Network Analysis of the Gulf of Mexico Commercial Red Snapper Fishery IFQ Program

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Introduction

In a 2009 article in the journal Science, a group of economist and scientists reviewed the state of global fisheries (Worm et al., 2009). The researchers found that even with recent increased regulation of fisheries 63% of fish stocks worldwide still require rebuilding and decreased exploitation rates are required to save species stocks vulnerable to collapse (Worm et al., 2009). The dismal state of fisheries worldwide even in the face of increased regulation has led to heightened scrutiny of the effectiveness of fishery management techniques. The major problem with fisheries management relates to the uncertainty inherent in monitoring fisheries. If fish populations and population growth rates could be accurately measured fisheries managers could simply limit the total allowable catch (TAC) of the fishery to a level that ensured optimal usage and continued sustainability. Regrettably, in most fisheries analysis of population, and population growth rate, is a very inaccurate science. In addition, the monitoring of fish catch and ability to forecast fishing behavior is also very difficult and subject to error (Ludwig et al., 1993).

Historically, fisheries management regulation has focused on controlling fishing behavior and effort. The problem is that this is usually done only when a problem of overcapacity in the fishery has been noticed. A common technique used is to limit the TAC. With limits on the TAC and too many fishermen, a situation arises in which those in the fishery race to catch their share of the TAC prior to a fishery closing. This form of management leads to fishing in dangerous conditions due to each fisherman's goal of harvesting as much of the TAC as possible, and market gluts since the entire catch comes to market in a short period of time. Another ill-advised fishery management technique that is often used is gear restrictions. Gear restrictions limit what techniques and tools fishermen have at their disposal to harvest fish. Restrictions can involve type of craft, engine power, and equipment used directly in harvesting. This form of management attempts to limit catch by limiting technology and leads to inefficient harvesting (Grafton et al., 2004).

Over the past 30 years there has been a steady movement towards what is known as rights-based management. Rights-based management attempts to alter fisher incentives as opposed to fisher behavior (Grafton et al., 2004). One of the more common tools of rights-based management is the use of individual fishing quotas (IFQs). IFQ programs set a TAC for a fishery in a given year, but divide it among the participants in the fishery usually based on past participation in the fishery. Each fisherman gets a quota, or percentage of the TAC, that they have exclusive rights to which they are oftentimes free to trade with other fishermen. The quota is usually a going concern meaning it applies to all future years as well as the current year.

The use of IFQs in fisheries management has been shown to stop overfishing, overcapitalization, and derby style fishing (e.g., Costello, Gaines, and Lynham 2008; Grafton et al. 2006). Two facets of IFQs create an alignment of interests between fishery managers and fishermen that decrease overcapacity and overfishing. The first facet is the long-lived nature of the quota asset. By making quota a perpetual asset it is in the fishermen's best interest to protect future harvests by not overharvesting in the current period. This is because overharvesting now will decrease future landings and the value of quota going forward. The second facet of IFQ programs that improves fisheries management is the tradability of quota. Economic reasoning leads to the conclusion that more efficient harvesters will place a higher value on quota than their less efficient counterparts and will buy out the less efficient fishers, which leads to decreased capacity and increased harvest efficiency. An added benefit of IFQs is that the quota awarded to each participant allows them to determine when to harvest as opposed to seasonal regulations which lead to derby style fishing.

Although IFQ programs have been successful in mitigating overcapacity and overfishing in many cases, criticism of such programs have developed. For example, in a 2009 analysis of the British Columbia halibut IFQ program, Pinkerton and Edwards found that sellers of both quota and allocation were able to exert market power. They noted that in the first 16 years (1993-2008), the allocation price as a percentage of ex-vessel price rose from 53% to 78%; in addition, the ex-vessel price as a percentage of quota price fell from 32% to 13%. The authors concluded that the high price of quota relative to the ex-vessel price led to increased leasing of quota by those fishermen not initially granted quota; in 2006, 79% of all quota was leased. This scenario led to two classes of fishermen: quota owners who still fished and fishermen forced to lease quota. The authors remarked that this system could diminish any efficiency gains expected by quota trading since quota owning fishermen did not face leasing costs and could, therefore, fish with less efficient gear and still earn outsized profits relative to lease fishermen.

In order for tradable rights programs to succeed the trading markets must function effectively. In short, this means that buyers and sellers must be able to find each other with relative ease (i.e., low transaction costs), information on quota prices must be readily available to all market participants, and no market participants should be able to exert undue influence on market prices.

The objective of this study is to use network analysis techniques to analyze the allocation (lease) trading market of the Gulf of Mexico Commercial Red Snapper Fishery IFQ program. Specific goals of the research are to determine:

- what type of trading market exists and how it has changed over the first three years of the program;
- whether the market is segmented into multiple trading communities, and if so are allocation prices different between communities;
- and how IFQ management has changed participation in the red snapper fishery (2007-2009).

In addition, the application of network analysis to fisheries research is relatively new and this research should provide a new approach to analyzing fisheries. Most of the past research has involved information sharing networks among fishers and how networks affect issues such as fishing success and adherence to fishing regulations. Crona and Bodin (2006) showed that patterns in social networks were able to help explain the failure of co-management governance arrangements in Kenyan fisheries. Meuller et al. (2008) found that fishing success in the Lake Michigan salmon charter fishing industry was driven by friendship networks among captains through which fishing location information was shared. Two studies (Weisbuch, Kirman, and Herreiner, 2000, and Kirman, 2001) that looked at buyer-seller interaction in the Marseille fish market found that during periods where demand outpaced supply it was beneficial for buyers to trade with only one seller; however, when supply was more plentiful buyer loyalty was less common as buyers shopped for the best deals. Van Putten, Hamon, and Gardner (2010) were the first to apply social network analysis to the trading in an IFQ market; they looked at trading in the Tasmanian rock lobster IFQ program. The authors were able to determine what roles participants were playing within the market, how trading in the IFQ program evolved, and how processors effected trading. This paper expands on the work of Van Putten, Hamon, and Gardner (2010) by also evaluating market segmentation.

The paper proceeds as follows. The next section provides a background on the Gulf of Mexico commercial red snapper fishery including past management strategies and the current IFQ management scheme. Next, the data used in the preliminary analysis is presented. The following section presents the research methodology and preliminary results. The paper concludes with some observations on the preliminary results and next steps in the research.

The Gulf of Mexico Commercial Red Snapper Fishery

The red snapper fishery in the Gulf of Mexico is a part of the Gulf of Mexico reef fish fishery. The reef fish fishery consists of numerous snapper and grouper varieties as well as amberjacks, triggerfish, porgies, tilefish, and a number of other species. Fishing is done using a either a weighted vertical line or using long-lining techniques. The fishing grounds are spread throughout the Gulf of Mexico near reef structures, favored fishing spots are often located more than 100 miles offshore. Oftentimes multiple locations are fished on a single trip (Weninger and Waters, 2003). Red snapper, vermillion snapper, red grouper, and shallow water grouper species are the most intensively harvested by weight.

The Gulf of Mexico red snapper fishery is managed by the Gulf of Mexico Fishery Management Council (GMFMC) through its Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico. The fishery management plan (FMP) was implemented in 1984 and regulates federal waters off the Alabama, Louisiana, Mississippi, Texas, and Florida Gulf coasts (Waters, 2001). The original FMP simply banned certain fishing techniques deemed harmful to the marine environment. From 1990 to 2006 the FMP used a total allowable catch (TAC) as the main means of limiting overfishing. The TAC was set annually with 51% of the TAC allocated to commercial fishermen (commercial quota) that held a required reef fishing permit and 49% allocated to recreational fishermen (recreational quota). The commercial quota of the TAC over the period from 1990 to 2006 ranged from a low of 2.04 million pounds in 1991 and 1992 to 4.65 million pounds in the years from 1996 to 2006. Once the commercial quota was caught each year the season was ended (GMFMC, 2006). The commercial quota led to a race to fish, for the period from 1993 to 2006 the red snapper commercial season never lasted longer than 131 days, and the season averaged just 77 days from 1996 to 2003 (NMFS, 2008).

The commercial quota in the red snapper fishery led to extreme fishing effort early in the season as individuals tried to maximize their share of the catch before the season closed. This behavior led to flooded markets for red snapper during open seasons. This flooding of the market during certain times of the year led to lower prices for commercial fishermen and lower revenue. In a 2003 study, Waters found that red snapper dockside prices had generally risen, in both nominal and real dollars, for the period from 1962 to 1990. This trend reversed when the commercial quota was implemented in 1990, and dockside prices declined in both real and nominal terms for the period from 1990 to 2002. In a 2001 study, Waters estimated the size of this quota effect on real average annual dockside prices as $1.14 per pound in 1999 dollars.

The race for fish caused by the commercial quota in the red snapper fishery also led fishermen to ignore hazardous weather during the red snapper season. In April 2001 the fishing vessel Wayne's Payne sank approximately 85 miles off Marsh Island, LA due to inclement weather. The boat's captain cited the red snapper season being open as his reason for fishing under hazardous conditions (Weninger and Waters, 2003).

In 2006, the GMFMC created Amendment 27 to the Reef Fish Fishery Management Plan to end the commercial quota system in the red snapper fishery and halt the negative effects associated with the quota. Amendment 27 created an IFQ system for the Gulf of Mexico commercial red snapper fishery which was implemented in 2007. The fishery was still governed by an overall commercial quota, 3.315 million pounds (2.297 million pounds gutted weight) in 2007[1], but the total allowable catch was pre-divided among the participants in the fishery based on their catch history.

Each fisherman's individual quota is transferrable and can be purchased by anyone. During the first five years of the program quota trading was limited to reef fish permit holders, but this restriction was lifted in 2012. Although quota can now be traded by the general public, harvesting of quota is still restricted to reef fish permit holders (NMFS, 2012). Individual quota

[1] At the beginning of 2007 the commercial quota was 2.55 million pounds but was increased to 3.315 million pounds in June of 2007.

can be transferred in two different ways. The first is allocation which transfers the right to quota only for the current year and is essentially the leasing of quota. The second is share which transfers the quota permanently. Quota shares are only transferable to other reef fish permit holders during the first five years of IFQ implementation and to anyone after that period (NMFS, 2008).

The red snapper IFQ program was created to decrease some of the overcapacity and overfishing in the fishery and end the market gluts and low dockside prices of red snapper caused by the race to fish in the old management system. The IFQ appear to have succeeded on all accounts. During the first five years of the program the number of IFQ shareholders dropped 25% and the fishing season has been year-around since IFQ implementation. Since IFQ implementation in 2007 the commercial sector has yet to exceed its share of the TAC. This end to overharvesting has allowed the GMFMC to increase the TAC three times since IFQ implementation. In 2011, the TAC for commercial fishers was 43% higher than at the start of the IFQ program in 2007(NMFS, 2012). The spreading out of the catch appears to have limited the problem of market gluts as median ex-vessel prices rose from approximately $3.50/lb in 2006 (the last year before IFQ implementation) to $4.00/lb in 2007 (NMFS, 2012). In 2008 the median ex-vessel price rose again to approximately $4.25/lb and remained relatively constant since then.

Data

The data used in this analysis was all lease transactions (allocation trades) in the Gulf of Mexico Commercial Red Snapper Fishery IFQ program from 2007 to 2009. The data for each transaction included the names and locations of the buyer and seller, the amount of allocation traded (lbs.), the date of the trade, and the price ($/lb.) if one was entered (prices are not required to be enter for the IFQ program). The data included 1,894 trades over the three years examined, approximately 36% of these trades included price information. There were 616 different participants/vertices for the three years of the program, but only approximately 350 participants/vertices per year due to migration in and out of the fishery. The data used was provided by the National Marine Fisheries Service.

Methodology and Preliminary Results

The networks analyzed were defined by the IFQ allocation market. The vertices were the buyers and sellers and the edges were the allocation trades. The networks were directed with edges pointing from the seller towards the buyer, in the direction of the allocation flow. Three separate networks were created; one for each year the program was analyzed. This was done because of the nature of the fishery. Each year the fishery manager, the Gulf of Mexico Fishery Management Council, sets the total allowable catch (TAC) for the fishery and then each fisher’s allocation (in lbs.), is based on their quota, or, percentage of the TAC. The allocation is only good for the current year since the TAC is reset each year; for this reason it made sense to create three separate networks for each year being evaluated.

The first objective of this research was to analyze the allocation trading network and how it changed over the first three years of the IFQ program. Figure 1 presents network visualizations, created using UCINET 6 software, for the allocation market in 2007 and 2009. In the visualizations the size, shape, and color of vertices convey information. The size of the vertex is the maximum value of quota holdings at the beginning of the year, landings for the year, or half of the total trades for the year. The shape of the vertex defines whether the fisher is: solely a fisher (circle), or both a fisher and a registered dealer legally allowed to purchase red snapper catch from other fishers (triangle). The color of the node indicates the type of allocation trader: net allocation sellers are blue, net allocation buyers are red, participants that sell all their allocation and do not fish (investors) are grey, pure fishers that do not trade are black, and traders that sell and buy equal amounts of quota are purple. The visualizations show that a number of the dealer-affiliated fishers are major hubs in the network. This finding seems reasonable as these participants often buy and sell fish from many other fishers, and thus, have contact with many potential trading partners.

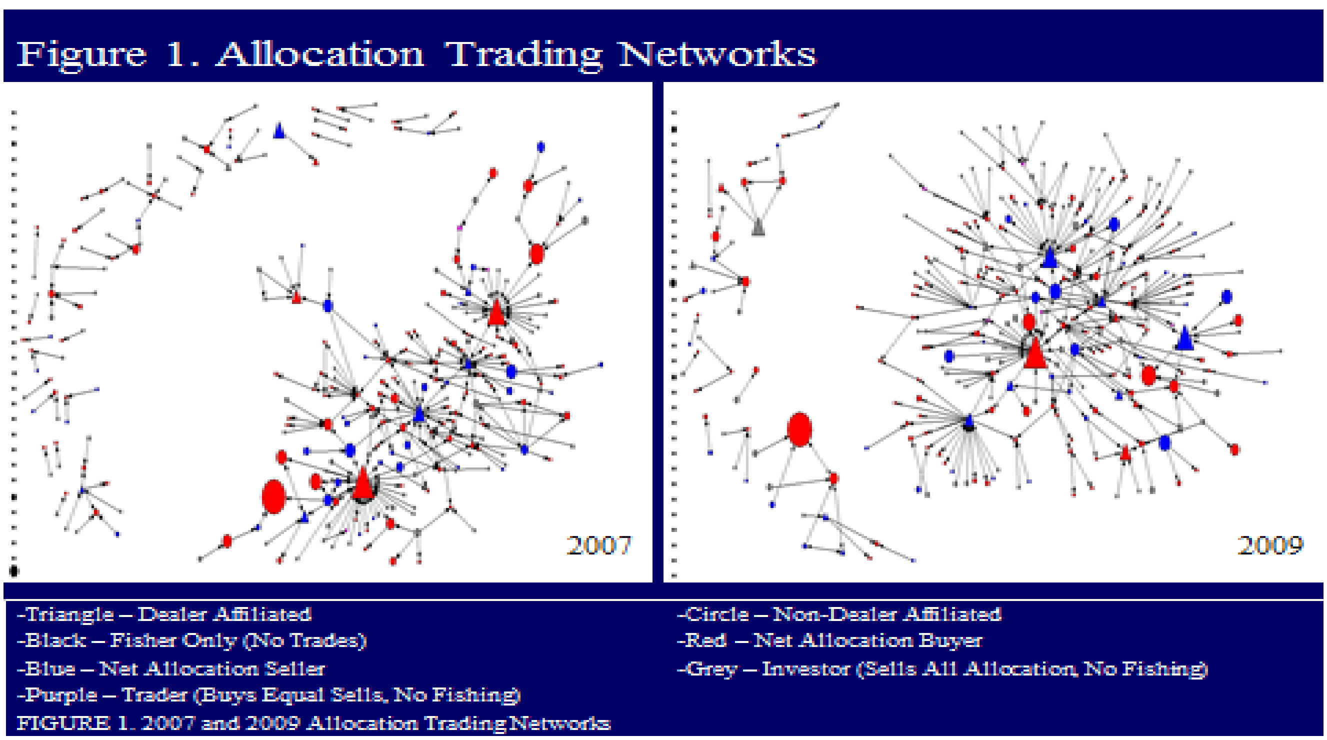


FIGURE 1. 2007 and 2009 Allocation Trading Networks

Both networks show a single major component, additional smaller components, and a number of isolated nodes representing fishers that do not trade. Table 1 presents some of the basic network level measures for each of the first three years of the red snapper IFQ program. Network density is the ratio of actual edges in the network compared to the number of possible edges in the network. The allocation trading network is sparse. Characteristic path length is the average number of edges between nodes in the major component. Clustering coefficient is a measure of the tendency for connected nodes to share neighbors (be connected to the same group of nodes). Network diameter is the longest of all the shortest paths between any two nodes in the main component of a network.

One of the more interesting characteristics in the network is the rather large drop in the number of trades between 2007 and 2008 (18%) and the subsequent rise in trades between 2008 and 2009 (34%). This large change was due to a number of smaller fishers exiting the fishery in 2007 that sold their allocation and quota separately. The large increase in trading in 2009 was due to a number of fishers that only catch red snapper as bycatch deciding to buy allocation and sell their snapper bycatch as opposed to discarding the fish at sea.

The table shows that although there was some variation in network size over the three years the network level metrics did not change a great deal. The clustering coefficient dropped after 2007 as allocation tended to move more frequently through "hub" vertices where the "spokes" were not connected through trades. The low clustering coefficient found in these networks is rare for social networks that often show much higher clustering coefficients. One plausible explanation for the low clustering coefficient is that the data being analyzed is trades as opposed to friendships, and that if friendships among the fishers were analyzed we would see a higher clustering coefficient. Another possible explanation is that the competitive nature of the fishery leads to the low clustering coefficient.

Table 1. Network Metrics			
	2007	*2008*	*2009*
Vertices	377	335	351
Edges	310	253	339
Density	0.002	0.002	0.003
Characteristic Path Length	6.694	5.887	7.464
Clustering Coefficient	0.044	0.023	0.025
Network Diameter	33	36	36

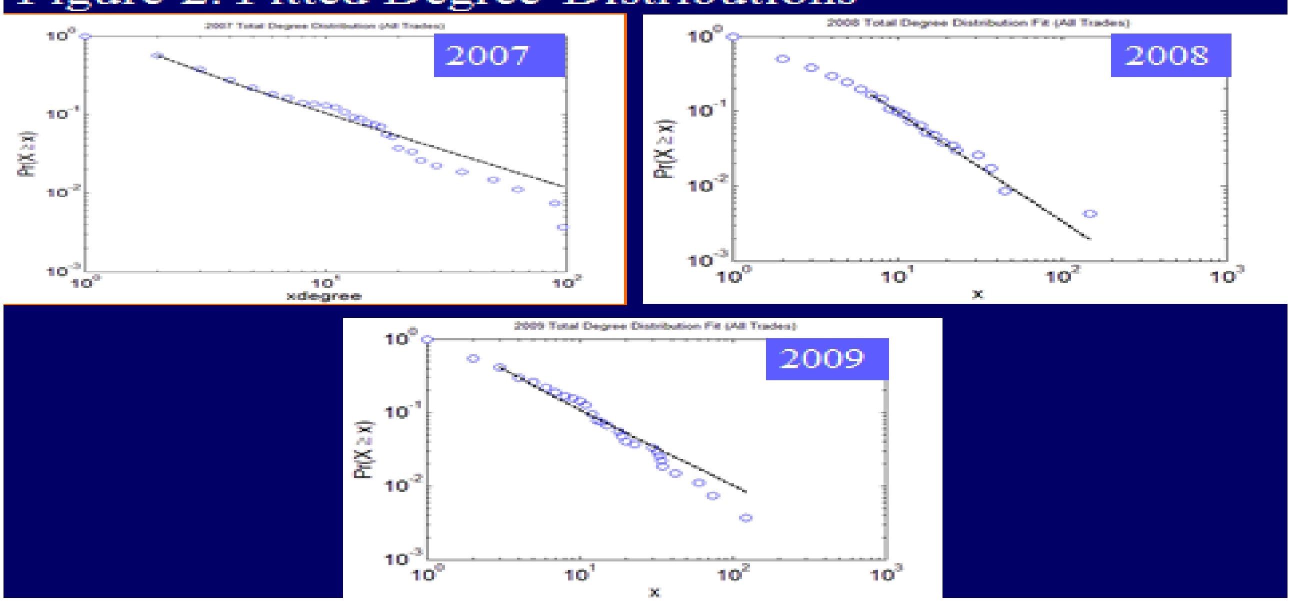
The next step in analyzing the allocation trading market was to determine the network structure. Network structure is determined by the degree (number of edges connected to a vertex) distribution and can be classified as either random or scale-free. Random networks, as the name implies, display seemingly random connections between vertices and a rather compact degree distribution with most vertices showing similar levels of degree (Watts, 1999). Scale-free networks contain a small number of highly connected vertices, or hubs, through which many of the interactions are funneled (Barabasi and Albert, 1998). An analysis of the degree distribution showed that the allocation trading networks exhibited a scale free structure with many of the trades involving highly centralized hub vertices.

Table 2 shows the results of fitting the degree distribution to a scale-free degree distribution for each year for out-degree (degree only includes leasing out transactions), in-degree (degree only includes leasing in transactions), and total degree (includes leasing in and leasing out). The analysis was done in MATLAB using fitting techniques developed by Clauset, Shalizi, and Newman (2009). The j min value is the lowest degree values used in the fitting and the alpha is simply the exponent on the power law distribution the data is estimated as ($P(k) \sim k^{-\alpha}$). The alpha values are roughly in the range of two to three as is usually found in real world networks that exhibit a power law distribution. The Kolmogorov-Smirnov statistic measures the distance from the empirical data to the normal scale-free distribution with the given alpha and number of observations. The data shows that the fit is fairly good across all degree distributions with only the 2009 out-degree distribution failing to fit at a .10 significance level. Figure 2 displays the fit of the total degree distributions relative to their respective scale-free distributions.

Table 2. Degree Distribution Fit Statistics.

	2007				*2008*				*2009*		
	Out	In	Total		Out	In	Total		Out	In	Total
j min	2	9	2		3	4	7		2	3	3
Alpha	2.1	3.2	1.93		2.02	2.35	2.43		1.88	2.16	2.01
Kolmogorov-Smirnov	0.064	0.087	0.049		0.099	0.075	0.056		0.106	0.094	0.082
N (# of observations)	194	143	269		162	134	232		198	157	270

Figure 2. Fitted Degree Distributions



The second piece of research involved using community detection techniques to determine if the allocation trading market was segmented. This analysis was undertaken because a preliminary analysis of allocation trading appeared to show a dysfunctional market where allocation prices did not obey the law of one price. In a commodity market, such as the red snapper allocation market, we would expect prices to fluctuate through time but show little variation around the time trend line. Figure 4 shows the priced trades, in dollars per pound, over the period analyzed with values below $.50/lb. and above $5.00/lb. excluded since they were either too low to represent an arms-length transaction, or, too high to be profitable for the buyer, respectively. Figure 4 shows a general increase in the average price of allocation through time but also a large amount of variation around the trend line. The price variation appears to show an inefficient market.

Market segmentation was analyzed using the modularity maximization approach of Clauset, Newman, and Moore (2004). 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 a number of node attributes including gender, age, race, or geographic location (Newman, 2010). Modularity is a measure between -1 and 1 that measures the level of assortative mixing. The 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. Modularity is calculated as follows:

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

In equation 1: 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, and $\delta(c_i c_j)$ 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 algorithm developed by Clauset, Newman, and Moore (2004) arranges the vertices into communities (c) so as to maximize the modularity of the network. For the current analysis minor components with less than four vertices were removed to avoid creating too many communities and biasing the modularity score upward[2].

[2] Minor components will always lead to an increased modularity value since they represent "true" subgroups in the network. While the minor components included in the analysis, those with 4 or more vertices, will lead to a higher modularity score there are only five of them for each year and they are large enough to be separate submarkets so they were included in the analysis.

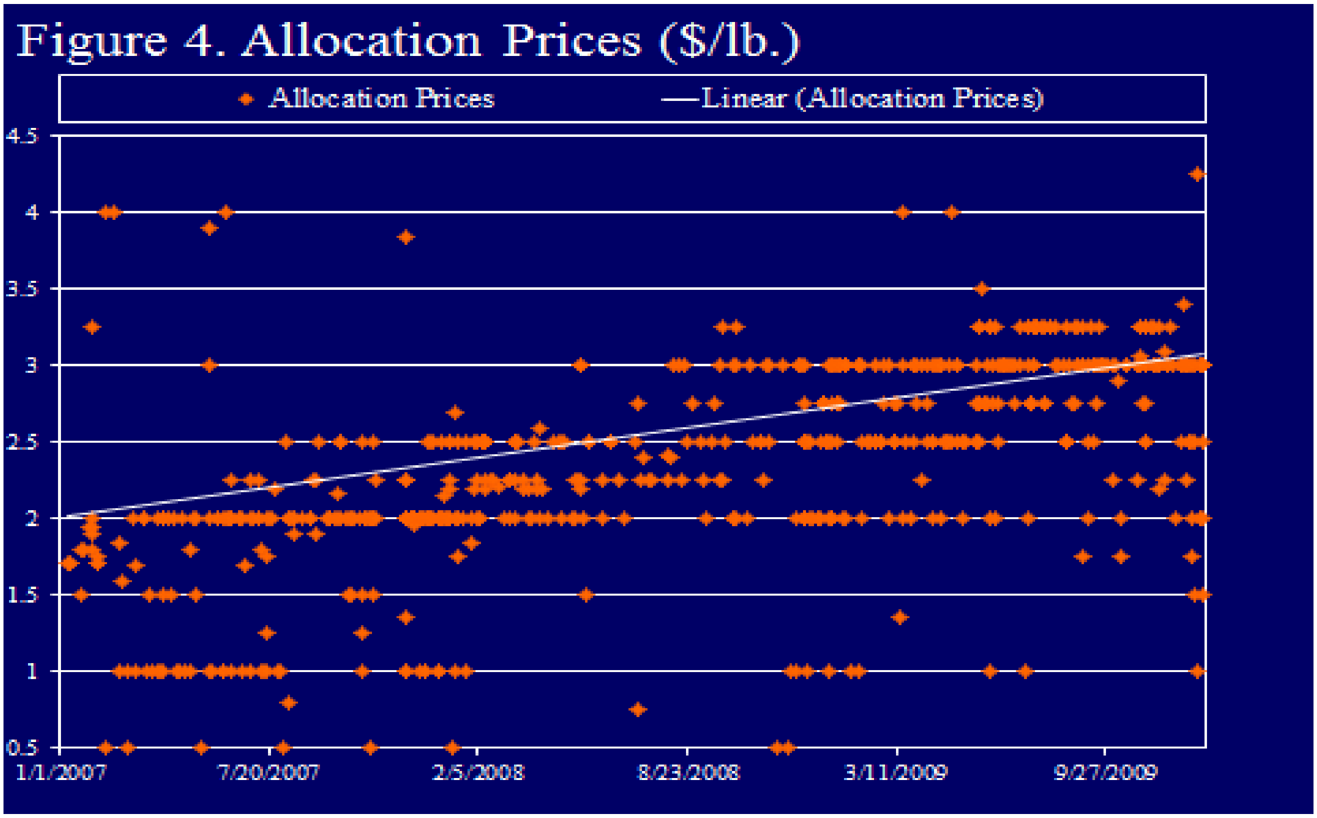


Figure 4. Allocation Prices ($/lb.)

Figure 5 displays the 2007 and 2009 networks (ORA visualizations) after the community detection algorithm was run and presents the modularity values in both cases. The modularity values (.8511 for 2007 and .8107 for 2009) are quite large and seem to indicate the trading network does have well defined communities.

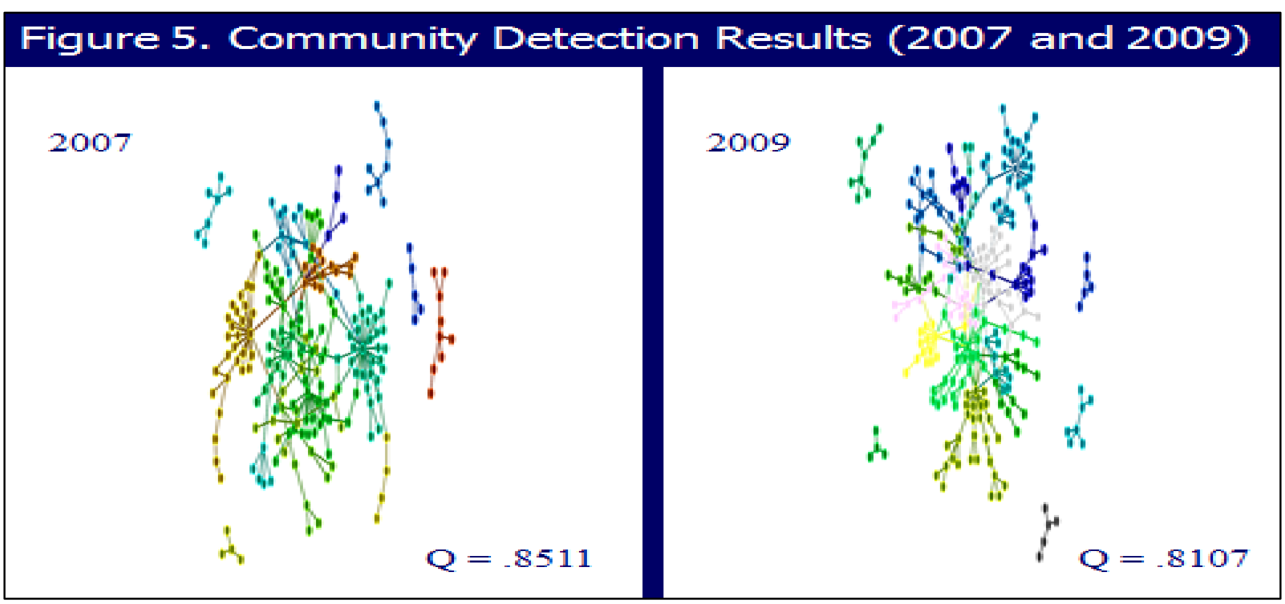
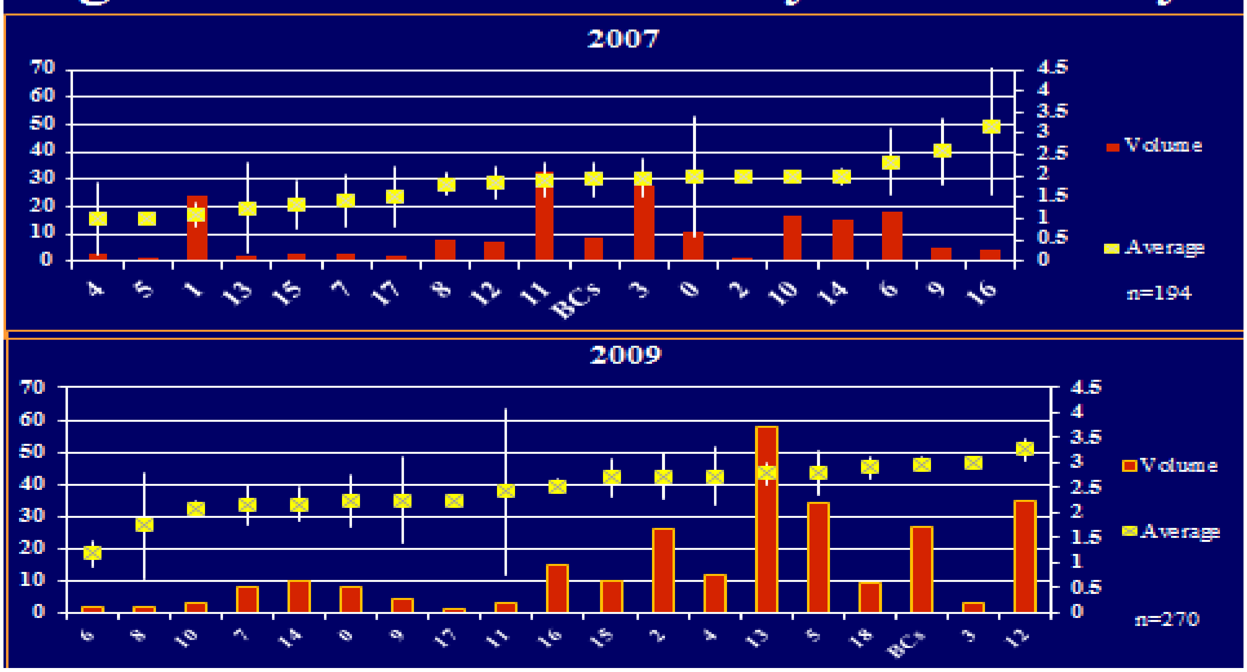


Figure 5. Community Detection Results (2007 and 2009)

The last step of the segmentation analysis was to determine if the different communities accounted for the price variation in the market. Figure 6 presents the priced trades by community for 2007 and 2009. The orange bars correspond to the volume of trades for each community which is measured by the left axis; the average price is represented by the yellow box measured by the right axis, the floating bar above and below the yellow box represents one standard deviation above and below the average price for the community being analyzed[3]. The data shows definitive differences in average prices for the different communities. In addition, the 2009 data shows a marked decrease in the price variation within communities, as measured by standard deviation; but only a small change in the average price discrepancies across communities. It appears that the law of one price became more clearly defined within communities but market segmentation allowed for continued price differences across regions. It is worth noting that the modularity maximization led to an average of approximately 18 communities per network. This led to a small number of trades in some communities so these preliminary results should be interpreted with this in mind.

Figure 6. Priced Trades by Community



[3] The numbers on the communities do not coincide with each other (2007 community 1 is not the same as 2009 community 1). In addition, the community labeled “BCs” are the trades that are between communities and not within communities.

The final objective of this research was to determine how IFQ management has changed participation in the fishery. A preliminary look at the roles participants in the red snapper IFQ market have assumed and how the importance of those roles have changed during the first three years was accomplished without the help of network analysis. Table 3 shows the percentage, by number of individuals, amount of quota holdings, and amount of total catch for 2007 and 2009 of six different types of market participants. One of the more interesting observations is the small size of the "pure" fishers, while this group makes up roughly a quarter of all market participants in 2009 they only account for 8% of the catch. Another interesting observation is the lack of what could be termed "pure" traders; however, it should be noted that some of the members of other groups that trade (allocation dependent fishers, investors, investor fishers, and supplementers) are quite active in the allocation market.

Table 3. Participant Types

		2007 (N=385)				2009 (N=353)		
Type	Description	Type	Quota	Landings		Type	Quota	Landings
Allocation Dependent	Fishers with over 50% of landings coming from allocation purchases.	20%	4%	25%		27%	2%	29%
Fisher	Only fishes, no allocation trading.	28%	10%	9%		23%	8%	8%
Investor	No landings, sells all quota as allocation.	26%	12%	0%		27%	20%	0%
Investor Fisher	Has landings, but sells some quota as allocation.	11%	39%	25%		11%	39%	27%
Supplementer	Has landings, but purchases some allocation (>50% of landings).	9%	31%	40%		8%	28%	35%
Trader	No landings, buys and sells equal amounts of allocation.	4%	2%	0%		2%	0%	0%

Discussion and Conclusions

This analysis found the red snapper IFQ allocation networks to be sparse, scale-free, and displaying little temporal variation in the network level metrics. The segmentation analysis showed a trading network that was highly segmented with the communities acting as submarkets that displayed different allocation prices, with the caveat that some of the communities had very few priced trades. Analysis of fishery participants found that by 2009 20% of the quota was held by entities that no longer fish and simply lease out their quota. Next steps in this analysis include: analyzing allocation prices with respect to vertex level metrics to determine if certain market participants have an informational advantage in the IFQ market that they can profit from, and performing the modularity maximization again with the number of communities capped at a lower level to see if modularity might remain relatively high with fewer communities allowing for more observations per community and more substantive results with the price analysis.

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