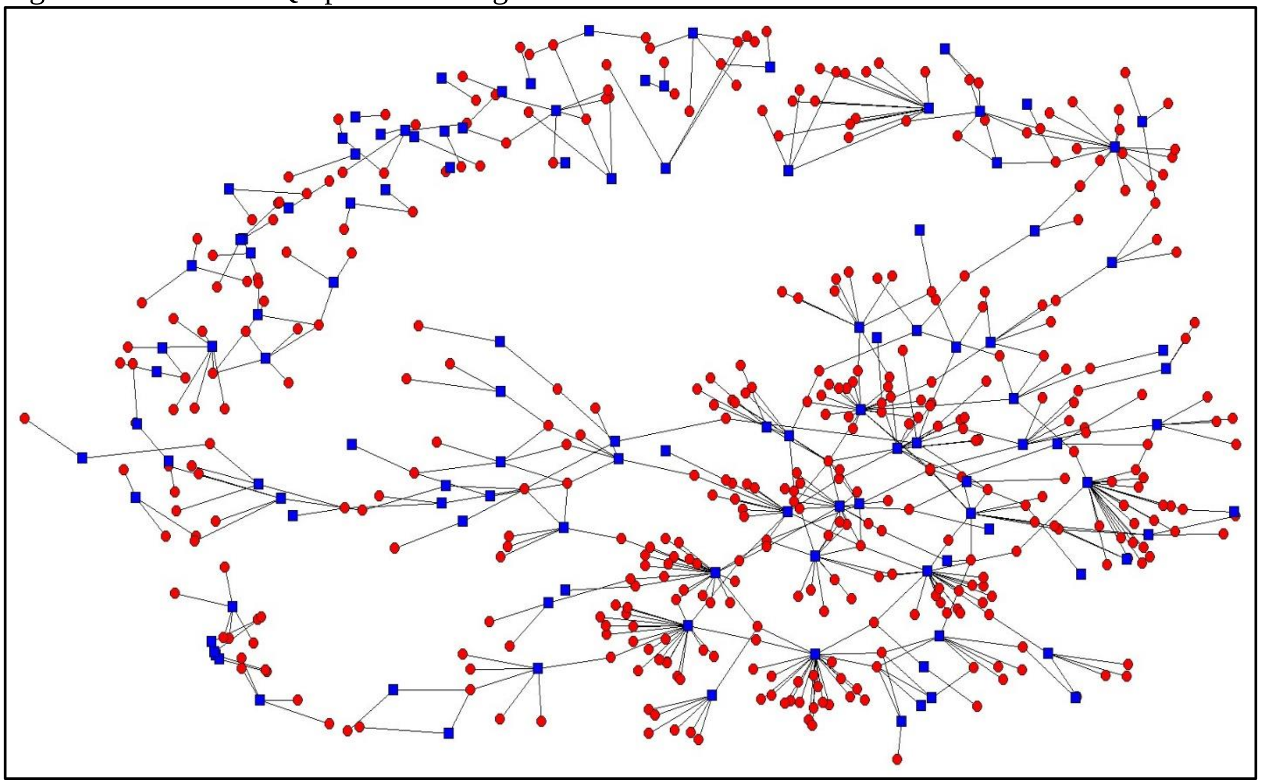
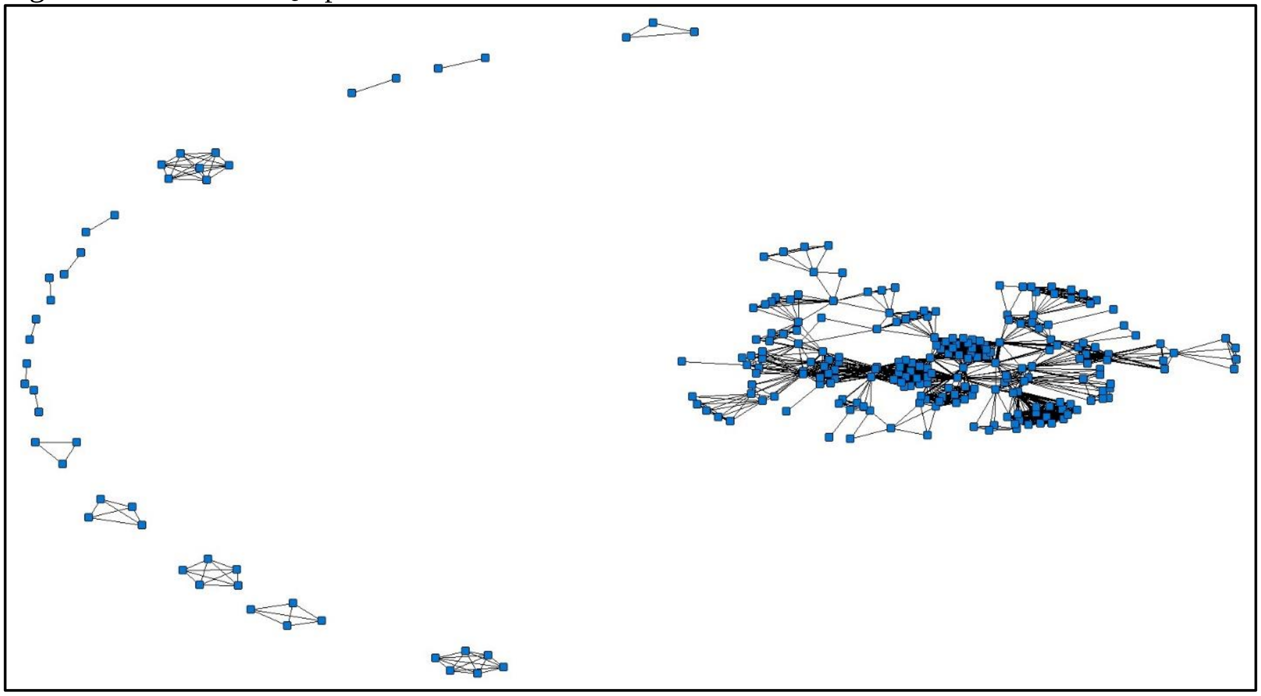


Figure 4 is the 2007 All IFQ Species/RS shared dealer network[5]. These networks are created by multiplying the landings network matrices by their transpose which creates a network solely comprised of shareholder accounts where ties between nodes indicate both nodes sold fish to the same dealer[6]. The visualization shows a landings network dominated by a few very active dealers that purchase fish from numerous fishers with a few smaller dealers that purchase from only a few fishers. The main component, to the right of the visualization, is extremely dense because all fishers selling to the same dealer are connected and these fishing communities are tied to other communities often by only one or two fishers or even landing transactions.

[5] Since RS was the only IFQ program in 2007 the RS network is the All IFQ Species network.

[6] Shared dealer networks are created using landings network matrices that only indicate the presence of a landings trading relationship, not the amount of pounds or number of transactions. These binary landings matrices lead to binary shared dealer matrices.

Figure 4. 2007 All IFQ Species/RS shared dealer network.



***Network Measures***

Several network measures are presented for the allocation, share, and landings networks in Tables 3, 4, and 5, respectively. For the allocation and share networks (Tables 3 and 4) the number of nodes (shareholders), edges (trading relationships), density with all nodes, allocation traders (shareholder accounts that traded allocation), isolates (accounts that landed fish and/or traded share but did not trade allocation), and network density with isolates removed. Network density is the number of edges (transaction relationships) 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[7]:

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

Density is calculated with both isolates included and isolates removed. Calculating density with isolates removed gives an idea of network density assuming everyone who wanted to transact in the network did so.

[7] This formula is for a directed network. Directed networks focus on the direction of the relationship, in this case who is the buyer and who is the seller. In a directed network each pair of nodes has two possible edges. An undirected network would only care about whether there was a trading relationship between two nodes and is given by the equation $D = 2m/(n(n-1))$.

Table 3. Allocation network measures (All IFQ Species groups and years).

| All IFQ Species | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Allocation Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 346 | 0.002 | 290 | 114 | 0.004 |
| 2008 | 360 | 282 | 0.002 | 255 | 105 | 0.004 |
| 2009 | 372 | 361 | 0.003 | 289 | 83 | 0.004 |
| 2010 | 615 | 1212 | 0.003 | 563 | 52 | 0.004 |
| 2011 | 619 | 1490 | 0.004 | 587 | 32 | 0.004 |
| 2012 | 622 | 1731 | 0.004 | 592 | 30 | 0.005 |
| 2013 | 579 | 1571 | 0.005 | 554 | 25 | 0.005 |
| 2014 | 606 | 1738 | 0.005 | 592 | 14 | 0.005 |
| 2015 | 632 | 1660 | 0.004 | 605 | 27 | 0.005 |
| 2016 | 644 | 1673 | 0.004 | 623 | 21 | 0.004 |
| 2017 | 647 | 1457 | 0.003 | 622 | 25 | 0.004 |
| 2018 | 645 | 1379 | 0.003 | 616 | 29 | 0.004 |
| 2019 | 616 | 1596 | 0.004 | 600 | 16 | 0.004 |
| **SWG** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Allocation Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2010 | 531 | 696 | 0.002 | 438 | 93 | 0.004 |
| 2011 | 552 | 1000 | 0.003 | 507 | 45 | 0.004 |
| 2012 | 547 | 1224 | 0.004 | 513 | 34 | 0.005 |
| 2013 | 506 | 1027 | 0.004 | 464 | 42 | 0.005 |
| 2014 | 527 | 1187 | 0.004 | 498 | 29 | 0.005 |
| 2015 | 550 | 1027 | 0.003 | 506 | 44 | 0.004 |
| 2016 | 544 | 1064 | 0.004 | 495 | 49 | 0.004 |
| 2017 | 546 | 791 | 0.003 | 482 | 64 | 0.003 |
| 2018 | 545 | 724 | 0.002 | 486 | 59 | 0.003 |
| 2019 | 519 | 865 | 0.003 | 481 | 38 | 0.004 |
| **RS** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Allocation Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 346 | 0.002 | 290 | 114 | 0.004 |
| 2008 | 360 | 282 | 0.002 | 255 | 105 | 0.004 |
| 2009 | 372 | 361 | 0.003 | 289 | 83 | 0.004 |
| 2010 | 435 | 627 | 0.003 | 384 | 51 | 0.004 |
| 2011 | 441 | 1246 | 0.006 | 411 | 30 | 0.007 |
| 2012 | 463 | 774 | 0.004 | 431 | 32 | 0.004 |
| 2013 | 447 | 847 | 0.004 | 427 | 20 | 0.005 |
| 2014 | 475 | 875 | 0.004 | 451 | 24 | 0.004 |
| 2015 | 496 | 991 | 0.004 | 475 | 21 | 0.004 |
| 2016 | 508 | 975 | 0.004 | 492 | 16 | 0.004 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2017 | 517 | 977 | 0.004 | 497 | 20 | 0.004 |
| 2018 | 523 | 948 | 0.003 | 509 | 14 | 0.004 |
| 2019 | 521 | 1088 | 0.004 | 509 | 12 | 0.004 |
| **DWGTF** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Allocation Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2010 | 312 | 310 | 0.003 | 262 | 50 | 0.005 |
| 2011 | 338 | 382 | 0.003 | 298 | 40 | 0.004 |
| 2012 | 346 | 454 | 0.004 | 317 | 29 | 0.005 |
| 2013 | 305 | 343 | 0.004 | 265 | 40 | 0.005 |
| 2014 | 298 | 450 | 0.005 | 273 | 25 | 0.006 |
| 2015 | 313 | 388 | 0.004 | 272 | 41 | 0.005 |
| 2016 | 306 | 374 | 0.004 | 269 | 37 | 0.005 |
| 2017 | 280 | 331 | 0.004 | 242 | 38 | 0.006 |
| 2018 | 294 | 364 | 0.004 | 263 | 31 | 0.005 |
| 2019 | 296 | 430 | 0.005 | 278 | 18 | 0.006 |

Table 4. Share network measures (All IFQ Species groups and years).

| **All IFQ Species** | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Share Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 82 | 0.0005 | 121 | 283 | 0.006 |
| 2008 | 360 | 40 | 0.0003 | 68 | 292 | 0.009 |
| 2009 | 372 | 65 | 0.0005 | 89 | 283 | 0.008 |
| 2010 | 615 | 367 | 0.0010 | 298 | 317 | 0.004 |
| 2011 | 619 | 234 | 0.0006 | 225 | 394 | 0.005 |
| 2012 | 622 | 258 | 0.0007 | 235 | 387 | 0.005 |
| 2013 | 579 | 210 | 0.0006 | 190 | 389 | 0.006 |
| 2014 | 606 | 231 | 0.0006 | 203 | 403 | 0.006 |
| 2015 | 632 | 278 | 0.0007 | 208 | 424 | 0.006 |
| 2016 | 644 | 205 | 0.0005 | 201 | 443 | 0.005 |
| 2017 | 647 | 172 | 0.0004 | 180 | 467 | 0.005 |
| 2018 | 645 | 159 | 0.0004 | 173 | 472 | 0.005 |
| 2019 | 616 | 143 | 0.0004 | 138 | 478 | 0.008 |
| **SWG** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Share Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2010 | 531 | 287 | 0.0010 | 249 | 282 | 0.005 |
| 2011 | 552 | 172 | 0.0006 | 188 | 364 | 0.005 |
| 2012 | 547 | 187 | 0.0006 | 186 | 361 | 0.005 |
| 2013 | 506 | 152 | 0.0006 | 140 | 366 | 0.008 |
| 2014 | 527 | 153 | 0.0006 | 140 | 387 | 0.008 |
| 2015 | 550 | 201 | 0.0007 | 164 | 386 | 0.008 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2016 | 544 | 128 | 0.0004 | 138 | 406 | 0.007 |
| 2017 | 546 | 104 | 0.0003 | 114 | 432 | 0.008 |
| 2018 | 545 | 83 | 0.0003 | 106 | 439 | 0.007 |
| 2019 | 519 | 81 | 0.0003 | 91 | 428 | 0.010 |
| **RS** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Share Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 82 | 0.0005 | 121 | 283 | 0.006 |
| 2008 | 360 | 40 | 0.0003 | 68 | 292 | 0.009 |
| 2009 | 372 | 65 | 0.0005 | 89 | 283 | 0.008 |
| 2010 | 435 | 65 | 0.0003 | 96 | 339 | 0.007 |
| 2011 | 441 | 61 | 0.0003 | 80 | 361 | 0.010 |
| 2012 | 463 | 65 | 0.0003 | 98 | 365 | 0.007 |
| 2013 | 447 | 52 | 0.0003 | 76 | 371 | 0.009 |
| 2014 | 475 | 79 | 0.0004 | 99 | 376 | 0.008 |
| 2015 | 496 | 84 | 0.0003 | 89 | 407 | 0.011 |
| 2016 | 508 | 69 | 0.0003 | 90 | 418 | 0.009 |
| 2017 | 517 | 83 | 0.0003 | 103 | 414 | 0.008 |
| 2018 | 523 | 84 | 0.0003 | 101 | 422 | 0.008 |
| 2019 | 521 | 71 | 0.0003 | 84 | 437 | 0.010 |
| **DWGTF** | | | | | | |
| **Year** | **Nodes** | **Edges** | **Density (All Nodes)** | **Share Traders** | **Isolates** | **Density (Isolates Removed)** |
| 2010 | 312 | 138 | 0.0014 | 159 | 153 | 0.005 |
| 2011 | 338 | 89 | 0.0008 | 120 | 218 | 0.006 |
| 2012 | 346 | 73 | 0.0006 | 102 | 244 | 0.007 |
| 2013 | 305 | 49 | 0.0005 | 75 | 230 | 0.009 |
| 2014 | 298 | 63 | 0.0007 | 79 | 219 | 0.010 |
| 2015 | 313 | 73 | 0.0007 | 81 | 232 | 0.011 |
| 2016 | 306 | 53 | 0.0006 | 63 | 243 | 0.014 |
| 2017 | 280 | 25 | 0.0003 | 38 | 242 | 0.018 |
| 2018 | 294 | 31 | 0.0004 | 50 | 244 | 0.013 |
| 2019 | 296 | 27 | 0.0003 | 39 | 257 | 0.018 |

In the share trading network (Table 4) an initial burst of share trading at IFQ implementation is followed by a general decline in trading. The allocation networks (Table 3) tell a different story, over time the two densities calculated converge indicating that increasing numbers of shareholders are entering the allocation trading market. This trend is also noticeable in the number of isolates in the allocation networks that continues to decrease through time. While the trend is less pronounced in the SWG allocation networks we believe this is caused by a quick adoption of allocation trading in that fishery (displayed by the large drop in isolates during early years of the program) and the impact of red tide on SWG species, namely red grouper, in later analysis years.

Limited share trading and increasing use of allocation markets by a larger percentage of shareholders provides insights into how IFQ markets have developed. Shareholders have relied on allocation trading, synonymous with leasing of fishing privileges, to change their fishing behavior (either increasing or decreasing landings) as opposed to buying and selling share. The tendency to rely on allocation trading could indicate that shareholders actively expanding their landings prefer the lower risk associated with purchasing allocation as opposed to share. Share purchases involve risk associated with potential stock declines (as seen recently with red grouper stocks), longer term consumer demand shifts, and any potential changes in fisheries management away from IFQ management. Additionally, the overwhelming use of allocation to trade quota could indicate lack of access to capital for fisher shareholders and/or a disconnect in how current share owners and fishers wishing to purchase share value the asset. Further analysis is needed to examine all of these possible explanations.

Transactions in the landings market involve fishers (IFQ participants) selling IFQ species to registered IFQ dealers. The landings network is a bi-modal network with two distinct types of nodes (fisher nodes and dealer nodes) with edges (landings transaction relationships) only occurring between different node types. Table 5 provides network metrics for the landings networks. Network measures provided include number of shareholder nodes, number of active dealer nodes (dealers that purchased fish dockside), edges (trading relationships between fisher shareholders and dealers), average number of dealers per fisher (number of edges divided by number of active fisher shareholders), network density with all nodes included, fisher shareholders, isolates (shareholders that traded share or allocation but did not land fish), and network density with isolates removed. The formula for network density of a bimodal network is presented in the equation below 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).[8]

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

Table 5. Landings network measures (All IFQ Species groups and years).

| **All IFQ Species** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Shareholder Nodes** | **Dealer Nodes** | **Edges** | **Avg. Dealers Per Fisher** | **Density** | **Fisher Shareholders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 75 | 345 | 1.264 | 0.011 | 273 | 131 | 0.017 |
| 2008 | 360 | 66 | 307 | 1.172 | 0.013 | 262 | 98 | 0.018 |
| 2009 | 372 | 65 | 309 | 1.207 | 0.013 | 256 | 116 | 0.019 |
| 2010 | 615 | 88 | 520 | 1.307 | 0.010 | 398 | 217 | 0.015 |
| 2011 | 619 | 96 | 507 | 1.287 | 0.009 | 394 | 225 | 0.013 |
| 2012 | 622 | 95 | 536 | 1.330 | 0.009 | 403 | 219 | 0.014 |

[8] This formula is for an unidirectional (or undirected) network. Since landings transactions only involve fishers selling fish to dealers a directed network was not calculated.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2013 | 579 | 95 | 503 | 1.310 | 0.009 | 384 | 195 | 0.014 |
| 2014 | 606 | 117 | 529 | 1.319 | 0.007 | 401 | 205 | 0.011 |
| 2015 | 632 | 119 | 528 | 1.294 | 0.007 | 408 | 224 | 0.011 |
| 2016 | 644 | 110 | 512 | 1.255 | 0.007 | 408 | 236 | 0.011 |
| 2017 | 647 | 118 | 555 | 1.303 | 0.007 | 426 | 221 | 0.011 |
| 2018 | 645 | 120 | 543 | 1.284 | 0.007 | 423 | 222 | 0.011 |
| 2019 | 616 | 120 | 524 | 1.333 | 0.007 | 393 | 223 | 0.011 |
| **SWG** | | | | | | | | |
| **Year** | **Shareholder Nodes** | **Dealer Nodes** | **Edges** | **Avg. Dealers Per Fisher** | **Density** | **Fisher Shareholders** | **Isolates** | **Density (Isolates Removed)** |
| 2010 | 531 | 82 | 469 | 1.303 | 0.011 | 360 | 171 | 0.016 |
| 2011 | 552 | 86 | 447 | 1.259 | 0.009 | 355 | 197 | 0.015 |
| 2012 | 547 | 91 | 493 | 1.332 | 0.010 | 370 | 177 | 0.015 |
| 2013 | 506 | 92 | 449 | 1.287 | 0.010 | 349 | 157 | 0.014 |
| 2014 | 527 | 108 | 475 | 1.312 | 0.008 | 362 | 165 | 0.012 |
| 2015 | 550 | 110 | 462 | 1.262 | 0.008 | 366 | 184 | 0.011 |
| 2016 | 544 | 104 | 449 | 1.230 | 0.008 | 365 | 179 | 0.012 |
| 2017 | 546 | 105 | 465 | 1.250 | 0.008 | 372 | 174 | 0.012 |
| 2018 | 545 | 106 | 463 | 1.262 | 0.008 | 367 | 178 | 0.012 |
| 2019 | 519 | 108 | 454 | 1.312 | 0.008 | 346 | 173 | 0.012 |
| **RS** | | | | | | | | |
| **Year** | **Shareholder Nodes** | **Dealer Nodes** | **Edges** | **Avg. Dealers Per Fisher** | **Density** | **Fisher Shareholders** | **Isolates** | **Density (Isolates Removed)** |
| 2007 | 404 | 75 | 345 | 1.264 | 0.011 | 273 | 131 | 0.017 |
| 2008 | 360 | 66 | 307 | 1.172 | 0.013 | 262 | 98 | 0.018 |
| 2009 | 372 | 65 | 309 | 1.207 | 0.013 | 256 | 116 | 0.019 |
| 2010 | 435 | 76 | 391 | 1.241 | 0.012 | 315 | 120 | 0.016 |
| 2011 | 441 | 79 | 376 | 1.221 | 0.011 | 308 | 133 | 0.015 |
| 2012 | 463 | 79 | 392 | 1.237 | 0.011 | 317 | 146 | 0.016 |
| 2013 | 447 | 78 | 391 | 1.241 | 0.011 | 315 | 132 | 0.016 |
| 2014 | 475 | 94 | 410 | 1.206 | 0.009 | 340 | 135 | 0.013 |
| 2015 | 496 | 102 | 422 | 1.216 | 0.008 | 347 | 149 | 0.012 |
| 2016 | 508 | 92 | 424 | 1.194 | 0.009 | 355 | 153 | 0.013 |
| 2017 | 517 | 103 | 460 | 1.257 | 0.009 | 366 | 151 | 0.012 |
| 2018 | 523 | 107 | 462 | 1.225 | 0.008 | 377 | 146 | 0.011 |
| 2019 | 521 | 108 | 458 | 1.287 | 0.008 | 356 | 165 | 0.012 |
| **DWGTF** | | | | | | | | |

| Year | Shareholder Nodes | Dealer Nodes | Edges | Avg. Dealers Per Fisher | Density | Fisher Shareholders | Isolates | Density (Isolates Removed) |
|---|---|---|---|---|---|---|---|---|
| 2010 | 312 | 50 | 136 | 1.079 | 0.009 | 126 | 186 | 0.022 |
| 2011 | 338 | 53 | 183 | 1.204 | 0.010 | 152 | 186 | 0.023 |
| 2012 | 346 | 47 | 200 | 1.205 | 0.012 | 166 | 180 | 0.026 |
| 2013 | 305 | 55 | 184 | 1.195 | 0.011 | 154 | 151 | 0.022 |
| 2014 | 298 | 55 | 169 | 1.158 | 0.010 | 146 | 152 | 0.021 |
| 2015 | 313 | 53 | 153 | 1.150 | 0.009 | 133 | 180 | 0.022 |
| 2016 | 306 | 53 | 151 | 1.144 | 0.009 | 132 | 174 | 0.022 |
| 2017 | 280 | 53 | 144 | 1.116 | 0.010 | 129 | 151 | 0.021 |
| 2018 | 294 | 59 | 159 | 1.214 | 0.009 | 131 | 163 | 0.021 |
| 2019 | 296 | 63 | 136 | 1.204 | 0.007 | 113 | 183 | 0.019 |

The landings networks are marked by high levels of fisher fidelity to dealers which leads to minimally dense networks. Most fishers sell their fish to only one dealer in a given year, the average number of dealers per fisher value is based on active fisher shareholders only and, as such, has a minimum possible average value of one. While the number of active dealers has increased it has not, in general, led to fishers selling landings to more dealers in a given year and subsequent higher network density. Based on high levels of dealer fidelity and the information contained in the shared dealer networks it appears that dealers, in some cases, serve as hubs of fishing communities where "their" fishers tend to trade allocation amongst themselves. The role of dealers in the allocation and share networks as both network hubs and active participants through affiliated shareholder accounts are explored in the following section.

***Allocation and Share Trading by Dealer Affiliated Accounts***

Tables 6 and 7 provide the percentage of allocation and share pounds bought and sold by dealer affiliated accounts, respectively. Trading is arranged by year and species group. While not presented in the tables, the percentage of active shareholder accounts that were dealer affiliated by year ranged from 9% to 16% indicating that dealer affiliated shareholders accounted for more pounds of share and allocation traded than would be expected if trading were evenly dispersed across all accounts. In the All IFQ Species group dealer affiliated shareholder accounts, on average, purchased 36% and sold 33% of all allocation transacted, and 28% of share purchased and 18% of share sold by year. The small mismatch in allocation purchased and sold is likely due to these dealer affiliated accounts acquiring allocation for their own vessels to harvest, but the tendency for these numbers to be relatively close to each other indicates dealer affiliated accounts are serving as brokers within the allocation network. This brokerage role is likely undertaken to guarantee supply of fish for their dealer operations.

Table 6. Allocation pounds traded by dealer affiliated accounts (by year and species group).

| | Dealer Affiliated Buyer | | | | Dealer Affiliated Seller | | | |
|---|---|---|---|---|---|---|---|---|
| Year | **All IFQ Species** | **SWG** | **RS** | **DWG** | **All IFQ Species** | **SWG** | **RS** | **DWG** |
| 2007 | - | - | 51% | - | - | - | 11% | - |
| 2008 | - | - | 30% | - | - | - | 35% | - |
| 2009 | - | - | 18% | - | - | - | 21% | - |
| 2010 | 36% | 30% | 38% | 49% | 33% | 22% | 22% | 35% |
| 2011 | 26% | 23% | 24% | 40% | 28% | 27% | 15% | 25% |
| 2012 | 30% | 32% | 29% | 28% | 30% | 33% | 14% | 23% |
| 2013 | 31% | 32% | 26% | 44% | 27% | 29% | 10% | 21% |
| 2014 | 38% | 36% | 36% | 48% | 33% | 33% | 21% | 30% |
| 2015 | 39% | 36% | 39% | 47% | 33% | 32% | 15% | 28% |
| 2016 | 38% | 36% | 36% | 50% | 33% | 35% | 12% | 28% |
| 2017 | 34% | 26% | 38% | 45% | 26% | 22% | 12% | 28% |
| 2018 | 36% | 32% | 36% | 48% | 27% | 26% | 11% | 27% |
| 2019 | 40% | 37% | 41% | 43% | 33% | 32% | 14% | 29% |

Table 7. Share pounds traded by dealer affiliated accounts (by year and species group).

| | Dealer Affiliated Buyer | | | | Dealer Affiliated Seller | | | |
|---|---|---|---|---|---|---|---|---|
| Year | **All IFQ Species** | **SWG** | **RS** | **DWG** | **All IFQ Species** | **SWG** | **RS** | **DWG** |
| 2007 | - | - | 51% | - | - | - | 11% | - |
| 2008 | - | - | 30% | - | - | - | 35% | - |
| 2009 | - | - | 18% | - | - | - | 21% | - |
| 2010 | 29% | 29% | 30% | 31% | 13% | 14% | 9% | 6% |
| 2011 | 12% | 11% | 13% | 15% | 22% | 28% | 6% | 9% |
| 2012 | 30% | 39% | 5% | 18% | 27% | 32% | 18% | 29% |
| 2013 | 26% | 30% | 3% | 43% | 17% | 23% | 1% | 1% |
| 2014 | 41% | 40% | 35% | 50% | 23% | 26% | 20% | 21% |
| 2015 | 25% | 29% | 20% | 16% | 16% | 18% | 7% | 8% |
| 2016 | 15% | 19% | 10% | 6% | 7% | 11% | 0% | 0% |
| 2017 | 26% | 27% | 24% | 32% | 7% | 12% | 0% | 0% |
| 2018 | 37% | 37% | 42% | 28% | 19% | 20% | 3% | 6% |
| 2019 | 28% | 26% | 53% | 9% | 19% | 22% | 7% | 5% |

**Allocation Trading Patterns Analysis**

The generalized goals of this research were to understand the mechanics of quota trading and how trading has evolved through time. In an effort to improve understanding related to these two issues we analyzed allocation trading patterns within the GOM IFQ fisheries through time. We developed several IFQ account traits and types of relationships that we believed might be correlated with likelihood of allocation trading between accounts and then constructed network matrices defining these traits or relationships to compare to the allocation trading networks. We then measured overlap between our relational/trait matrices and allocation matrices and examined the likelihood of the overlap if trading were random to analyze the ability of our IFQ account traits and relation types to explain allocation trading.

*Methodology*

We developed four sets of relational matrices to examine allocation trading patterns: 1) shared dealer, 2) shared county of residence, 3) allocation transaction in prior year, and 4) dealer affiliated matrices. The shared dealer network, as previously discussed, indicated whether two fishers sold IFQ landings to the same dealer in a given year. The premise of this analysis was to investigate the idea of dealers serving as the structure around which 'fishing communities' are built, and these fishing communities could represent subnetworks where IFQ participants are more likely to trade allocation and share information (Ropicki and Larkin 2014). Similarly, the shared county of residence network evaluates the importance of proximity in whether IFQ account holders trade allocation. The allocation transaction in prior year matrices have edges between two IFQ accounts if they traded allocation in the previous year. These networks allow us to examine if previous trading relationships increase the likelihood of current trading. Lastly, the dealer affiliated matrices indicate whether one, or both, of a pair of IFQ accounts were dealer affiliated.

We compared each relational/trait matrix to its associated (by year) allocation matrix using the Jaccard Index to measure overlap. The Jaccard index (JI) calculates the similarities between sample sets as the size of the intersection divided by the size of the union (Hanneman and Riddle, 2005):

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

For our purposes, the two networks intersect if the same two IFQ participants were connected in both networks and the union is all pairs connected in at least one of the networks. The value ranges from a minimum of 0 (no overlap) to a maximum of 1 (perfect overlap).

Once the Jaccard Index was calculated we used a quadratic assignment procedure (QAP) to test for statistical significance of the tendency for edges in the two networks to be correlated[9]. The observed correlation is compared to 2,500 pairs of matrices with the same number of nodes and

[9] QAPs are used to measure correlation as opposed to traditional statistical inference tests due to the lack of independence among observations in network data. Traditional statistical inference tests require observations be independent to be valid which is not the case with network data. With network data all observations related to a node (IFQ account) lack independence so traditional statistical methods are invalid (Borgatti et al. 2013).

edges but where the data is known to be independent. Independence is achieved by taking one of the two matrices and randomly rearranging its rows and columns; because the changes are random the new matrix is independent of the original (Borgatti et al. 2013). The statistical significance of the relationship (p-value) is the proportion of randomly generated similar matrices with a greater correlation than the observed pair. Allocation trading patterns were analyzed for the years 2011 to 2019. We examined the All IFQ Species allocation networks which span from 2010 to 2019; however, due to the use of the previous years allocation trading explanatory matrix we were not able to analyze 2010 since the grouper-tilefish IFQ program did not begin until 2010.

*Analysis*

QAP results are presented in Table 8. The results specific to each of the four relationships examined are presented separately. The first row contains the observed Jaccard Index for each year. The second row provides the average Jaccard Index from the 2,500 Monte Carlo simulations with one of the two network matrices randomized by rearranging the rows and columns. The third row has the p-value which is the proportion of simulated matrices that had higher Jaccard Index values than the observed data. The last row, titled 'Observed/Random' is the observed Jaccard Index divided by the Average Random Jaccard Index, the value indicates how much more likely allocation trading was between account holders connected in the relational network than if allocation trading were completely random. For example, the 25.75 value for the 2011 shared dealer analysis indicates that account holders that both traded allocation and shared a dealer occurred 25.75 times more frequently than when trading was randomized through Monte Carlo simulations.

Table 8. Allocation trading patterns QAP results.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Shared Dealer QAP Analysis** | | | | | | | | | |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| **Obs. JI** | 0.103 | 0.117 | 0.115 | 0.121 | 0.099 | 0.096 | 0.088 | 0.090 | 0.089 |
| **Avg. Random JI** | 0.004 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 |
| **p-value** | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| **Observed/Random** | 25.75 | 23.40 | 23.00 | 24.20 | 24.75 | 24.00 | 22.00 | 22.50 | 17.80 |
| **Shared County QAP Analysis** | | | | | | | | | |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| **Obs. JI** | 0.045 | 0.046 | 0.047 | 0.048 | 0.043 | 0.044 | 0.037 | 0.038 | 0.044 |
| **Avg. Random JI** | 0.006 | 0.006 | 0.007 | 0.007 | 0.006 | 0.006 | 0.005 | 0.005 | 0.006 |
| **p-value** | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| **Observed/Random** | 7.50 | 7.67 | 6.71 | 6.86 | 7.17 | 7.33 | 7.40 | 7.60 | 7.33 |
| **Previous Year Allocation Trade QAP Analysis** | | | | | | | | | |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| **Observed JI** | 0.252 | 0.296 | 0.297 | 0.279 | 0.318 | 0.309 | 0.369 | 0.370 | 0.331 |
| **Avg. Random JI** | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| **p-value** | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| **Observed/Random** | 84.00 | 98.67 | 74.25 | 93.00 | 106.00 | 103.00 | 123.00 | 123.33 | 110.33 |
| **Dealer Affiliated Accounts QAP Analysis** | | | | | | | | | |
| | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| **Obs. JI** | 0.011 | 0.013 | 0.014 | 0.015 | 0.012 | 0.013 | 0.011 | 0.011 | 0.013 |
| **Avg. Random JI** | 0.006 | 0.007 | 0.008 | 0.007 | 0.007 | 0.006 | 0.006 | 0.005 | 0.007 |
| **p-value** | 0.001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| **Observed/Random** | 1.83 | 1.86 | 1.75 | 2.14 | 1.71 | 2.17 | 1.83 | 2.20 | 1.86 |

All of the Jaccard Indices were highly statistically significant indicating all of the relationships analyzed are associated with a greater likelihood of allocation trading between IFQ accounts connected through the relationship being examined. With the exception of the previous year trade QAP analysis, all of the observed Jaccard Index values are relatively small. The small values are a result of the low density of the allocation trading network relative to the other three relational networks. Allocation trading is done on an as needed basis to match fishing needs leading to a minimally dense network, given this minimal density relative to the relational networks there are fewer chances for intersection between the two networks.

The results indicate that trading is localized with a high degree of within dealer-centric fishing community trading than would be expected if trading were random[10]. The results also indicate that trading relationships often span multiple years, and as expected based on the analysis in the

[10] The shared dealer and shared county relationships are highly correlated themselves as would be expected.

previous section, dealers are very involved in the allocation trading market. The results also point to some interesting trends over the time period analyzed. The shared dealer Jaccard Index has generally decreased in recent years indicating less reliance of fishing communities for trading. There has also been a general increase in the tendency to trade through previously developed relationships.

**Fishing Community Trading Analysis**

The large amount of allocation trading conducted through dealer affiliated accounts and the tendency for fishers to trade through shared dealer connections provide some evidence of dealer-centric fishing communities that serve as allocation trading subnetworks. Based on past research (Ropicki and Larkin 2014) and results previously presented we examine the idea of registered dealers serving as hubs within allocation trading networks. In this section we create a network of dealer-centric fishing communities based on IFQ account fishing and trading behavior, evaluate our community delineation strategies, quantify the amount of allocation traded within these communities, and evaluate trading among these communities by developing fishing community level networks.

The development of fishing communities for analysis required a means of placing IFQ accounts into dealer-centric fishing communities. In determining how to place IFQ accounts in fishing communities we first evaluated pounds of allocation trading based on account type as shown in table 9[11]. Fisher accounts are those that landed IFQ species during the year, non-fisher accounts traded allocation but did not have any IFQ species landings. While non-fisher trading has become more prevalent, active fishers were involved in 92% of all allocation pounds traded during the time period analyzed compared to non-fishers who were only involved in 52% of total allocation pounds traded. Our placement algorithm involved first placing IFQ accounts into communities based on landings (fishing behavior) and then based on allocation trading behavior for those accounts that did not fish.

Table 9. Allocation pounds traded by account type and year.

| Trade Type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fisher sells to Fisher** | 61% | 57% | 59% | 49% | 57% | 50% | 39% | 38% | 36% | 31% |
| **Fisher sells to Non-Fisher** | 8% | 7% | 5% | 8% | 6% | 9% | 14% | 11% | 9% | 11% |
| **Non-Fisher sells to Fisher** | 29% | 32% | 32% | 39% | 33% | 33% | 35% | 40% | 39% | 42% |
| **Non-Fisher sells to Non-Fisher** | 2% | 4% | 3% | 4% | 4% | 8% | 13% | 12% | 16% | 16% |

[11] Analysis of fishing communities focused on years when both IFQ programs were in place (2010-2019).

Fisher accounts were placed into the community of the dealer they sold the majority of their IFQ species landings to during the year. Table 10 provides summary statistics on the tendency for fishers to sell to a primary dealer, dealer fidelity across years, and fisher-to-fisher allocation trading within years. An overwhelming majority of landings transactions and pounds landed in the GOM IFQ fisheries involve the fisher's primary dealer. Additionally, the majority of fishers use the same primary dealer year to year. Lastly, an examination of allocation trading shows that fisher-to-fisher allocation trading is conducted mainly through their shared dealer network and the percentage of allocation pounds traded through these connections is generally increasing.

Table 10. Summary statistics on landings behavior and fisher-to-fisher allocation trading.

| | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Avg. % of Transactions with Primary Dealer** | 94% | 95% | 95% | 95% | 95% | 95% | 96% | 95% | 95% | 94% |
| **% of Total Landings to Primary Dealer** | 93% | 94% | 94% | 94% | 96% | 96% | 97% | 97% | 97% | 95% |
| **% of Fishers with same Primary Dealer as Previous Year** | 85% | 85% | 89% | 84% | 84% | 86% | 86% | 90% | 87% | 84% |
| **Fisher-to-Fisher Allocation Trades within Community** | 68% | 52% | 59% | 63% | 61% | 69% | 63% | 75% | 70% | 71% |

Non-fisher IFQ accounts had to be placed into dealer-centric fishing communities based on their allocation trading behavior. Given that the majority of non-fisher allocation trades involved transacting with fishers we decided to examine trading with respect to fisher trading partner communities to see if non-fishers tended to trade within fishing communities as well. Table 11 provides summary statistics on the non-fisher trading with fishing communities. The results indicate that non-fishers generally only trade allocation with fishers from one or two fishing communities with a majority of allocation transactions with a single primary community. The total allocation pounds traded with non-fisher primary communities are skewed downwards by a small group of very active allocation traders that transact with multiple communities in a brokerage role; however, allocation transactions with fishers in non-fisher primary communities still account for 80% of all non-fisher/fisher allocation pounds traded across all years. Additionally, non-fishers tend to work with the same fishing communities across years.

Table 11. Summary statistics on allocation trading between non-fishers and fishers.

| | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Avg. Number of Communities Transacted with by Non-Fishers** | 1.56 | 1.69 | 1.78 | 1.90 | 1.76 | 1.86 | 1.83 | 1.77 | 1.83 | 2.24 |
| **Avg. % of Allocation Pounds Transacted with Primary Community** | 93% | 93% | 94% | 91% | 91% | 91% | 92% | 93% | 93% | 90% |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **% of Total Allocation Pounds to Primary Community** | 76% | 72% | 79% | 73% | 81% | 84% | 84% | 84% | 80% | 80% |
| **% of Non-Fishers with same Primary Community as Previous Year** | 62% | 56% | 65% | 63% | 59% | 73% | 73% | 72% | 68% | 68% |

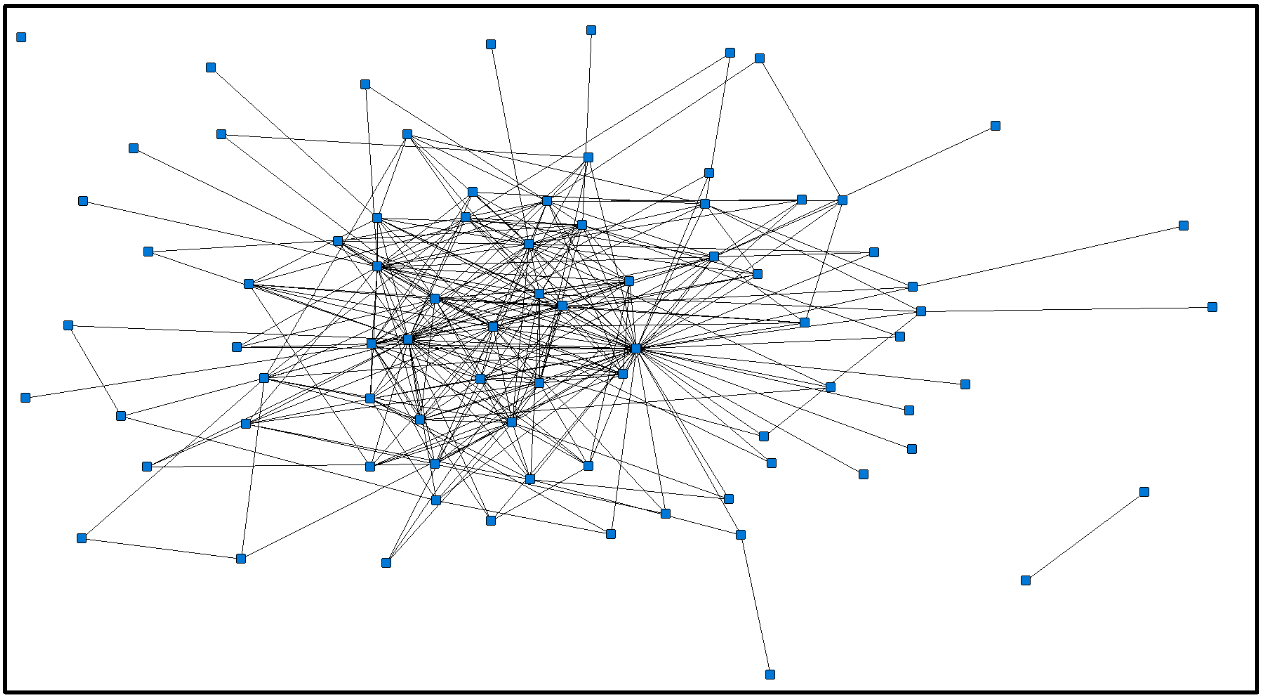
The total percentage of allocation pounds traded within dealer-centric fishing communities is presented in table 12. The results indicate that these communities, as defined, account for a majority of allocation pounds traded and there is a generally increasing trend in the amount of pounds traded within these communities.

Table 12. Total allocation pounds traded within dealer-centric fishing communities.

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| **% of Allocation Pounds Traded Within Communities** | 70% | 59% | 66% | 67% | 69% | 75% | 73% | 80% | 75% | 76% |

The delineation of dealer-centric fishing communities allowed for analysis of allocation trading between these communities. We combined fishing community members and their transactions into groups and analyzed the network of trades between fishing communities. Figure 5 is a visualization of the 2011 fishing community matrix. In this network nodes are fishing communities and edges indicate that members of the two communities traded allocation. The network is highly connected with only one isolated fishing community (no allocation transactions with other communities) and one minor component of two fishing communities that traded among themselves but not with any other fishing communities. The network also displays a dense core of highly connected fishing communities, this general structure was present for all years analyzed.

Figure 5. Fishing community allocation trading network.



We calculated several network metrics for the fishing community annual networks, these values are shown in table 13. The second column shows the number of distinct fishing communities (nodes) in these networks. The third column shows the number of fishing communities (nodes) in the major component. The major component is the largest group of connected nodes within the network (regardless of path length). The results show that almost all fishing communities are connected to each other (at least through other communities if not directly). The fourth column shows the number of connections in the network and the fifth shows the networks density. These fishing community networks are significantly more dense than the account holder level allocation networks. The sixth column shows the average geodesic distance between all connected nodes in the network. The geodesic distance is the shortest path between two nodes. For instance, if nodes A and B are connected, and B and C are connected, but A and C are not connected then the geodesic distance between A and C is two, and the geodesic distances between A and B, and B and C, are both one.

Table 13. Fishing community network metrics by year.

| Year | Communities (Nodes) | Nodes in Major Component | Edges | Density | Average Distance |
|---|---|---|---|---|---|
| 2010 | 76 | 74 | 365 | 0.068 | 2.427 |
| 2011 | 81 | 77 | 443 | 0.076 | 2.265 |
| 2012 | 84 | 80 | 552 | 0.087 | 2.179 |
| 2013 | 83 | 79 | 508 | 0.082 | 2.256 |
| 2014 | 102 | 98 | 568 | 0.060 | 2.455 |
| 2015 | 102 | 98 | 519 | 0.055 | 2.349 |
| 2016 | 101 | 99 | 488 | 0.050 | 2.354 |
| 2017 | 98 | 97 | 442 | 0.047 | 2.488 |
| 2018 | 103 | 97 | 438 | 0.047 | 2.440 |
| 2019 | 103 | 103 | 553 | 0.053 | 2.312 |

Our analysis indicates that a majority of allocation trading (71% of trading across all years) occurs through dealer-centric fishing communities as we have defined them. We have also found evidence that both fishers and non-fishers have a tendency to stay in these fishing communities for multiple years. The remaining 29% of allocation trading involves trades between these fishing communities, we created fishing community level allocation trading networks to examine this trading. We found relatively dense fishing community networks with, on average, 96% of communities located in the major component of the network. Across all years, the fishing community networks contained a dense core of highly connected fishing communities that account for most of the allocation trading relationships (similar to figure 5).

**Allocation Market Cointegration Analysis**

Our analysis of fishing communities has indicated that quota allocation trading is segmented within fishing communities. The segmentation of trading within these fishing communities raises the question - are these subnetworks distinct allocation trading markets with different allocation prices or is trading generally localized, with all subnetworks belong to a single, broader Gulf-wide allocation market? While economic definitions of a market vary slightly the delineation of a market is generally based on the price of a good; Stigler and Sherwin (1985) defined the market for a good as “the area within which the price of a good tends to uniformity, allowance being made for transportation costs.” In this section we employ cointegration analysis of regional allocation prices to determine if allocation prices across different subnetworks of the fishery are cointegrated (move together) and behave as a single market. Additionally, we examine whether these subnetworks are perfectly cointegrated (obey the LOP). According to the LOP, the price of a homogenous commodity traded in an efficient market should converge to a single price through arbitrage (Lamont and Thaler 2003). Species specific allocation in the GOM IFQ fisheries should represent a homogenous commodity since there are no geographic restrictions on trading or use of allocation. This analysis provides insights into the market structure of GOM IFQ allocation markets.

*Methodology*

Ordinary least squares analysis of market integration requires that the variables are covariance stationary. A variable is covariance stationary if its mean and all of its autocovariances are finite and do not change over time. Cointegration analysis allows for market analysis including estimation, inference, and interpretation of variables where the first differences (sequential changes in value across a time series) are covariance stationary. Similar to other studies of market cointegration we analyze the natural logarithm of prices (Asche, Gordon, and Hannesson 2004; Asche et al. 2012; Norman-López et al. 2014). When evaluating market integration using time-series price data the relationship of interest can be defined as follows:

$$\ln p_{1t} = \alpha + \beta \ln p_{2t},$$

where α is a constant that captures difference in the level of prices and β indicates the relationship between the prices. If β=1 the prices are proportional and if β=0 there is no relationship between the prices. When prices are proportional the two prices are stationary relative to each other and the LOP is considered to be upheld. If β is between 0 and 1 then the prices are related but the relative price is not constant (Asche et al. 2012). Unfortunately, traditional econometric techniques are invalid when the time-series being analyzed are non-stationary as is often the case with time-series price data; however, cointegration analysis can be employed with nonstationary price series (Asche, Gordon, and Hannesson 2004).

We employ the Johansen test to check for market integration and the LOP in GOM IFQ allocation markets (Johansen 1988, 1991). The Johansen test models price relationships in a vector autoregressive error correction model (VECM) format which allows for analysis of nonstationary prices and statistical inference and test of the LOP. The test for cointegration among a vector of n prices ($P_t$) can be written as follows:

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-1} + \Pi_k P_{t-k} + \mu + e_t.$$

Π is a matrix containing the cointegration vectors (parameters in the long run relationship), $e_t$ is assumed i.i.d., and $\Gamma_i = -I + \Pi_1 + \ldots + \Pi_i$ and $i = 1,\ldots,k-1$ (Asche et al. 2012; Asche, Gordon, and Hannesson 2004)[12]. Give $r$ cointegrating vectors, $\Pi_k$ can be factorized ($\Pi_k = \alpha\beta'$), where both α and β are N*r matrices. Trace tests are used to determine the rank of Π and tests of the structural

[12] The initial vector autoregressive (VAR) process considered is as follows: $P_t = \sum_{i=1}^{k-1} \Pi_i P_{t-i} + \Pi_k P_{t-k} + \mu + e_t$ (Johansen, 1988) which can be rewritten in VECM form as shown above.

relationships between price series (submarkets) are tests of restrictions on the parameters in β. The α parameters measure the impact of deviations from the long run relationships between price series and are interpreted as adjustment speeds (Asche et al. 2012).

*Price Data and Subnetwork Delineation*

While we identified 76,221 arms-length allocation transactions across all IFQ species groups between 2010 and 2019 the number of transactions with useable price data was much lower. IFQ participants are not required to provide prices when reporting allocation trades and a majority of trades do not report prices or report values that do not reflect the value of allocation[13]. Our analysis only involved transaction prices indicated by the National Marine Fisheries Service Southeast Regional Office annual reports to be representative of allocation value (NMFS 2020a, 2020b). This left 34,279 arms-length transactions with representative price data across all IFQ species groups (RS, RG, GG, OSWG, DWG, and TF)[14].

Our allocation market integration analysis was species specific meaning subnetwork trading was compared only among the same IFQ allocation species (i.e., red snapper in region 1 compared to red snapper in region 2). We subdivided IFQ accounts into regions based on the location of their fishing community as determined in the previous section (Fishing Community Trading Analysis). The fishery was broken into three subnetworks for analysis: 1) IFQ account holders operating in communities located in Florida south and or east of Taylor County, FL, 2) IFQ account holders operating between Taylor County, FL and north or east of Plaquemines Parrish, LA, and 3) IFQ account holders operating in, or west of, Plaquemines Parrish, LA. Allocation transactions between two account holders in different regions were assigned to the region of the allocation buyer. The majority of allocation trades were between IFQ account holders operating in the same regions due to the segmentation in the network previously noted. Table 14 includes the percentage of allocation pounds traded within and between regions. Ideally, we would have like to explore more regional variation by breaking down the fishery into smaller regions (subnetworks), but the lack of priced trading data did not allow for this.

Table 14. Allocation pounds traded by region (% sum vertically).

| | Buyer Region | | |
|---|---|---|---|
| Seller Region | 1 | 2 | 3 |
| 1 | 91.10% | 6.01% | 10.42% |
| 2 | 6.30% | 91.85% | 14.79% |
| 3 | 2.59% | 2.14% | 74.79% |

[13] These values are either too low ($.01/lb of allocation is a common value given regardless of IFQ species and time of year) or too high (values above the maximum amount paid dockside for the landed species).
[14] We did not include either gag grouper multiuse (GGM) or red grouper multiuse (RGM) in our analysis to avoid issues with the additional versatility associated with this allocation.

Quarterly average allocation prices, by species group and region, were calculated for the market integration analysis. Allocation trading of grouper-tilefish is limited in the western Gulf and a lack of priced trade data led to many quarters with either no or only one priced trade for an IFQ species in Regions 2 and 3. Because of the lack of data our analysis was limited to the following allocation market integration analyses:

1. Red Grouper - Regions 1 and 2
2. Gag Grouper - Regions 1 and 2
3. Red Snapper – Regions 1, 2, and 3

All other subnetwork/species grouping included quarters with either no trades or a single trade.

*Analysis*

Prior to performing market integration tests we examined the time series properties of the price series. The species level allocation price series evaluated are displayed in figures 6, 7, and 8. The figures display several interesting patterns in the data. Red grouper and gag grouper allocation prices both decreased during the last few years of the analysis period before leveling off in 2019. The red snapper price series show a generally increasing trend with several sharp price drops during the second half of years.

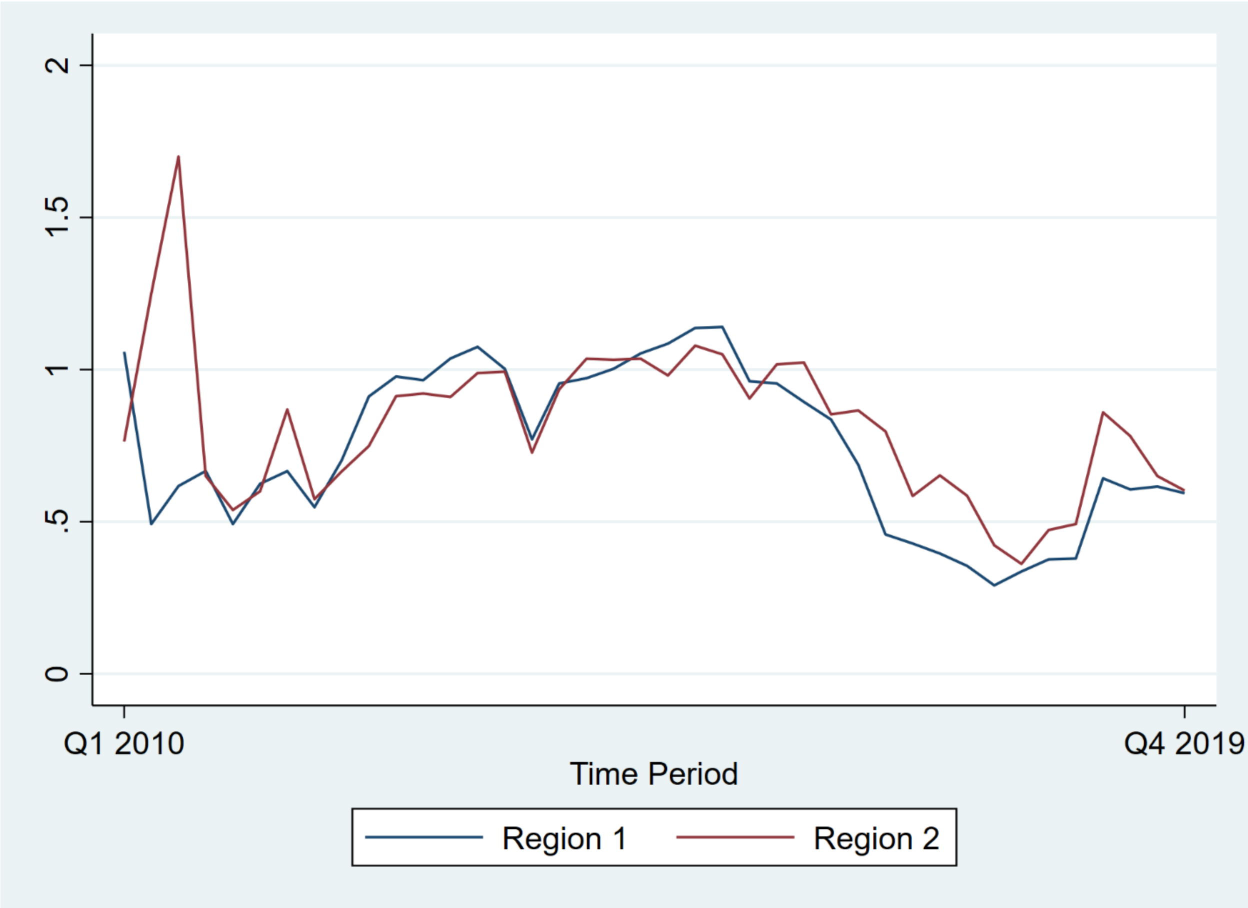


Figure 6. Red grouper price series analyzed.

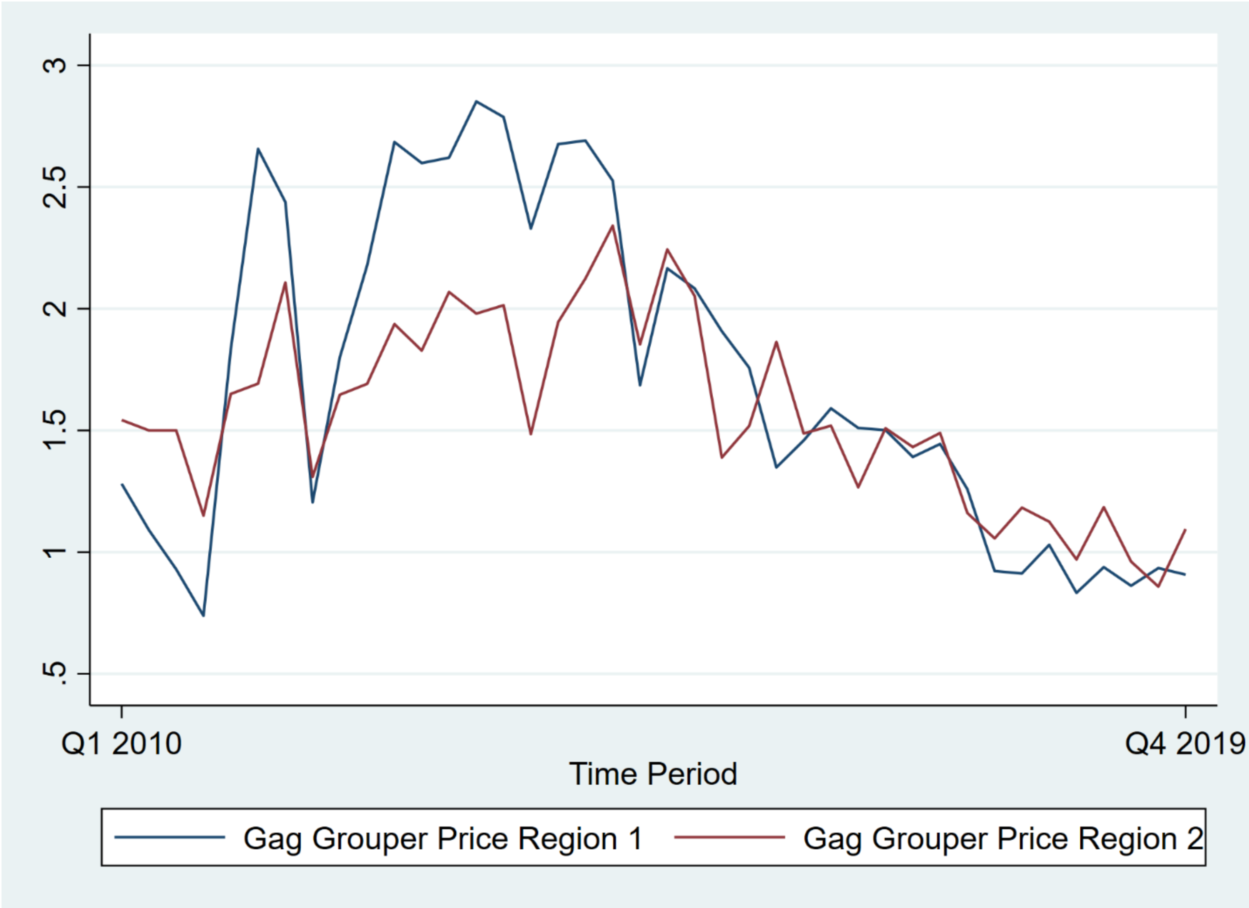


Figure 7. Gag grouper price series analyzed.

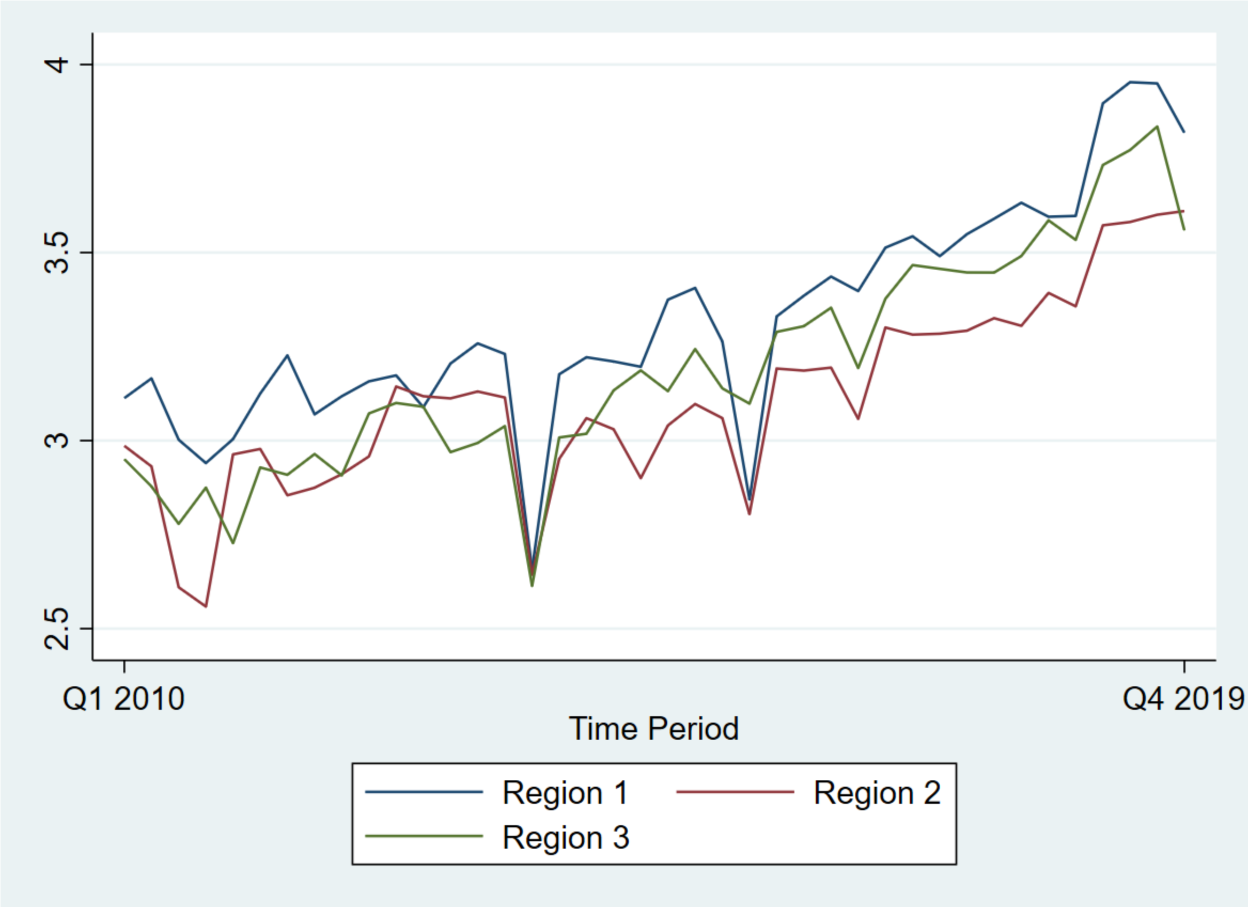


Figure 8. Red snapper price series analyzed.

Table 15 provides the results of Augmented Dickey-Fuller tests. In all cases we cannot reject the null hypothesis that the time series are nonstationary in levels, but we can reject the null that these series are nonstationary in first differences. All of the price series are integrated of order one and can be evaluated using the Johansen test (Asche, Gordon, and Hannesson 2004; Johansen 1991). These conclusions were fairly robust to the number of lags chosen and the inclusion of a trend variable[15].

[15] The exceptions to the findings of integration of order one were: 1) first differences of RG Price Region 1 was only statistically significant up to 1 lag, 2) RG Price Region 2 was not statistically significant with 3 lags and a trend variable, and 3) levels of GG Price Region 1 was statistically significant at 4 lags.

Table 15. Augmented Dickey Fuller Unit Root Tests of allocation price series.

| **Levels** | | | |
|---|---|---|---|
| **Variable** | **Test Statistic** | **Test Statistic with Trend** | **# of Lags** |
| Red Grouper Region 1 | -1.320 | -1.666 | 2 |
| Red Grouper Region 2 | -1.467 | -1.780 | 3 |
| | | | |
| Gag Grouper Region 1 | -1.329 | -2.711 | 2 |
| Gag Grouper Region 2 | -0.636 | -1.782 | 3 |
| | | | |
| Red Snapper Region 1 | 0.309 | -1.540 | 4 |
| Red Snapper Region 2 | -0.226 | -1.780 | 4 |
| Red Snapper Region 3 | -0.333 | -2.208 | 4 |
| | | | |
| **First Differences** | | | |
| **Variable** | **Test Statistic** | **Test Statistic with Trend** | **# of Lags** |
| Red Grouper Region 1 | -4.431** | -4.391 | 1 |
| Red Grouper Region 2 | -5.122** | -4.934** | 2 |
| | | | |
| Gag Grouper Region 1 | -5.687** | -6.089** | 1 |
| Gag Grouper Region 2 | -6.180** | -7.265** | 2 |
| | | | |
| Red Snapper Region 1 | -4.331** | -4.440** | 3 |
| Red Snapper Region 2 | -3.660* | -3.670* | 3 |
| Red Snapper Region 3 | -4.304** | -4.150** | 3 |

* indicates significance at the 5% level and ** indicates significance at the 1% level.

Pairwise cointegration procedures were implemented for all applicable region pairs for the IFQ species group analyzed. The results of the five pairwise cointegration tests performed are presented in Table 16. Columns 2 and 3 display the calculated values for the maximum eigenvalue and trace tests of whether there exist no cointegrating vectors, since all test are statistically significant each pair of prices has cointegrating vectors. Columns 4 and 5 contain the test statistics under the null hypothesis that there are less than or equal to one cointegrating vector for each price pair, all of these tests are not statistically significant indicating we can not reject the null of less than or equal to one cointegrating vector. These results indicate that each pair of allocation prices has one cointegrating vector. The LOP tests involves imposing the restriction that $\beta_1=-\beta_2$ for each pair of prices with the null hypothesis that the LOP holds. The LOP is rejected for red and gag grouper indicating that although these subnetworks are cointegrated they are not perfectly cointegrated.

The LOP cannot be rejected for any of the red snapper comparisons indicating that these three subnetworks function as a single market despite the segmented trading of allocation regionally.

Table 16. Johansen Tests for cointegration.

| | Rank = 0 | | Rank = 1 | | |
|---|---|---|---|---|---|
| Prices | Max | Trace | Max | Trace | Law of One Price |
| Red Grouper 1/2 | 38.902** | 41.856** | 2.954 | 2.954 | 24.730** |
| Gag Grouper 1/2 | 19.101** | 20.180** | 1.079 | 1.079 | 7.567** |
| Red Snapper 1/2 | 20.085** | 20.247** | 0.162 | 0.162 | 0.780 |
| Red Snapper 1/3 | 17.809* | 18.455* | 0.646 | 0.646 | 3.344 |
| Red Snapper 2/3 | 20.919** | 23.105** | 2.186 | 2.186 | 2.832 |

* indicates significance at the 5% level and ** indicates significance at the 1% level.

The allocation market cointegration analysis indicates that allocation prices within the different regions of the GOM previously defined are cointegrated and generally move similarly through time. Only red snapper allocation was found to be perfectly cointegrated with regional trading prices being indicative a single market for the commodity (in accordance with the LOP). However, the rejection of the LOP for red and gag grouper should be regarded carefully as a limited number of priced transactions in region 2 led to some quarterly average price estimates based on only 5-10 observations that may not be indicative of the true regional market price.

**Summary**

The objectives of this study were 1) develop and analyze quota trading and landings networks for each year and species group of the Gulf of Mexico IFQ fisheries, 2) to determine how the Gulf of Mexico IFQ fisheries quota and landings markets are connected using network analysis techniques, 3) evaluate how the Gulf of Mexico IFQ markets have changed since implementation, 4) examine the role of dealers in the Gulf of Mexico IFQ markets, and 5) evaluate market cointegration of allocation subnetworks to determine if these subnetworks represent individual allocation markets or are part of an integrated allocation network. Data used in this analysis came from IFQ program data from 2007 through 2019 provided by the National Marine Fisheries Service Southeast Regional Office (NMFS SERO). Several hundred networks were created, delineated by year and species group.

Our analysis indicated that the landings and quota markets are highly connected and dealers, generally, serve as brokers within the allocation market. Dealer affiliated accounts that purchase landings from fishers are actively involved in allocation trading and generally account for 20-50% of pounds traded depending on species and year. Additionally, our analysis indicated that fishers that share dealers are more likely to trade allocation than fishers not connected in the landings or shared dealer networks. Lastly, we developed dealer-centric fishing communities with 71% of allocation pounds traded within these communities. Allocation trading is generally localized and is driven both by dealer affiliated accounts trading and trading within the fishing communities surrounding dealers.

Temporal analysis showed a general increase in allocation trading over time with over 90% of active shareholder accounts trading allocation by 2019, a considerable increase from early years of the program. Although allocation trading is the prevalent form of quota trading, the networks were still marked by limited density indicating that trading is accomplished using only one or a few trading partners in a given year, this finding was relatively constant through time. Additionally, IFQ markets have seen a marked increase in trading by shareholder accounts that do not land fish. There has also been an increase in the tendency for allocation to be traded within dealer-centric fishing communities as opposed to between them.

The segmentation of the allocation trading markets and the tendency to trade allocation through fishing communities warranted an analysis of regional differences in allocation prices. Our analysis indicated that species specific allocation prices were cointegrated across regions meaning that they generally move together. However, only red snapper allocation was found to be perfectly cointegrated as would be expected with a commodity good such as species-specific allocation. It is important to note that data for this analysis was limited due to limited price reporting and the finding of imperfect cointegration of red and gag grouper prices should be regarded carefully.

## References


Addicott, E.T, K. Kroetz, M.N. Reimer, J.N. Sanchirico, D.K. Lew, and J. Huetteman. 2018. "Identifying the potential for cross-fishery spillovers: A network analysis of Alaskan permitting patterns." *Canadian Journal of Fisheries and Aquatic Sciences* 76(1): 56-68.

Asche, F., D.V. Gordon, and R. Hannesson. 2004. "Tests for Market Integration and the Law of One Price: The Market for Whitefish in France." *Marine Resource Economics* 19(2): 195-210.

Asche, F., L.S. Bennear, A. Oglend, and M.D. Smith. 2012. "U.S. Shrimp Market Integration." *Marine Resource Economics* 27(2): 181-192.

Barnes, M.L., J. Lynham, K. Kalberg, and P. Leung. 2016. "Social networks and environmental outcomes." *Proceedings of the National Academy of Sciences of the United States of America* 113 (23): 6466-6471.

Barnes, M.L., E. Mbaru, and N. Muthiga. 2019. "Informed access and knowledge exchange in co-managed coral reef fisheries." *Biological Conservation* 238: 108198.

Bodin, Ö., B. Crona, and H. Ernstson. 2006. "Social Networks in Natural Resource Management: What is There to Learn from a Structural Perspective?" *Ecology and Society* 11(2).

Bodin, Ö., and B. Crona. 2009. "The Role of Social Networks in Natural Resource Governance: What Relational Patterns Make a Difference?" *Global Environmental Change* 19, 366-374.

Borgatti, S.P., Everett, M.G., and Johnson, J.C. 2013. *Analyzing Social Networks.* Sage Publications Limited: London, UK.

Fuller, E.C., J.F. Samhouri, J.S. Stroll, S.A. Levin, and J.R. Watson. 2017."Characterizing fisheries connectivity in marine social-ecological systems." *ICES Journal of Marine Science* 74(8): 2087-2096.

Gephart, J.A., and M.L. Pace. 2015. "Structure and evolution of the global seafood trade network." *Environmental Research* 10(12), p.125014.

Hanneman, R., and Riddle, M. 2005. *Introduction to Social Network Methods*. http://faculty.ucr.edu/~hanneman/nettext/.

Innes, J., O. Thebaud, A. Norman-Lopez, and L.R. Little. 2014. "Does size matter? An assessment of quota market evolution and performance in the Great Barrier Reef fin-fish fishery." *Ecology and Society* 19(3).

Johansen, S. 1988. "Statistical Analysis of Cointegration Vectors." *Journal of Economic Dynamics and Control* 12:231-254.

Johansen, S. 1991. "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Autoregressive Models." *Econometrica* 59: 1551-1580.

Lamont, O.A., and R.H. Thaler. 2003. "Anomalies: The Law of One Price in Financial Markets." *The Journal of Economic Perspectives* 17(4): 191-202.

National Marine Fisheries Service Southeast Regional Office. 2020a. Gulf of Mexico Red Snapper Individual Fishing Quota Report (2019 update). SERO-LAPP-2020-2. https://portal.southeast.fisheries.noaa.gov/reports/cs/2019_RS_AnnualReport_SEROFinal.pdf.

National Marine Fisheries Service Southeast Regional Office. 2020a. Gulf of Mexico Grouper-Tilefish Individual Fishing Quota Report (2019 update). SERO-LAPP-2020-2. https://portal.southeast.fisheries.noaa.gov/reports/cs/2019_GT_AnnualReport_SEROFinal.pdf.

Newman, M.E.J. 2010. *Networks: An Introduction*. Oxford University Press: Oxford, NY.

Norman-López, A., S. Pascoe, O. Thébaud, I. van Putten, J. Innes, S. Jennings, A. Hobday, B. Green, and E. Plaganyi. 2014. "Price integration in the Australian rock lobster industry: implications for management and climate change adaptation." *The Australian Journal of Agricultural and Resource Economics* 58(1): 43-59.

Olsson, P., C. Folke, and F. Berkes. 2004. "Adaptive Comanagement for Building Resilience in Social-Ecological Systems." *Environmental Management* 34(1), 75-90.

Olsson, P, C. Folke, V. Galaz, T. Hahn and L. Schultz. 2007. "Enhancing the fit through adaptive co-management: creating and maintaining bridging functions for matching scales in the Kristianstads Vattenrike Biosphere Reserve, Sweden." *Ecology and Society* 12(1): 28. URL: http://www.ecologyandsociety.org/vol12/iss1/art28.

Ropicki, A.J., and S. Larkin. 2014. "Social Network Analysis of Price Dispersion in Fishing Quota Lease Markets." *Marine Resource Economics* 29(2): 157-176.

Sandström, A. 2008. "Policy Networks: The Relationship Between Structure and Performance." Department of Business Administration and Social Sciences, Luleå University of Technology, Luleå, Sweden.

Squires, D., H. Campbell, S. Cunningham, C. Dewees, R.Q. Grafton, S.F. Herrick, Jr., J. Kirkley, S. Pascoe, K. Salvanes, B. Shallard, B. Turris, and N. Vestergaard. 1998. "Individual transferable quotas in multispecies fisheries." *Marine Policy* 22(2): 135-159.

Stigler, G.J., and R.A. Sherwin. 1985. "The Extent of the Market." *The Journal of Law & Economics* 28(3): 555-585.

Van Putten, I., K.G. Hamon, and C. Gardner. "Network analysis of a rock lobster quota lease market." *Fisheries Research* 107(1-3): 122-130.

Vasta, M. 2019. Network Analysis of the Northeast Multispecies (Groundfish) Annual Catch Entitlement (ACE) Transfer network (May 2010 – April 2016).