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Network Analysis of the Northeast Multispecies (Groundfish) Annual Catch Entitlement (ACE) Transfer Network (May 2010 – April 2016)

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
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1. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) broadly defines catch shares as "fishery management strategies that allocate a specific portion of the total allowable fishery catch to individuals, cooperatives, communities, or other entities. Each recipient of a catch share is directly accountable to stop fishing when its exclusive allocation is reached" (NOAA 2010, p. i). Evidence from global catch share programs suggests that, compared to traditional open-access approaches to fishery management, adopting this type of regulatory regime can lead to improvements in environmental, economic, and social conditions within the affected fisheries (e.g., Costello et al. 2008; Branch 2009; Essington 2010; Grimm et al. 2012; Brinson and Thunberg 2016). For example, a 2016 study assessing the socioeconomic performance of 16 US catch share fisheries found that average ex-vessel prices for all catch share-regulated species increased by 19% from baseline prices during the first year of catch share management, and average revenue per vessel earned from catch share-regulated species increased during the first year of catch share management for the majority (14) of the fisheries evaluated (Brinson and Thunberg 2016). This analysis also revealed that 11 of the examined fisheries experienced significantly longer fishing seasons during the first year of catch share management compared to baseline values, suggesting that catch share management may have given operators in these fisheries the flexibility to operate more safely and avoid the "race to fish" (Brinson and Thunberg 2016).

In 2010, the NOAA Catch Share Policy was released in order to provide guidance on the formation and implementation of catch share management programs in the United States (NOAA 2010). Included in this policy is a list of 9 guiding principles to be followed when designing and evaluating US catch share programs (NOAA 2010). One of these guiding principles has to do with the transferability of fishing quotas; specifically, the policy advises that Fishery Management Councils "should thoroughly assess the range of options and net benefits of allowing transferability of catch shares" when designing catch share management plans (NOAA 2010, p. iii). Studies on catch share programs have demonstrated that quota transferability provisions may result in a number of social and economic impacts to fishery stakeholders. One of the goals of many individual transferable quota (ITQ) programs is to reduce overcapitalization and excess capacity in the affected fisheries (McCay 1995). This outcome may be accomplished, in part, as less efficient operators sell or lease their shares to more efficient operators (McCay 1995; Salvanes and Squires 1995; Grafton 1996; Squires et al. 1998; Grimm et al. 2012; Emery et al. 2014; Acheson et al. 2015). While this approach may increase the overall economic efficiency of the fishery, concentration of quota ownership can also lead to less desirable socioeconomic impacts such as reduced employment in the fishery, diminished small-boat participation, increased barriers to new entrants, regional shifts in fishing effort and capacity, threats to cultural heritage, and perceptions of inequity amongst fishery constituents (McCay 1995; NRC 1999; Eythórsson 2000; McCay 2004; Yandle and Dewees 2008; Sumaila 2010; Olson 2011). Transferable quotas can be particularly important in multispecies fisheries, as share transferability can enable fishery participants to tailor their fishing portfolios to better match the mix of species that they encounter at sea (Squires et al. 1998; Sanchirico et al. 2005). In order to better understand how the impacts of share transferability may be distributed amongst participants in catch share fisheries, it can be helpful to first gain an understanding of how quota moves between these participants.

Reviews of several US catch share management programs have relied on social network analysis techniques to visualize patterns in quota transfers and examine how these patterns have evolved over time. The Red Snapper Individual Fishing Quota (IFQ) Program 5-year Review used network analysis in order to analyze share transfer relationships between fishery participants from 2007 – 2011 (GMFMC and NMFS 2013). The Atlantic sea scallop Limited Access General Category (LAGC) IFQ Program Review for fishing years 2010 - 2015 used a similar technique to investigate how relationships amoung fishermen and relationships between fishermen and processors changed during 2010 – 2015 (NEFMC and NMFS 2017), and the Twenty-Year Review of the Pacific Halibut and Sablefish IFQ Management Program recommended that social network analysis be used in the future to examine patterns in quota share transfers (NPFMC and NMFS 2016).

This research focuses on the sector management program regulating the northeast multispecies (groundfish) fishery. Sector management is a type of catch share program in which quota (called Annual Catch Entitlement, or "ACE") is allocated annually to groups known as "sectors" that operate similarly to harvest cooperatives. In a manner similar to that of other catch share program reviews, this report uses social network analysis to examine ACE trading within the northeast groundfish fishery. The primary purpose of this analysis is to begin to explore patterns in how ACE moves between groundfish sectors. Specifically, this report attempts to: (1) characterize the structure and composition of the groundfish ACE transfer network, (2) track changes in network metrics over time, and (3) identify which sectors occupy various positions in the groundfish ACE transfer network. This paper provides background information about groundfish management and a general treatment of social network analysis methods. In the final 2 sections, findings from the network analysis are reported and followed by study conclusions and recommendations for further research.

2. BACKGROUND

2.1 Management of the Groundfish Fishery

The groundfish fishery is managed under the Northeast Multispecies Fishery Management Plan (FMP), 1 of 10 management plans administered by the New England Fishery Management Council (NEFMC).[1] Thirteen species of large-mesh groundfish, known collectively as the "groundfish complex," are managed under the Northeast Multispecies FMP:

- Cod (*Gadus morhua*)
- Haddock (*Melanogrammus aeglefinus*)
- Yellowtail flounder (*Limanda ferruginea*)
- Pollock (*Pollachius virens*)
- American plaice (*Hippoglossoides platessoides)*
- Witch flounder (*Glyptocephalus cynoglossus*)
- White hake (*Urophycis tenuis*)
- Windowpane flounder (*Scophthalmus aquosus*)
- Winter flounder (*Pseudopleuronectes americanus*)
- Acadian redfish (*Sebastes fasciatus*)
- Atlantic halibut (*Hippoglossus hippoglossus*)
- Atlantic wolffish (*Anarhichas lupus*)
- Ocean pout (*Macrozoarces americanus*)

[1] Additional information on these management plans can be found on the NEFMC website

The groundfish complex comprises 20 distinct stocks. Three of these stocks are transboundary Georges Bank (GB) stocks (GB cod, GB haddock, and GB yellowtail flounder) which are managed jointly with Canada under the US/CA Resource Management Understanding.

Most of the groundfish that are landed commercially in the Northeast are caught in the Gulf of Maine and in Georges Bank, but fishing also occurs in Southern New England and along the Mid-Atlantic Bight (Figure 1). Vessels targeting groundfish vary in size, generally ranging from 30' to 75' in length. Groundfish are harvested with several different types of fixed and mobile gear, depending on the species being targeted and the area being fished. Bottom trawl gear is most commonly used by vessels targeting groundfish, but additional gear types include sink gillnets, bottom longlines, and rod and reel gear.

The Northeast Multispecies FMP was originally implemented in 1986; since its inception, the FMP has been updated through a series of annual framework adjustments and plan amendments. For several decades, fishing activity under limited access groundfish permits was regulated by using traditional input controls such as area closures, gear restrictions, trip limits, and days-at-sea (DAS) constraints. Amendment 13 to the Northeast Multispecies FMP, implemented in 2004, contained a number of significant changes to groundfish regulations. Amendment 13 reduced baseline DAS allocations, created additional DAS categories, established DAS transfer and DAS leasing programs, and introduced sector management to the groundfish fishery, among other changes. Under sector management, northeast multispecies permit holders could voluntarily organize themselves into self-governing harvest cooperatives called "sectors." Under Amendment 13, sectors would receive a hard annual Total Allowable Catch (TAC) for each requested groundfish stock based on the fishing history of the permits collectively enrolled in that sector. Importantly, in return for accepting a hard TAC, sectors were able to request exemptions from effort controls such as trip limits, DAS, and gear restrictions. As a whole, each sector was responsible for ensuring that its members did not exceed the sector's collective allocation of the requested stocks. The Georges Bank Cod Hook Sector was the first sector to be authorized in 2004[2], and the Georges Bank Fixed Gear Sector became the second in 2007[3]. These 2 sectors requested allocation only to a single stock, which was Georges Bank cod. These 2 sectors later merged into 1, the GB Cod Fixed Gear Sector, in 2010.

Amendment 16 to the Northeast Multispecies FMP, which took effect on May 1, 2010, contained several substantial updates to federal groundfish regulations. First, Amendment 16 established acceptable biological catches (ABCs), annual catch limits (ACLs), and accountability measures (AMs) for all 20 stocks managed under the groundfish FMP. Additionally, Amendment 16 expanded the existing sector management program into a larger system of catch share management and required allocations to all stocks, which removed the option to selectively choose among stocks sectors could request. Under this management regime, limited access groundfish permit holders are given the option to enroll their permits in a sector or in the "common pool." Fishing effort by members of the common pool is still constrained by using traditional effort controls, but members of groundfish sectors are exempt from many of these measures. Instead, fishing activity by sector members is primarily managed through the use of hard TACs. Every year, each sector receives an allocation for 15 of the 20 stocks contained in the groundfish complex[4]. These sector allocations, called Annual Catch Entitlements (ACE), represent

[2] For additional details on the authorization of the Georges Bank Cod Hook Gear Sector, see 69 FR 22905.
[3] For additional details on the authorization of the Georges Bank Cod Fixed Gear Sector, see 72 FR 26563.
[4] *Allocated stocks*: Gulf of Maine (GOM) cod; Georges Bank (GB) cod; GOM haddock; GB haddock; Cape Cod/Gulf of Maine (CC/GOM) yellowtail flounder; GB yellowtail flounder; Southern New England/Mid-Atlantic

percentages of each groundfish stock's total ACL that the members of a sector can collectively harvest during a given fishing year. A sector's ACE varies depending on the permits which are enrolled in that sector. Each limited access permit is linked to a Moratorium Rights Identifier (MRI), a unique identification number that tracks a permit's fishing history, specifications, and eligibility. National Marine Fisheries Service (NMFS) uses the fishing history of a permit according to its MRI to calculate that permit's Potential Sector Contribution (PSC). PSC is a percentage of each groundfish stock's ACL that the permit is allowed to catch based on that permit's fishing history from 1996-2006. A sector's ACE is calculated by summing the PSCs of all the permits enrolled in that sector. Amendment 16 specified that any northeast multispecies permit holder that held a limited access groundfish permit as of May 1, 2008 was eligible to join a sector. In total, 17 groundfish sectors were approved and operated in 2010, the first year of sector management.

Amendment 16 included provisions that allow ACE to be traded between members of the same sector, and that allow ACE to be traded between sectors, on an annual basis. Intra-sector ACE transfers are handled internally within the sector and do not require NMFS approval to be finalized, as each sector is tasked with the responsibility of deciding how its cumulative ACE allocation should be distributed amongst its members. Inter-sector ACE transfers, on the other hand, must be approved by NMFS before they can be completed. Details pertaining to the amount of ACE traded and compensation exchanged are at the discretion of the sector. Sectors can trade ACE at any point during the fishing year, up to 2 weeks after the close of the fishing year on April 30.

Most sectors have adopted a right of first offer or right of first refusal system regarding ACE transfers. In general, this means that whenever a sector member wishes to transfer his/her portion of the sector ACE outside of the sector, they must give their fellow sector members the opportunity to match the trade offer and retain the ACE within a sector. Additionally, when a member of one of the Northeast Fishery Sectors (NEFS I - XIII), who are all members of the Northeast Sector Service Network, wishes to transfer ACE to a non-NEFS sector, right of first offer is extended to members of the other NEFS sectors as well as members of the transferor's own sector. Similarly, when a member of a Sustainable Harvest Sector (SHS 1-3) wants to transfer ACE to a non-SHS sector, all SHS members retain the right of first refusal. Furthermore, the NEFS sectors have also included provisions in their Sector Operations Plans restricting non-active members' ability to participate in the ACE transfer network. The majority of these sectors specify that non-active sector members may only participate in inter-sector ACE transfers as long as the transfer results in a net increase to their sector's ACE, and they may not lease ACE in from other members of their sector. NEFS 4, which operates as a lease-only sector, states that members may only transfer ACE to active sector members, unless written approval to do otherwise is secured from the Sector Board of Directors. The aforementioned provisions were initially devised by sectors and their affiliated administrators with the intent to maximize the benefits to their own members by retaining sector ACE internally.

The transferability of ACE is crucial to the performance of the sector management program. Once a sector has exceeded its ACE for a particular stock, that sector must cease all fishing activity in the pertinent stock area. Fishing activity in that stock area may resume once the sector has secured additional ACE from another sector. If the sector is unable to account for this

(SNE/MA) yellowtail flounder; pollock; American plaice; witch flounder; white hake; GOM winter flounder; GB winter flounder; SNE/MA winter flounder; redfish. *Non-allocated stocks*: GOM/GB (northern) windowpane flounder; SNE/MA (southern) windowpane flounder; Atlantic halibut; Atlantic wolffish; and ocean pout.

overage by the conclusion of the fishing year, the amount of the overage gets deducted from that sector's allocation in the following fishing year. ACE trading enables sectors to obtain the ACE they need to account for accidental overages, to continue fishing, and to avoid being penalized in the following year. Additionally, the ability to trade ACE gives sectors the flexibility to adjust their fishing portfolios based on prevailing ecological and economic conditions.

2.2 Social Network Analysis

Any group of objects (nodes) connected to one another via edges (links, ties) creates a network. In a social network, the nodes represent a set of actors (e.g., individuals, groups, organizations), and the ties represent the formal or informal relationships which connect those actors (Brass et al. 1998; Weber and Khademian 2008). Social network analysis is a technique that allows researchers to visualize social networks and measure patterns in the relationships between participants in order to better understand the structure and function of those networks (Hanneman and Riddle 2005).

There are numerous compositional and structural metrics that can be computed in order to describe a social network and track its evolution over time. In terms of the compositional components of the network, details on the number of nodes and ties contained in the network can provide a preliminary picture of how large the network is and how connected its participants are. Another measure of network composition is the number of isolates, or nodes without ties to any other nodes, that are present in a social network (Hanneman and Riddle 2005). A high proportion of isolates can indicate that a network is not highly connected and that many potential ties between node pairs are not being realized (Hanneman and Riddle 2005).

In terms of the structural characteristics of a social network, there are several different metrics that can be calculated in order to examine the level of cohesion present in a network. The first of these characteristics is network density, or the ratio of existing ties to potential ties in a network, which is calculated by dividing the total number of ties present in a network by the total number of possible ties in that network (e.g., Freeman 1982; Granovetter 1983; Scott 1987; Wasserman and Faust 1994; Abrahamson and Rosenkopf 1997; Scott 2000; Bodin and Crona 2009). Therefore, as more potential ties are actualized in a network, that network becomes denser (Granovetter 1983). Network density provides a measure of the overall level of interaction, connectedness, or cohesiveness between network participants (Bott 1957; Freeman 1982; Scott 1987; Sparrowe et al. 2001; Bodin et al. 2006; Bodin and Crona 2008; Borgatti et al. 2009). Network density has been positively linked to level of trust between the actors in a network (Bodin et al. 2006). Trust can help to reduce the transaction costs affiliated with collaboration, mobilize resources, and inspire reciprocity between individuals in a social network (Abrahamson and Rosenkopf 1997; Pretty and Ward 2001). In addition, higher density networks are generally less vulnerable to disruption when an actor is lost (Bodin et al. 2006).

Another way to measure network cohesion is to examine the percentage of reciprocal ties that are present within that network. The ties connecting actors in a social network can either be directed or undirected. Undirected ties indicate the presence of a symmetric relationship between 2 actors (Hanneman and Riddle 2005). In other words, if Actor A declares a connection to Actor B, Actor B is also connected to Actor A in the same fashion. Directed ties originate at one node and terminate at another; these ties are not necessarily reciprocated by both actors (Hanneman and Riddle 2005). Therefore, even if Actor A declares a connection to Actor B, Actor B may not necessarily declare the same connection to Actor A. Reciprocated ties are believed to be more stable than asymmetrical ties, and a higher level of reciprocity may be indicative of a more cohesive network (Hanneman and Riddle 2005).

Some structural characteristics of a social network can help to indicate how power is distributed throughout that network. Network centralization is a measure of the variability in the centrality scores of each individual node in a social network (Bodin and Crona 2009). Therefore, a highly centralized network will include nodes with both very high and very low individual centrality scores (Bodin and Crona 2009). Network centralization can be calculated based on a variety of different types of node centrality, such as degree centrality or betweenness centrality. Research suggests that highly centralized networks may be well-equipped to solve simple problems or react to changes because high centrality actors can act as leaders and coordinators within the network (Leavitt 1951; Feinberg et al. 2005; Bodin et al. 2006). This structure may enable highly centralized networks to organize themselves and determine their priorities more quickly than less centralized networks (Leavitt 1951; Sandström and Carlsson 2008).

While details on network composition and structure can provide insight into how the network functions as a whole, individual node characteristics can help reveal some of the patterns and dynamics dictating the overall structure. An actor's position in a social network can indicate how much relative influence that actor holds and the accessibility of information and resources within that network (Bodin and Crona 2009). There are several node characteristics that can be used to measure influence within a social network. The first of these characteristics is degree centrality, or the number of ties that a node possesses (Bodin and Crona 2009). In a directed network, degree centrality can be broken into in-degree centrality and out-degree centrality. In-degree centrality measures the number of ties coming into a node, while out-degree centrality measures the number of ties originating from a node (Hanneman and Riddle 2005). Degree centrality is indicative of how involved an actor is in a social network (Ernstson et al. 2008). An actor with high degree centrality is connected to many other actors, which may make it easier for that actor to access resources and guide collective actions (Ernstson et al. 2008).

Another node characteristic that can be used to assess an actor's level of influence in a network is betweenness centrality. Betweenness centrality measures the degree to which actors "serve as bridges or brokers connecting pairs of actors in the network" (Feinberg et al. 2005, p. 286). Actors with high betweenness centrality occupy a network position connecting many pairs of otherwise disconnected nodes (Freeman 1978/79), and they are often referred to as "broker nodes" (van Putten et al 2011). Betweenness centrality is a useful measure of influence because even if an actor has relatively low degree centrality (i.e., relatively few connections to other actors), a high betweenness centrality can indicate that the ties that actor does possess are valuable in terms of bridging gaps in the network (Smythe et al. 2014).). Broker nodes tend to have the ability to access a wide array of resources and information through their connections (Bodin and Crona 2009). Additionally, because of their positions as bridges between other actors, broker nodes have the power to influence the flow of information and resources through the network (Bodin and Crona 2009; Ernstson et al. 2008; Freeman 1978/79).

2.3 Social Networks and Fisheries Research

The use of social network analysis methodology has gained traction in natural resource governance literature in recent years, as research suggests that the presence of social networks with certain characteristics may help increase community resilience and facilitate collaboration amongst resource management stakeholders (Tompkins and Adger 2004; Newman and Dale 2005;

Bodin et al. 2006). In terms of fisheries-specific research, scientists have used social network analysis techniques to examine topics such as information sharing between UK fishermen (Turner et al. 2014), adaptability of small-scale fishermen to changes in resource abundance in Mexico (Lasseter 2008), site selection by recreational fishermen in Nebraska (Martin et al. 2017), stakeholder participation in Great Lakes fishery management (Mulvaney et al. 2015), and resource access patterns in Alaskan fishing communities (Himes-Cornell and Santos 2017).

Other researchers have used network analysis specifically to examine patterns in resource markets that arose following the implementation of catch share management programs. A 2011 study by van Putten et al. used network analysis to examine patterns in the rock lobster trap tag lease market in Tasmania and found that over time, the market gradually became larger, more connected, and more active. Additionally, researchers found that as the demand for quota grew, the network became more reliant on broker nodes to facilitate the movement of resources between network participants (van Putten et al. 2011). Vignes and Etienne (2011) used network analysis to examine price setting in a Marseille fish market and found that sellers with higher centrality scores tended to receive the highest prices. Finally, Ropicki and Larkin (2014) used social network analysis to investigate price dispersion in the Gulf of Mexico red snapper quota lease market. Findings indicated that buyers and sellers with more negotiating power tended to receive better prices in the red snapper quota lease market; this ability translates as higher prices for sellers, and lower prices for buyers (Ropicki and Larkin 2014). Individuals' negotiating power is impacted by the amount of information they have about the market, and network analysis data suggest that number of trade partners may impact access to market information more strongly than number of trades (Ropicki and Larkin 2014).

It is worth noting that studies using social network analysis techniques to examine resource markets focus on networks that are built on potentially adversarial relationships. Participants in resource transfer networks are connected through business relationships, which may involve an unknown degree of haggling over price or quantity of the goods being exchanged. While both parties theoretically benefit from these relationships (e.g., one party receives a necessary resource, and the other party receives compensation for that resource), what is best for the transferor may not always be what is best for the transferee, and vice-versa. The dynamics shaping these networks may therefore be quite different from those shaping a network connected through less contentious relationships, such as friendships, family ties, or information sharing.

3. METHODS

Although each sector is tasked with managing its own ACE allocation, all inter-sector ACE transfers must be approved by the NMFS prior to completion. Sector managers may submit transfer requests via paper copies of the ACE Transfer Request form or through an electronic portal called the Sector Information Management Model (SIMM). The Greater Atlantic Regional Fisheries Office (GARFO) maintains thorough records of all inter-sector ACE transfers, some details of which are publically available for download from the GARFO website. These data include information on:

- The identities of the sectors transferring and receiving ACE
- The stock(s) being traded
- The amount (in live pounds) of ACE being traded
- The date when the ACE transfer was initiated

- The date when the ACE transfer was completed

GARFO ACE transfer summary data are updated daily, and records are available dating back to the implementation of the catch share program in 2010. For the purposes of this network analysis, ACE transfer data from 2010 – 2015 were downloaded and separated by fishing year.

Once prepared, the data were organized into a series of 6 adjacency matrices, 1 for each fishing year during 2010 - 2015. An adjacency matrix is a table which lists all possible pairs of actors in a given network, as well as the presence or absence of a relationship linking each pair (for example, see Table 1). In this case, adjacency matrices listed every groundfish sector that operated during each fishing year and indicated whether a transfer of ACE had occurred between each pair of sectors. Each adjacency matrix was subsequently uploaded to UCINET 6 (Borgatti et al. 2002) for analysis, and the accompanying network visualization software, NetDraw, was used to generate sociograms depicting annual ACE transfer networks.

Several sector attributes were compiled and used to describe the sectors participating in the groundfish ACE transfer network. First, each sector's initial ACE allocation was computed for each fishing year. Initial ACE allocations were calculated by summing the PSCs of all the permits enrolled in each sector during each fishing year.[5] The number of MRIs enrolled in each sector was also tallied for each fishing year.[6] Sectors were binned into groups based on whether they were SHS sectors, NEFS sectors, or other[7] sectors. Additionally, during each fishing year, each sector was classified as being either an active sector, a lease-only sector, or a permit bank sector. Active sectors are sectors that contain at least 1 member who took at least 1 sector trip[8] in a given fishing year. Lease-only sectors are sectors whose members did not take any sector trips during the fishing year, and permit bank sectors are state-operated permit banks whose purpose is to make ACE available for lease by members of other groundfish sectors. Finally, every sector was determined to be either a net importer or a net exporter of ACE during each fishing year. Net importer refers to a sector that transferred more ACE in than out in a given fishing year, while a net exporter refers to a sector that transferred more ACE out than in during that year.

4. RESULTS AND DISCUSSION

In total, 22 sectors were approved and operated in at least 1 year during 2010 – 2015; 14 sectors operated continuously during all 6 years of the time series (Table 2). Each sector actively participated in the groundfish ACE transfer network at least once during this 6 year study period. In other words, each sector either transferred ACE to, or received ACE from, another sector during 2010 – 2015. In terms of the number of MRIs enrolled in each sector annually, the FGS, NEFS 2, NEFS 3, and SHS 1 sectors tended to be the largest sectors throughout most years in this time series (Figure 2). In terms of live lbs. of ACE allocated annually to each sector, the FGS, NEFS 2, NEFS 9, NEFS 13, and SHS 1 sectors tended to receive the largest annual ACE allocations throughout most years in this time series (Figure 3). Most sectors experienced an overall decline

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[5] PSC data are publically available for download on the GARFO PSC webpage.
[6] MRI enrollment data is publically available for download on the GARFO PSC webpage.
[7] SHS sectors include SHS, SHS 1, and SHS 3. NEFS sectors include NEFS 1 – NEFS 13. Other sectors include FGS, NCCS, MEPB, NHPB, PCCS/MCCS, and TSS.
[8] A sector trip is defined as "a trip declared into the NE multispecies fishery (either under a groundfish DAS or as a sector vessel) via a Vessel Monitoring System (VMS) or the Interactive Voice Response System (IVR), as applicable, by a vessel participating in an approved sector on which the groundfish catch counts against a sector's ACE for that stock." For more detail, please see the GARFO Sector Trip Information Sheet.

in the absolute amount of ACE they received in their annual initial allocations; this decline was due to the fact that the ACLs for many key groundfish stocks were reduced during this study period.

Both the number of MRIs and the amount of ACE attributed to each sector varied yearly for most sectors throughout 2010 – 2015. Annual changes in the number of MRIs attributed to each sector likely occurred in part as permit holders changed their operational status from year-to-year. Permit holders may have opted to move from one sector to another, they may have opted to move between a sector and the common pool, or they may have chosen to stop participating in the fishery altogether. Additionally, changes in the number of MRIs enrolled in each sector may be due to changes in permit ownership over time. While all sectors experienced annual variations in MRI enrollment and ACE allocations, the change in the number of MRIs enrolled in SHS 1 and SHS 3, as well as the change in the amount of ACE allocated to each of these sectors, was particularly striking in 2015. These changes are due to an adjustment in the management of the SHS sectors. During 2010 – 2014, SHS 3 operated as a smaller lease-only sector and SHS 1 operated as a larger active sector. In 2015, SHS 3 began operating as an active sector, and both sectors implemented new voluntary fishing restrictions for their respective members. Many of the permits previously enrolled in SHS 1 moved to SHS 3.[9]

4.1 Network Composition

Throughout 2010 – 2015, the groundfish ACE transfer network was fairly connected and active (Figure 4). In total, there were 281 unique ties formed between node pairs in the groundfish ACE transfer network during 2010 – 2015 (Figure 4). The majority (188 ties, 67%) of these ties were repeat relationships, meaning they were formed in at least 2 separate years, while the remaining 93 ties were realized during only 1 year (Figure 5). When examining relationship length, it is important to remember that not all sectors operated during every year from 2010 – 2015, and some sectors never operated concurrently. Therefore, a relationship that appears objectively short may actually represent the maximum amount of time that 2 sectors could interact with one another. For example, Northeast Fishery Sector 1 (NEFS 1) only operated during the final 2 years of the study period (2014 and 2015). Therefore, the maximum relationship length that NEFS 1 could have achieved with any other sector was only 2 years. The fact that the majority of the ties in this network were repeated throughout multiple years might indicate that each sector's ACE needs remained fairly constant over time. If this were the case, ACE transfer participants may have learned from past history and repeatedly leased ACE to and/or from the same trade partners year after year. The large number of repeat relationships present in this network also may suggest that trade loyalties formed between certain sectors or between certain sector members over time.

When broken down by fishing year, data show that the groundfish ACE transfer network underwent several compositional changes throughout 2010 – 2015 (Table 4; Figure 6). The number of ties composing the groundfish ACE leasing network varied annually during 2010 – 2015, rising from 129 ties in 2010 to a 6-year high of 164 ties in 2011 (Table 4; Figure 6). The number of ties in the ACE transfer network declined to a low of 124 ties in 2014, and ultimately rose to 139 ties in 2015 (Table 4; Figure 6). Variations in the annual number of ties present in the network closely reflect fluctuations in the total number of ACE transfers conducted within each fishing year. Generally speaking, the number of ties in the network increased as the number of annual transfers

[9] For more details, please see the SHS 3 Membership Contract for Fishing Years 2015 - 2016 and the SHS 1 Membership Contract for Fishing Years 2015 - 2016.

increased. In other words, it appears that more individual ACE transfers means more opportunities for unique trade relationships to be formed.

The number of nodes composing the groundfish ACE transfer network also fluctuated throughout the first half of the study period, rising from a low of 17 nodes in 2010 to a high of 20 nodes in 2012 (Table 4; Figure 6). In 2013, the number of nodes present in the network dropped to 19, and this number stayed constant throughout the rest of the time series (Table 4; Figure 6). Variations in the number of nodes present in the network were the direct result of changes in the number of sectors that were approved and operated during each fishing year. Each sector participated in at least 1 inter-sector ACE transfer during every year that it operated, so there were no isolates present at any point during 2010 – 2015 (Figure 6). During every year except 2012, the number of nodes that were net exporters of ACE exceeded the number of nodes that were net importers of ACE (Table 4).

There are many underlying factors that might impact the composition of the groundfish ACE transfer network. Some of these changes in network composition could reflect the fact that there was an adjustment period following the transition to catch share management during which sector members were learning how to manage their fishing businesses and sector managers were learning how to manage the needs of their respective members. For example, the fact that the number of unweighted ties in the network was at its second-lowest point in 2010 suggests that sector members and managers may not have known how to accurately anticipate their ACE needs during the first year of catch share management, how to advertise available ACE, how to find needed ACE, or how to negotiate trade compensation. The uptick in the number of ties (164 ties, +35 from 2010) and the number of inter-sector ACE transfers (1,345 transfers, +272 from 2010) in 2011 may signify that members and managers became more familiar with the ACE market and their ACE needs during the first year of catch share management, and therefore they may have been more willing to participate in ACE trading. The fact that the number of ties and transfers declined after 2011 may indicate that members and managers learned how to balance their ACE portfolios more efficiently over time, and they were able to achieve their ACE needs through fewer transactions with fewer partners. Additionally, the number of unique ties in the network may have declined over time as sector members and managers formed loyalties to certain ACE trading partners.

Compositional changes in the groundfish ACE transfer network may also reflect changes in the fishing activity of the vessels enrolled in groundfish sectors. Data show that 292 sector vessels took at least 1 groundfish trip[10] in 2010, but by 2015 this number had declined to 206 sector vessels (Murphy et al. 2018). Additionally, the number of groundfish trips taken by sector vessels declined from 11,239 trips in 2010 to 7,471 trips in 2015 (Murphy et al. 2018). If the vessels enrolled in sectors took fewer targeted groundfish trips over time, and/or if fewer sector vessels remained active in the groundfish fishery over time, each groundfish sector's annual ACE requirements may have changed and the need to transfer ACE into/out of the sector may have diminished. Regulatory changes in the way that groundfish stocks are managed may also have impacted the composition of the ACE transfer network. For example, the total number of unweighted ties in the network was at its lowest (124 ties) in 2014. In November 2014, an interim action[11] was implemented in the northeast groundfish fishery to decrease fishing mortality for

[10] A groundfish trip is defined, in this report, as "a trip where the vessel owner or operator has declared, either through the vessel monitoring system (VMS) or through the interactive voice response system, that the vessel was making a groundfish trip" (Murphy et al. 2018, p. 16).
[11] For more details about this interim action, please see 79 FR 67362.

GOM cod. Specifically, this action implemented time and area closures in the GOM, established trip limits for GOM cod, restricted trip declarations in the GOM, established a zero-possession limit for recreationally caught GOM cod, and revoked exemptions for sector vessels fishing with gillnets in the GOM. These regulatory constraints, among others, may have restricted fishing activity in such a way to impact sector fishermen's ACE needs.

4.2 Network Structure

4.2.1 Network Density

In addition to the compositional changes discussed in Section 4.1, several separate network metrics were computed in order to describe the structure of the groundfish ACE transfer network over time. Network density is a measure of network cohesion which calculates the ratio of realized ties to potential ties in a network; higher network density indicates a more cohesive network (e.g., Freeman 1982; Granovetter 1983; Scott 1987; Wasserman and Faust 1994; Abrahamson and Rosenkopf 1997; Scott 2000; Bodin and Crona 2009). During the period from 2010 – 2015, the density of the groundfish ACE transfer network fluctuated but remained quite high, indicating that this network is fairly interconnected. Throughout this 6-year period, network density ranged between 0.363 - 0.480 annually (Table 4). In other words, in every year from 2010 – 2015, between 36.3% and 48.0% of the potential ties that may have existed in the network were actualized via an ACE transfer from one sector to another. The density of the groundfish ACE transfer network was at its highest in 2011 and at its lowest in 2014 (Table 4). Overall, the groundfish ACE transfer network became slightly less dense throughout the time series, falling from 0.474 in 2010 to 0.406 in 2015 (Table 4).

The fact that the density of the groundfish ACE transfer network remained relatively high throughout this time series likely has to do in part with the size of the network. Generally speaking, larger networks with more participants tend to be less dense, as it is logistically more challenging for participants to form connections with large numbers of others (Smythe et al. 2014). Additionally, the relatively high density of this network may indicate that it is fairly easy for sector members to locate trade partners and negotiate trade terms. This tendency is likely due, in part, to the administrative structure of groundfish sectors. Each groundfish sector appoints a sector manager, whose responsibilities include (but are not limited to) overseeing day-to-day sector business, ensuring compliance with sector operations plans, monitoring sector landings and discards, and communicating with NMFS. Sector managers also help arrange transfers of ACE within their own sector, and transfers of ACE between their sector and other sectors. This logistical assistance on the part of the manager likely facilitates ACE trading between members of different sectors, which could contribute to heightened network density.

Much like the observed changes in the composition of the ACE transfer network, variations in structural metrics such as network density may be linked in part to participants' level of experience with the sector management system. For example, sector members and sector managers may have learned to trade ACE more efficiently over time, enabling them to balance their annual ACE portfolios through fewer transactions with fewer partners. If this were the case, the percentage of potential ties that were actualized in the network could have declined, resulting in the observed decrease in network density. Similarly, network density may have declined over time if sector managers and members formed loyalties to specific trade partners and stopped trading ACE with a wide variety of other sectors. The overall reduction in ACE transfer network density could also be influenced in part by a shift in fleet demographics over time. As the size of the fleet and the amount of effort being directed into the fishery declined, sector members' ACE needs, and therefore their trading behavior, may have changed in ways that decreased overall network cohesion.

4.2.2 Tie Reciprocity

In general, ties that are reciprocated are considered to be stronger than one-way ties; therefore, a network containing a large number of reciprocated ties is believed to be more stable and cohesive than one with less reciprocity (Hanneman and Riddle 2005). In the case of the groundfish ACE transfer network, level of tie reciprocity indicates that the groundfish ACE transfer network was relatively stable during 2010 – 2015. During this time series, the percentage of ties that were reciprocated between node pairs remained fairly high, fluctuating between 59.7% - 76.0% annually (Table 4). Overall, percent tie reciprocity declined from 2010 – 2015, dropping from a 6-year high of 76.0% in 2010 to 64.7% in 2015 (Table 4). Percent tie reciprocity dropped to a 6-year low of 59.7% in 2014; this decrease is likely due in part to the corresponding 6-year low in network density in 2014, as fewer achieved relationships could mean less potential for reciprocated ties (Table 4). Similarly, percent tie reciprocity was at a 6-year high of 76.0% in 2010, which was the year that the network had the fewest nodes and the second-highest density score (Table 4).

The large number of reciprocated relationships in this network could suggest that ACE transfer participants are loyal to partners with whom they have successfully traded in the past. Alternatively, the high level of tie reciprocity present in the ACE transfer network may indicate that a large percentage of the ACE transfers that occur within this network are fish-for-fish transfers. In other words, rather than transferring fish for money, participants may frequently trade one stock of fish for another stock of fish as means of compensation. This would result in a reciprocated relationship in which quota was transferred in both directions between 2 nodes.

4.2.3 Network Degree Centralization

Network degree centralization measures the variability in the individual degree centrality scores of the nodes composing a network (Bodin and Crona 2009); therefore, a centralization score close to 1.00 (100%) indicates a network which is highly centralized. In the case of a directed network, network degree centralization is broken down into 2 separate components: in-degree centralization, and out-degree centralization. Overall, network in-degree centralization declined over the course of the time series, falling from 0.559 (55.9%) in 2010 to 0.451 (45.1%) in 2015 (Table 4). This decrease indicates that, over time the ACE transfer network became less organized around a small number of ACE recipients. Network out-degree centralization scores, on the other hand, increased slightly overall during this time series, rising from 0.293 (29.3%) in 2010 to 0.333 (33.3%) in 2015 (Table 4). This shift shows that over time, the groundfish ACE transfer network became more organized around a small number of ACE transferors. The fact that network out-degree centralization scores were consistently lower than network in-degree centralization scores indicates that the groundfish ACE transfer network is more centralized around ACE recipients (i.e., lessees, buyers) then it is around ACE transferors (i.e., lessors, sellers). In other words, a small number of sectors function as important quota recipients within this network, while a larger number of sectors play an important role as quota providers.

Annual fluctuations in network in-degree and out-degree centralization could be due in part to yearly changes in fishing regulations. If adjustments to federal regulations, such as cuts to stock ACL, lead groundfish fishermen to change the extent to which they target various groundfish species, this factor could impact their annual ACE requirements and their resulting ACE transfer behavior. Annual adjustments to fishing regulations could impact each sector's relative importance as an ACE buyer or a seller, based on the mix of stocks in that sector's initial ACE allocation. The resulting shifts in the mix of influential buyers and sellers could alter overall network in-degree or out-degree centralization from year to year.

4.2.4 Network Betweenness Centralization

Betweenness centralization is another structural network metric which can help to explain the distribution of power in a social network. In general, a low network betweenness centralization score indicates that the shortest paths between pairs of actors in a network are fairly direct and do not need to route through many intermediaries (Feinberg et al. 2005). In other words, there is not much variability in individual node betweenness centrality scores, and the network is not centralized around a small number of "broker nodes." During the period spanning 2010 – 2015, the betweenness centralization of the groundfish ACE transfer network fluctuated, ranging from 7.36% - 18.24%. Overall, from 2010 – 2015, network betweenness centralization declined, falling from 15.07% in 2010 to 11.26% in 2015. This change indicates that, over time, the sectors participating in the groundfish ACE transfer network became more directly connected and the variability in the betweenness centrality scores of individual nodes decreased (Table 4).

There are several factors that may have contributed to the observed decrease in network betweenness centralization throughout the study period. First, as time went on and sector managers and sector members became more familiar with the ACE leasing market, they may have gained the knowledge necessary to form more direct trade relationships with other sectors, effectively reducing the role of broker nodes in the network. Additionally, the decline in network betweenness centralization may have partially resulted from changes in sector membership over time. For example, if a permit holder that was originally enrolled in one sector joined another sector in a subsequent fishing year, that member may have introduced trade relationships to their new sector that did not exist before, directly linking 2 previously unconnected sectors.

4.3 Node Characteristics

4.3.1 Node Degree Centrality

While changes in compositional and structural network metrics can indicate how the groundfish ACE transfer network as a whole evolved during 2010 - 2015, variations in individual node characteristics can reflect changes in a node's position and relative level of influence over time. Node degree centrality provides a measure of how connected each node is to others in the network, which can indicate that node's relative level of influence within the network (Bodin and Crona 2009). Like network degree centralization, node degree centrality can also be divided into in-degree centrality (number of ties coming into a node, or number of sectors that a specific sector received ACE from) and out-degree centrality (number of ties going out of a node, or number of sectors that a specific sector transferred ACE to) in a directed network. In order to evaluate patterns in node connectivity during this time series, overall degree centrality, in-degree centrality, and out-degree centrality scores were computed annually for each node during the 2010 – 2015 period (Figures 7-9).

Overall degree centrality scores suggest that the majority of the groundfish sectors that participated in the ACE transfer network from 2010 – 2015 were fairly well-connected and formed trade relationships with many other sectors during this time period (Figure 7). Certain nodes, such as NEFS 2, NEFS 3, NEFS 5, NEFS 9, NEFS 11, NEFS 13, SHS, and SHS 1, consistently achieved the highest degree centrality scores in the network during the years in which they operated (Figure 7). Their comparatively high level of connectivity within the groundfish ACE transfer network may indicate that these sectors play an important role in the ACE leasing market. Additionally, the members of these consistently well-connected sectors may experience a variety of advantages resulting from their sector's overall position in the network. Members or managers from highly connected sectors may find it easier to locate trade partners within the ACE transfer network, reducing the search costs associated with executing an ACE transfer. Furthermore, network analysis studies on other catch share fisheries indicate that highly connected nodes may have access to more market information than less connected nodes, which can influence the amount of bargaining power that a node has within the network (Vignes and Etienne 2011; Ropicki and Larkin 2014). Conversely, nodes such as MEPB, NHPB, NCCS, NEFS 1, TSS, NEFS 4, NEFS 12, and SHS 3 tended to have the lowest degree centrality scores during the majority of the years in which they operated (Figure 7). This finding suggests that these sectors may have a more difficult time finding ACE trading partners, and they may have less access to information about the ACE transfer market. The fact that the majority of the most highly connected sectors in the network are NEFS sectors, and the fact that many of the least connected sectors in the network are non-NEFS sectors, may also suggest that sectors' right of first refusal provisions are restricting the movement of ACE from NEFS sectors to non-NEFS sectors.

In terms of directed centrality measures, calculations indicate that each node's in-degree centrality score varied from year-to-year throughout 2010 – 2015 (Figure 8). Some nodes, such as MEPB, NHPB, NEFS 4, and NEFS 1, tended to have relatively low in-degree centrality scores during each year they were in operation (Figure 8). This tendency is likely due to the fact that these sectors operated as lease-only or permit bank sectors; since their members did not actively fish, these sectors had little incentive to lease ACE in. This supposition is supported by the fact that the in-degree centrality score for SHS 3 increased dramatically in 2015, which was the first year that this sector began actively fishing and ceased to operate as a lease-only sector (Figure 8). There are also more administrative barriers in place preventing non-active sector members from leasing ACE in, which would have made it challenging for these sectors to obtain ACE if they wanted it. Several active sectors, such as NCCS, TSS, and NEFS 12, also had fairly low in-degree centrality scores during this time series (Figure 8). This may be partly due to the fact that these sectors received relatively small initial allocations of ACE during each fishing year. Many members of these sectors may have chosen not to actively fish their groundfish allocations, leaving the sector as a whole with little reason to lease in additional ACE. Other active sectors, such as NEFS 2, NEFS 9, NEFS 13, and SHS 1, tended to have the highest in-degree centrality scores during the years that they operated (Figure 8). This finding may indicate that that the members of these sectors were more active within the groundfish fishery during the study period, and the sectors may have had to lease in more ACE in order to balance their portfolios against their members' fishing activity.

Much like in-degree centrality, out-degree centrality scores varied annually for each node present in the groundfish ACE transfer network (Figure 9). Some nodes, such as NEFS 1, MEPB, and NHPB, tended to have the lowest out-degree centrality scores during the years that they operated (Figure 9). For NEFS 1, this low score may be partly due to the fact that this sector only operated for 2 years near the end of the time series; perhaps NEFS 1 had not yet had time to establish a wide variety of trading relationships with other sectors. Additionally, the low out-degree centrality scores achieved by NEFS 1 could be due to the fact that this sector's initial ACE allocation is fairly small, which might limit that sector's ability to transfer ACE to many other sectors. In the case of the MEPB and the NHPB sectors, their small out-degree centrality scores may be partially due to administrative restrictions on who these sectors can lease ACE to. Each of these permit banks was designed to lease ACE to fishermen located in their respective states, which could limit the number of other sectors that they could transfer ACE to. Other nodes, such as FGS, NEFS 2, NEFS 3, and SHS 1, consistently had the highest out-degree centrality scores of any node during the years that they operated (Figure 9). In the case of SHS 1, this could be partly due to the fact that this sector had the highest initial ACE allocation of any sector during 2010 – 2014, and therefore it may have had more ACE available to transfer than other sectors. Once SHS 1 and SHS 3 restructured their membership in 2015, SHS 1's initial ACE allocation became much smaller and this sector's out-degree centrality declined (Figure 9).

4.3.2 Node Betweenness Centrality

In some social networks, nodes with high betweenness centrality scores indicate actors that function as "brokers" in the network, taking in information or resources from one actor and passing it along to another otherwise disconnected actor (Bodin and Crona 2009; Ernstson et al. 2008; Freeman 1978/79). In the case of the groundfish ACE transfer network, much of the ACE that is leased into a sector is caught (harvested and/or discarded) by the members of that sector. Once this happens, that ACE is no longer available to be leased out to another sector, so the ACE is effectively "tied up" in the sector that first leased it in. Therefore, in the groundfish ACE transfer network, nodes with high betweenness centrality scores are not necessarily sectors that act as brokers to move ACE between otherwise disconnected sectors. Rather, high betweenness centrality scores indicate sectors that are influential in controlling how ACE flows through the network. If any of these sectors were removed from the network, the structure and composition of the ACE transfer network would be altered. Additionally, if one of these high-betweenness centrality sectors were removed from the network, there would likely be more ACE available for the remaining sectors.

As with degree centrality, betweenness centrality scores were calculated annually for each node from 2010 – 2015. Results indicate that, in general, NEFS 2, NEFS 11, NEFS 13, and SHS 1 tended to exhibit the highest betweenness centrality scores throughout the years that these sectors operated (Figure 10). This finding suggests that overall, these sectors may have impacted the movement of ACE through the network the most heavily during 2010 – 2015. Additionally, much of the ACE that was available for leasing during this time period may have gotten "tied up" in these sectors, leaving less for the remaining network participants. Several other nodes, such as PCCS/MCCS, NEFS 3, NEFS 5, NEFS 6, and NEFS 9 achieved high betweenness centrality scores during at least one year during 2010 - 2015, but these relatively high scores were not sustained throughout the time series (Figure 10). The betweenness centrality score of SHS 3 increased dramatically in 2015 (Figure 10), which was likely due to the changes in the membership structure and operational status that the sector underwent at the beginning of 2015. Throughout this time series, the nodes that consistently displayed the lowest betweenness centrality scores (NCCS, TSS, NEFS 1, NEFS 4, NEFS 7, NEFS 8, NEFS 10, NEFS 12, MEPB, NHPB) all occupied more peripheral positions in the groundfish ACE transfer network (Figure 10).

4.4 Transfers between Related Sectors

Most sector operations plans include right of first refusal provisions regarding inter-sector ACE leasing. According to these rules, whenever sector members wish to transfer ACE outside of their own sector, other members of the transferring sector or any related sectors have the opportunity to match the trade offer. These provisions were originally developed in order to help maximize benefits to the members of each sector; however, concerns have been raised about whether or not these provisions act as significant barriers to ACE trading between certain sectors or certain groups of sectors. In order to investigate this, annual percentages of transfers between different groups of sectors were calculated.

Results show that the majority of all the ACE transfers that occurred during 2010 – 2015 were received by NEFS sectors (Figure 11). The annual percentage of total ACE transfers received by NEFS sectors varied, ranging from 60% in 2015 to 81% in 2012 and 2010 (Figure 11). Many of the transfers received by one NEFS sector were received from another NEFS sector. During each year from 2010 – 2015, the percentage of total transfers that occurred between 2 NEFS sectors fluctuated, ranging from 42% in 2015 to 64% in 2010 (Figure 11). 2015 was the only year during this time series where less than 50% of total ACE transfers involved 2 NEFS sectors. The remainder of the ACE transfers received by NEFS sectors during this time period were received from non-NEFS sectors. During 2010 – 2015, the percentage of total ACE trades that went from non-NEFS sectors to NEFS sectors varied, ranging from 14% in 2013 and 2014 to 28% in 2012 (Figure 11).

The percentage of total ACE trades that were received by non-NEFS sectors from NEFS sectors also fluctuated during this time period but generally remained lower than the proportion of transfers from non-NEFS sectors to NEFS sectors. The percentage of total ACE transfers from NEFS sectors to non-NEFS sectors ranged from 5% in 2011 to 19% in 2013 (Figure 11). The amount of ACE transferred between SHS 1 and SHS 3 was relatively small every year from 2011 – 2015. The amount of ACE transferred between these 2 SHS sectors increased dramatically in the final year of this time series, rising from 3% of total ACE transfers in 2014 to 15% of total ACE transfers in 2015 (Figure 11).

The fact that the bulk of the ACE transfers that occurred during 2010 – 2015 took place between 2 NEFS sectors might simply be due to the fact that NEFS sectors outnumber other sectors during each year of this time period, so it is more likely that a transfer would involve NEFS sectors. These sectors collectively are allocated a large percentage of the total ACE in every year, and many of the MRIs enrolled in groundfish sectors are enrolled in NEFS sectors. However, the large percentage of transfers that occur between NEFS sectors, as well as the relatively small percentage of transfers from NEFS sectors to non-NEFS sectors, may also indicate that right of first refusal provisions are restricting the flow of ACE through the network.

5. CONCLUSIONS AND RECOMMENDATIONS

Overall, the groundfish ACE transfer network remained fairly stable throughout the first 6 years of catch share management. The network increased slightly in size during 2010 – 2015, both in terms of the number of nodes and number of ties present. However, the number of ACE transfers and the total volume of ACE transferred annually both fell overall during this time period. Small reductions in network density and percent tie reciprocity during 2010 - 2015 suggest that the network became slightly less cohesive throughout this time period. Network in-degree and out-degree centralization scores indicate that during 2010 -2015, the groundfish ACE transfer network was more centralized around ACE recipients (e.g., lessees, buyers) and less organized around ACE transferors (e.g., lessors, sellers). This trend suggests that ACE recipients may exert more influence over the transfer network than do ACE transferors. An overall increase in network betweenness centralization scores during 2010 – 2015 indicates that the connections between network participants became more direct and less dependent on intermediaries over time.

In terms of the individual nodes in the network, degree centrality scores suggest that the majority of the sectors that participated in the ACE leasing network were fairly well-connected throughout 2010 – 2015. There was more variation in directional degree centrality scores than there was in overall degree centrality scores during this time period. NEFS 2, NEFS 9, NEFS 13, and SHS 1 exhibited comparatively high annual in-degree centrality scores during the majority of this time period, implying that these sectors may occupy advantageous positions as ACE buyers in the network. Additionally, the FGS, NEFS 2, NEFS 3, SHS 1 sectors tended to have the highest annual out-degree centrality scores during this period, suggesting that these sectors may occupy advantageous positions as ACE sellers in the network. NEFS 2, NEFS 11, NEFS 13, and SHS 1 showed consistently high betweenness centrality scores during 2010 - 2015, indicating that these sectors may play a relatively important role in controlling the movement of ACE through the transfer network. Calculations show that the majority of ties formed between node-pairs during 2010 - 2015 were formed between 2 NEFS sectors, indicating that these sectors trade ACE frequently with one another as opposed to trading with SHS sectors or other sectors. This may be partly due to the fact that there are fewer administrative barriers in place preventing 2 NEFS sectors from trading ACE with one another. It may also be due, in part, to the fact that the majority of the sectors that operated during 2010 – 2015 were NEFS sectors, and these sectors collectively were allocated a large percentage of the total ACE available during this time period.

There are many socioeconomic, regulatory, and ecological factors that may impact the composition and structure of the groundfish ACE transfer network. For example, some of the observed changes in the network composition, density, and betweenness centralization could have resulted as sector managers and members gained familiarity and experience working within the sector management system. Over time, sector manager and members may have formed trade loyalties to other managers or members with whom they had traded successfully in the past. Sector managers and members may have also learned how to balance their sector's ACE portfolios more efficiently over time, achieving their desired mix of stocks in fewer transactions with fewer partners. In addition, the movement of members from one sector to another, or the movement of members out of sectors completely, could have impacted the way various sectors interact in the ACE transfer network.

Changes in resource abundance or fishing regulations may also have influenced the structure and composition of the ACE transfer network. Fluctuations in resource availability or adjustments to fishing regulations (e.g., cuts to stock ACLs, implementations of closed areas) impact the extent to which groundfish fishermen target certain species. Changes in fishing behavior may impact sector fishermen's annual ACE demands, which in turn could impact their level of involvement in the ACE transfer network. Overall reductions in the number of sector vessels fishing for groundfish and the number of groundfish trips taken over time likely also impacted the dynamics of the ACE transfer network.

This report presents results from the first attempt at using social network analysis to investigate the groundfish ACE transfer network. The findings from this analysis may help sector fishermen and managers to identify areas where new trade relationships could be formed, which could help to increase the efficiency of the quota transfer system. While this preliminary analysis of the groundfish ACE transfer network provides some helpful insight into how ACE moves between groundfish sectors, additional research is needed to understand more about why some of these patterns have arisen. There are a number of factors that may influence ACE transfer relationships between sectors during a given fishing year. For instance, annual adjustments in groundfish stock ACLs may change the way power is distributed throughout the network, depending on the mix of stocks in each sector's initial ACE portfolio. Additionally, certain administrative barriers may make it more difficult for some sectors to trade ACE with one another. For example, the NEFS sectors' right of first offer system could make it challenging for a NEFS sector to transfer ACE to a non-NEFS sector. Additionally, ACE lease prices and wholesale fish prices may also impact fishermen's willingness to participate in ACE leasing at any given time. Future studies should expand on the factors that encourage or discourage the formation of ACE leasing relationships between different sectors.

This network analysis investigated the ACE leasing relationships that exist between groundfish sectors; however, analysis at this level does not provide information about how individual sector members participate in the ACE leasing network. Future network analyses should try to link inter-sector ACE leases and intra-sector PSC leases to specific sector members in order to visualize the ties between individual fishermen and fishing businesses. Finally, this network analysis helped to determine what positions each groundfish sector occupies in the ACE transfer network. Future research could investigate how certain node characteristics and network positions may impact sector performance.

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Table 1. Example adjacency matrix for a network of 6 people.

	Jane	John	Maria	Julia	Daniel	Tyler
Jane	0	1	1	1	0	0
John	1	0	0	0	1	0
Maria	1	0	0	1	0	1
Julia	1	0	1	0	0	0
Daniel	0	1	0	0	0	0
Tyler	0	0	1	0	0	0

A “1” in the adjacency matrix indicates the presence of a tie between the 2 individuals named in in the corresponding row and column, while a “0” indicates the absence of a tie. Note that the ties in this network are all symmetrical.

Table 2. Name and operational status of all groundfish sectors, by fishing year (2010 – 2015). Years of operation are shaded and marked with an "X".

Sector	2010	2011	2012	2013	2014	2015
Fixed Gear Sector	X	X	X	X	X	X
Port Clyde Community Groundfish Sector/ Maine Coast Community Sector*	X	X	X	X	X	X
Northeast Coastal Communities Sector	X	X	X	X	X	X
Tri-State Sector	X	X	X			
Northeast Fishery Sector 1					X	X
Northeast Fishery Sector 2	X	X	X	X	X	X
Northeast Fishery Sector 3	X	X	X	X	X	X
Northeast Fishery Sector 4	X	X	X	X	X	X
Northeast Fishery Sector 5	X	X	X	X	X	X
Northeast Fishery Sector 6	X	X	X	X	X	X
Northeast Fishery Sector 7	X	X	X	X	X	X
Northeast Fishery Sector 8	X	X	X	X	X	X
Northeast Fishery Sector 9	X	X	X	X	X	X
Northeast Fishery Sector 10	X	X	X	X	X	X
Northeast Fishery Sector 11	X	X	X	X	X	X
Northeast Fishery Sector 12	X	X	X	X		
Northeast Fishery Sector 13	X	X	X	X	X	X
Sustainable Harvest Sector**	X					
Sustainable Harvest Sector 1		X	X	X	X	X
Sustainable Harvest Sector 3		X	X	X	X	X
Maine Permit Bank		X	X	X	X	X
New Hampshire Permit Bank			X	X	X	X

*In 2013, the name of this sector changed from the Port Clyde Community Groundfish Sector to the Maine Coastal Communities Groundfish Sector.
**The Sustainable Harvest Sector split into 2 separate sectors (Sustainable Harvest Sectors 1 and 3) after 2010.

Table 3. Compositional characteristics of the groundfish Annual Catch Entitlement (ACE) transfer network, by fishing year (2010 – 2015).

	2010	2011	2012	2013	2014	2015
Number of nodes	17	19	20	19	19	19
Number of ties	129	164	150	141	124	139
Number of ACE transfers	1,073	1,345	1,139	1,222	862	1,011
Total ACE transferred (live lbs.)	16,349,038	17,339,371	21,432,767	15,779,448	10,027,309	14,089,417
Net ACE importers	7	11	9	8	9	8
Net ACE exporters	10	8	11	11	10	11

Table 4. Structural characteristics of the groundfish Annual Catch Entitlement (ACE) transfer network, by fishing year (2010 – 2015).

	2010	2011	2012	2013	2014	2015
Network density	0.474	0.480	0.395	0.412	0.363	0.406
Tie reciprocity	76.0%	72.0%	62.7%	73.8%	59.7%	64.7%
In-degree centralization	0.559	0.432	0.471	0.562	0.438	0.451
Out-degree centralization	0.293	0.315	0.360	0.269	0.380	0.333
Betweenness centralization	15.07%	10.02%	7.36%	10.75%	18.24%	11.26%

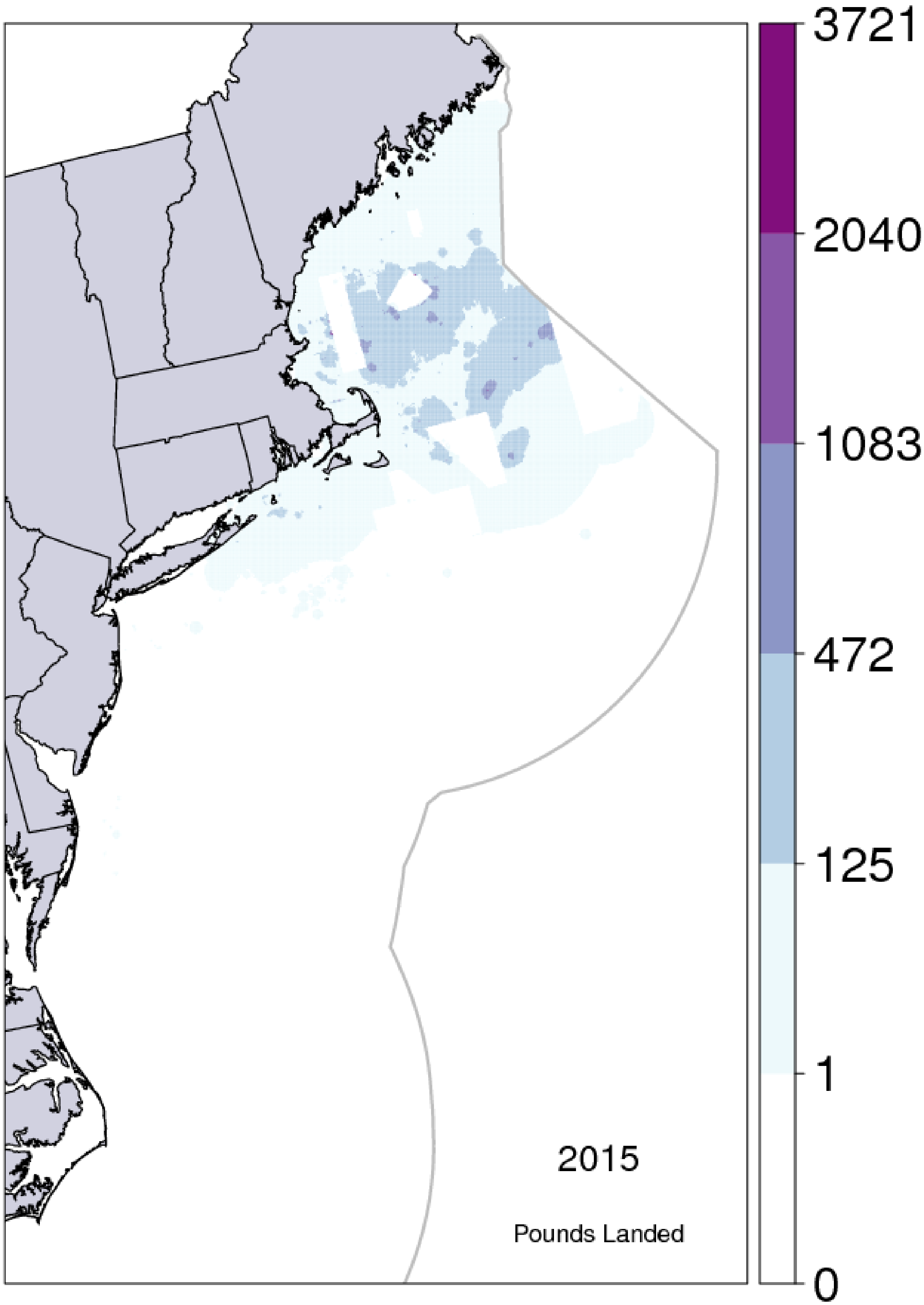

Figure 1. Pounds of regulated groundfish landed on commercial fishing trips in 2015. Source: [NEFSC SSB Fishing Footprints webpage](). (NEFSC SSB 2010)

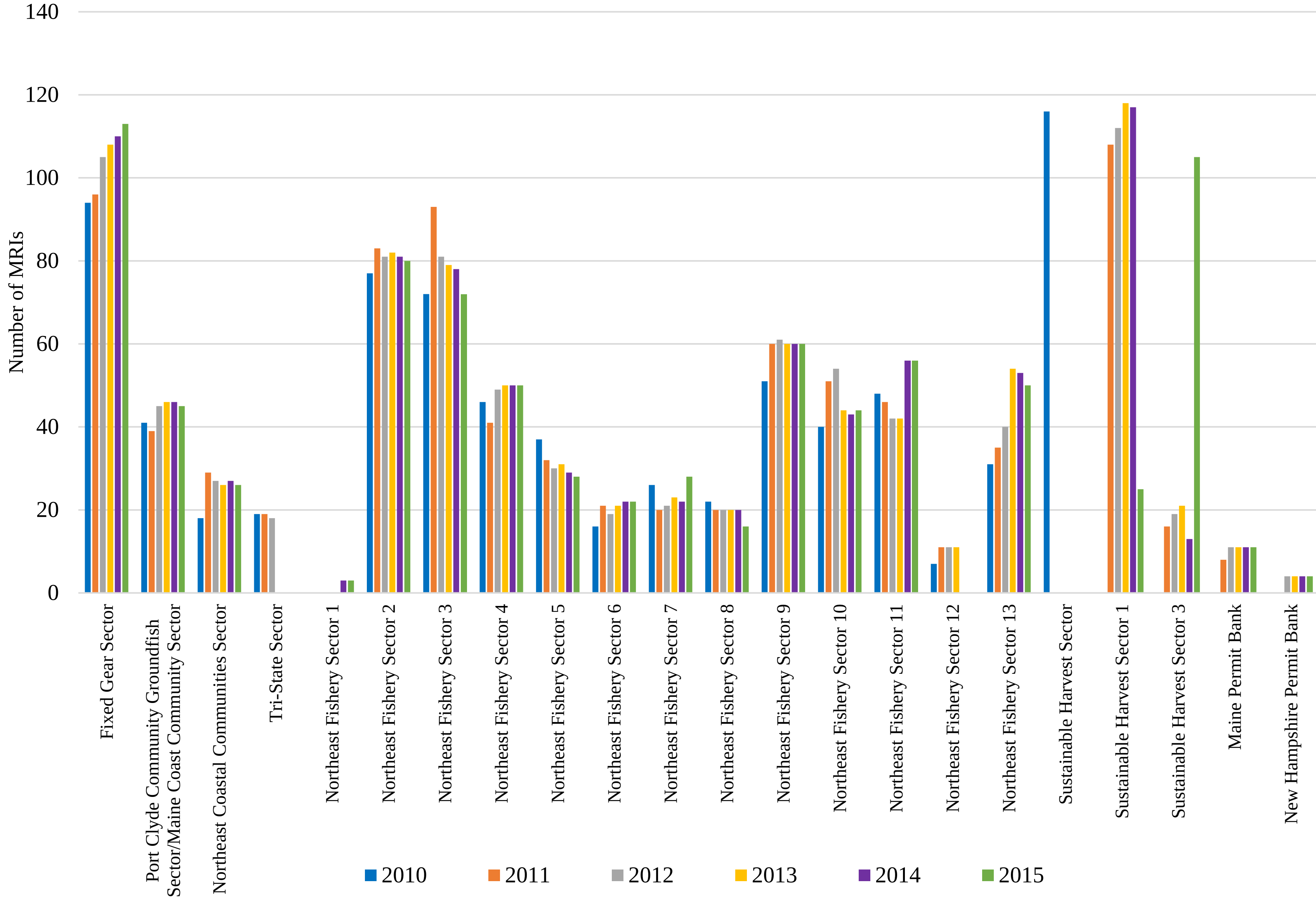

Figure 2. Number of Moratorium Rights Identifiers (MRIs) enrolled in each sector annually, by fishing year (2010 - 2015).

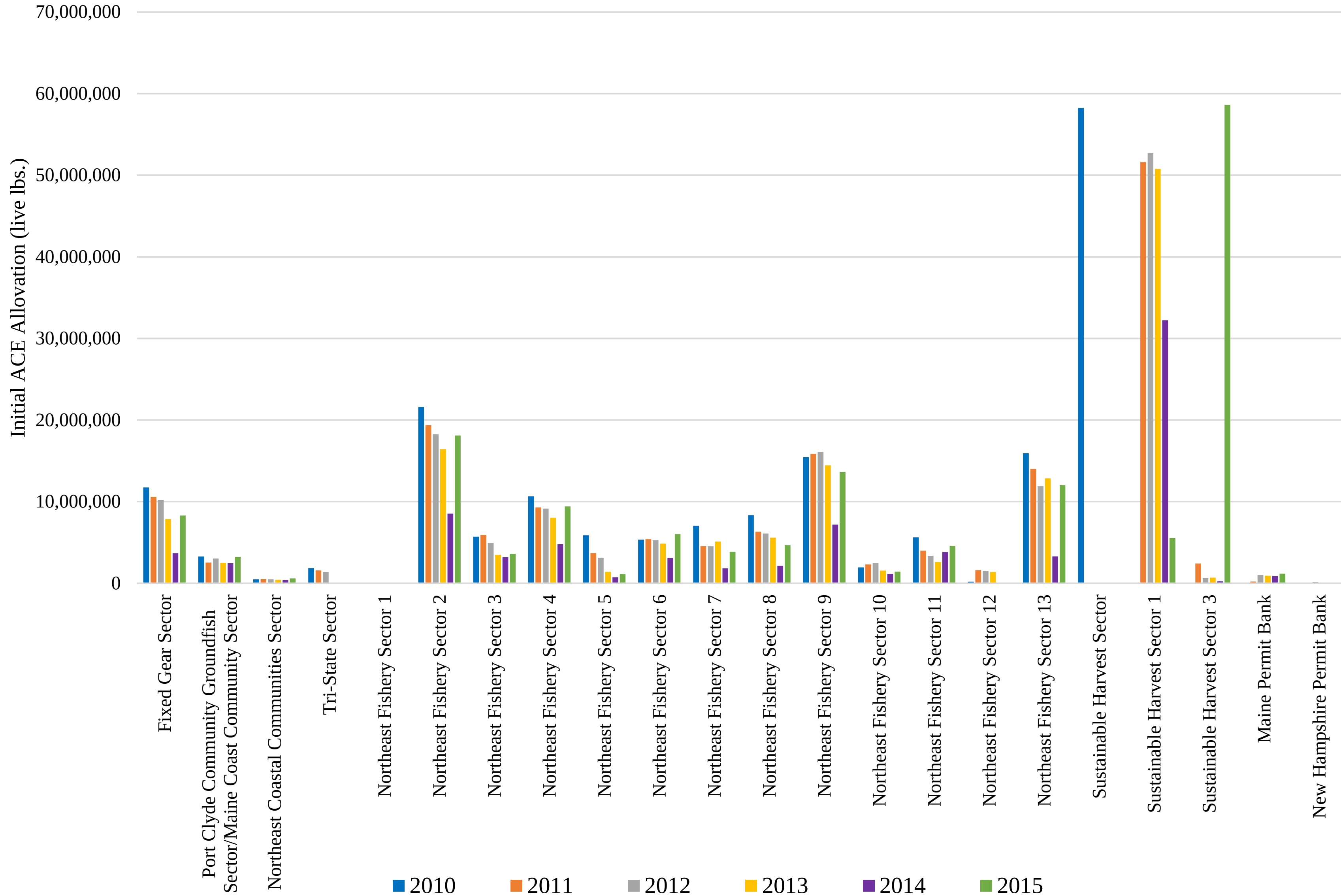

Figure 3. Initial Annual Catch Entitlement (ACE) allocation, in live lbs., allocated annually to each groundfish sector (2010 - 2015).

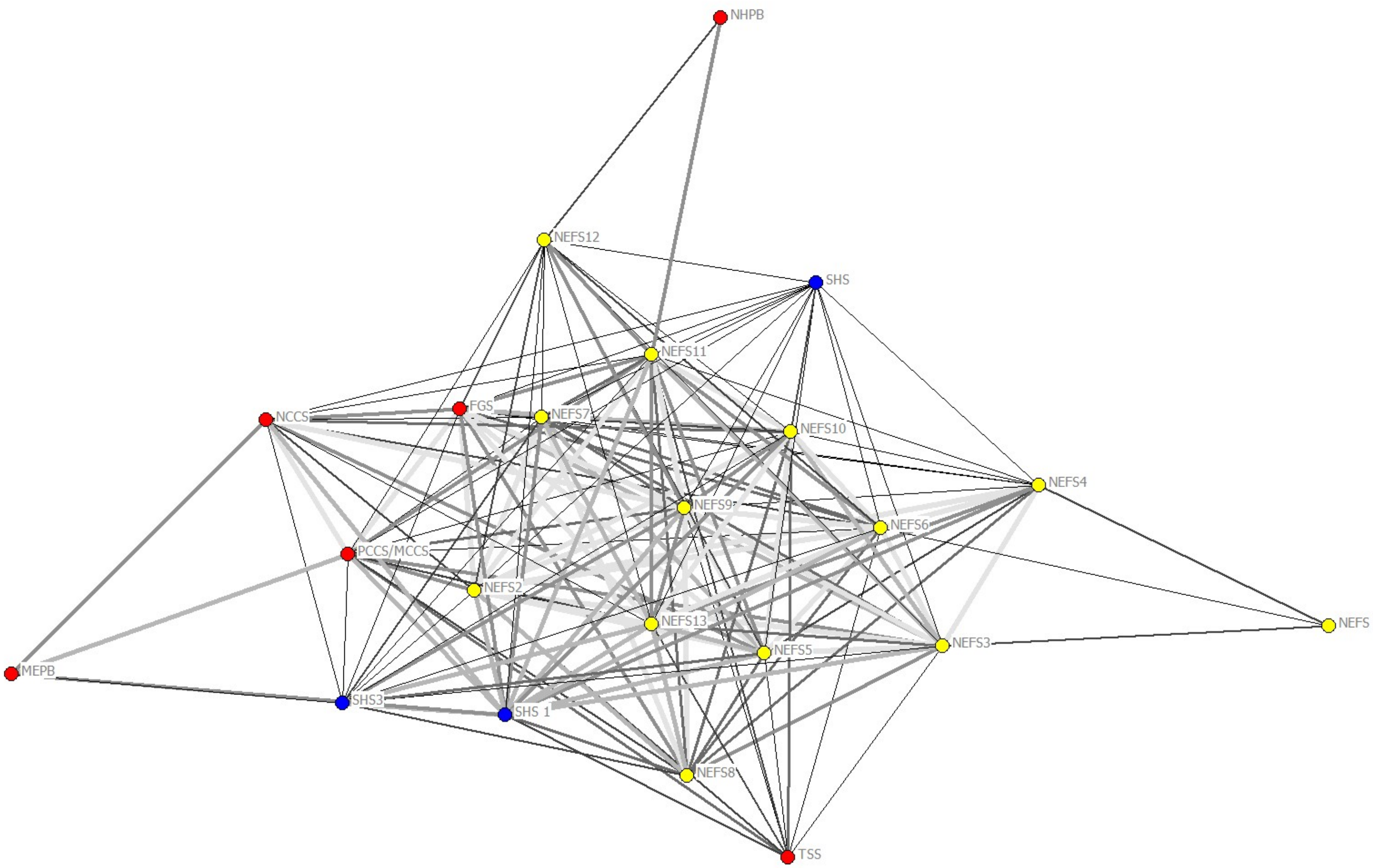

Figure 4. Sociogram of all trades in the groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Ties are weighted and color-coded to reflect the number of years during which two sectors formed trade relationships; thinner, darker ties indicate shorter relationships; thinner, darker lines indicate shorter relationships, while thicker lighter lines represent longer relationships. Nodes[12] are color-coded to reflect groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors.

[12] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

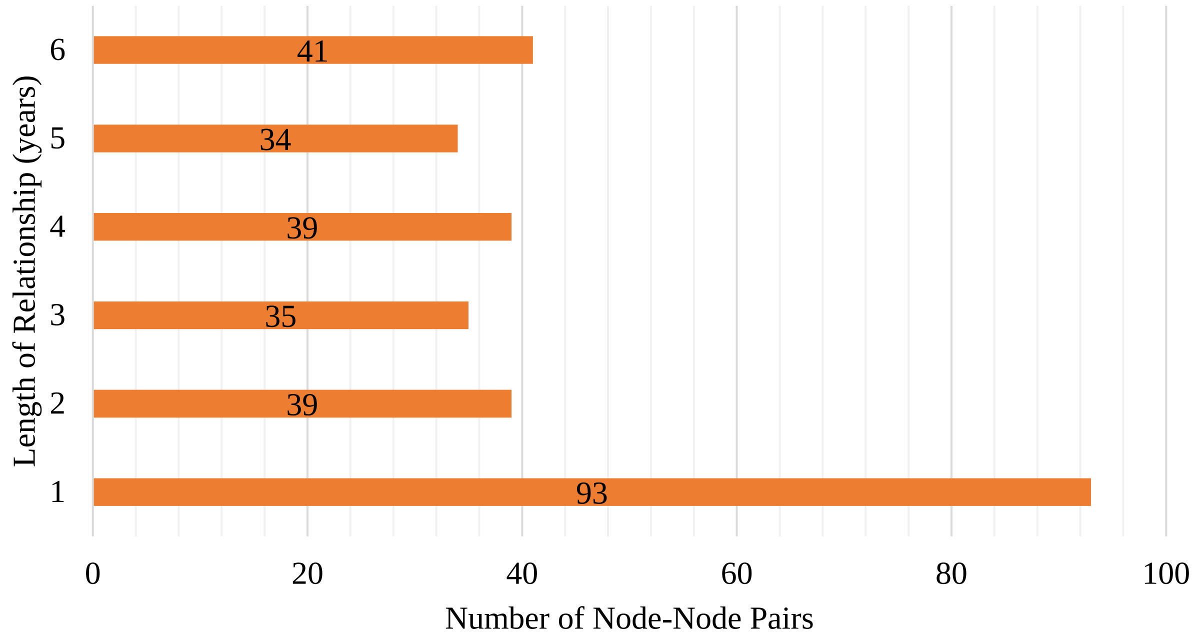

Figure 5. Length of relationships between all node pairs (2010 – 2015).

2010

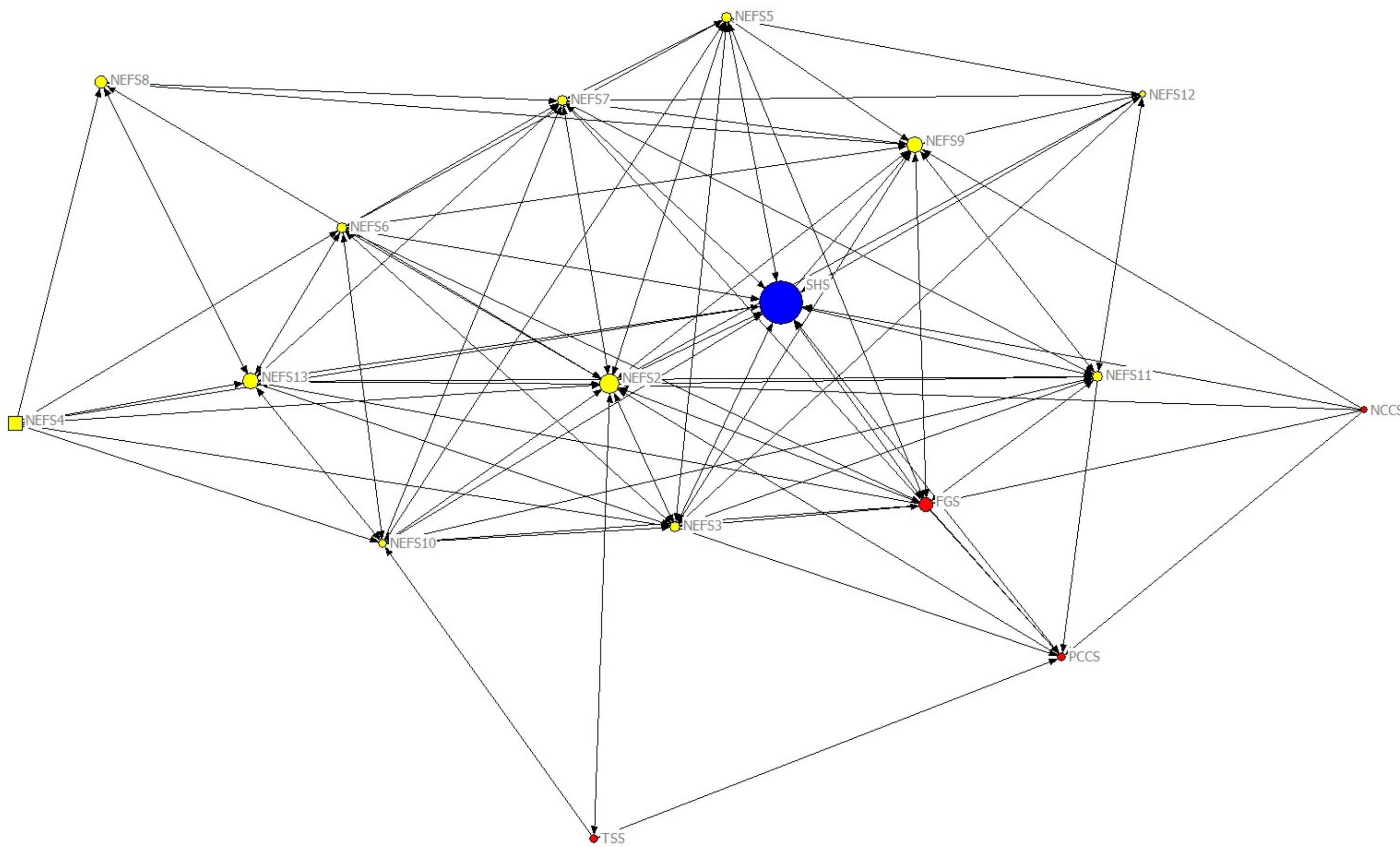

Figure 6. Sociograms of the annual groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Nodes are sized to reflect initial ACE allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[13] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality.

[13] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

2011

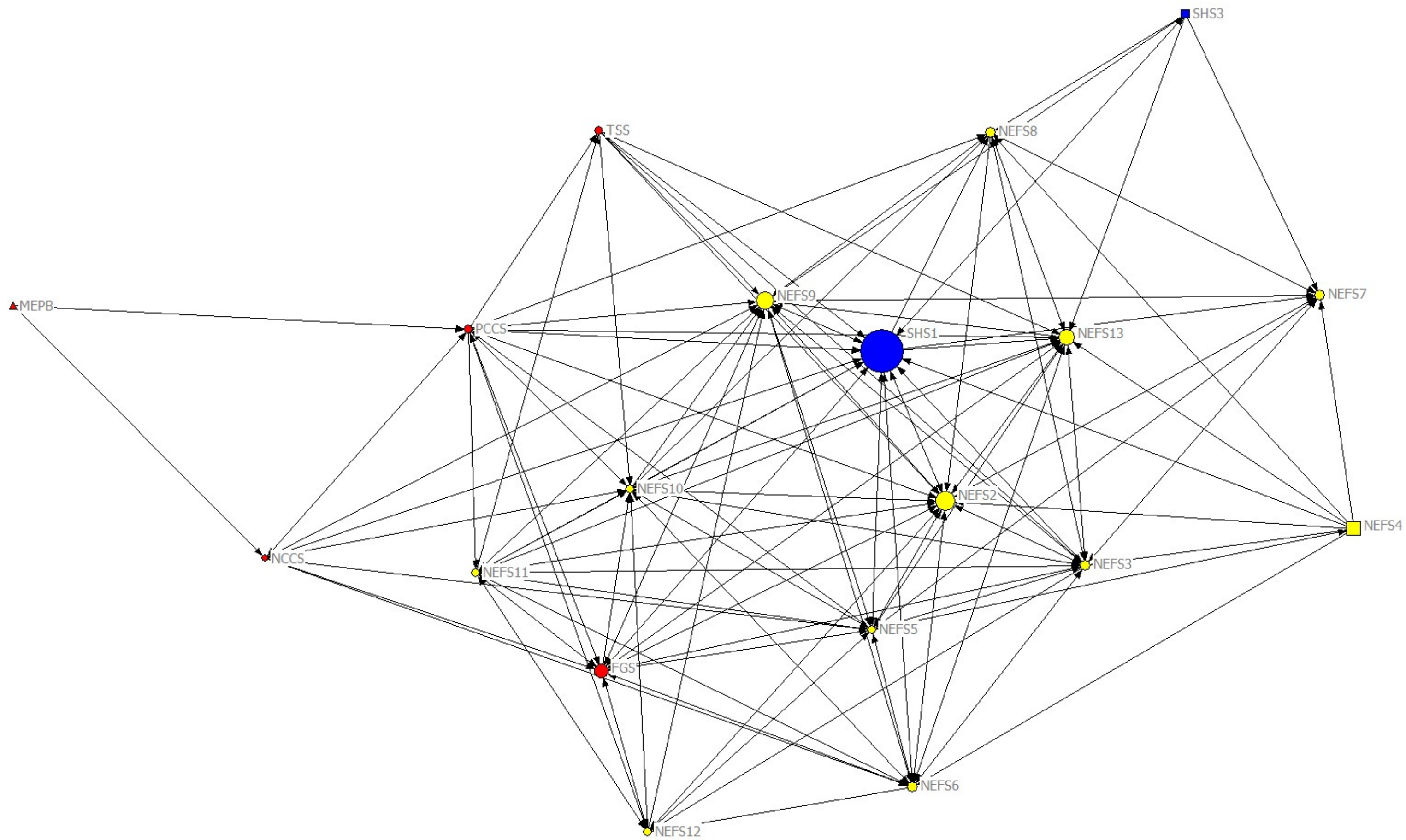

Figure 6 (continued). Sociograms of the annual groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Nodes are sized to reflect initial ACE allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[14] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality.

[14] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

2012

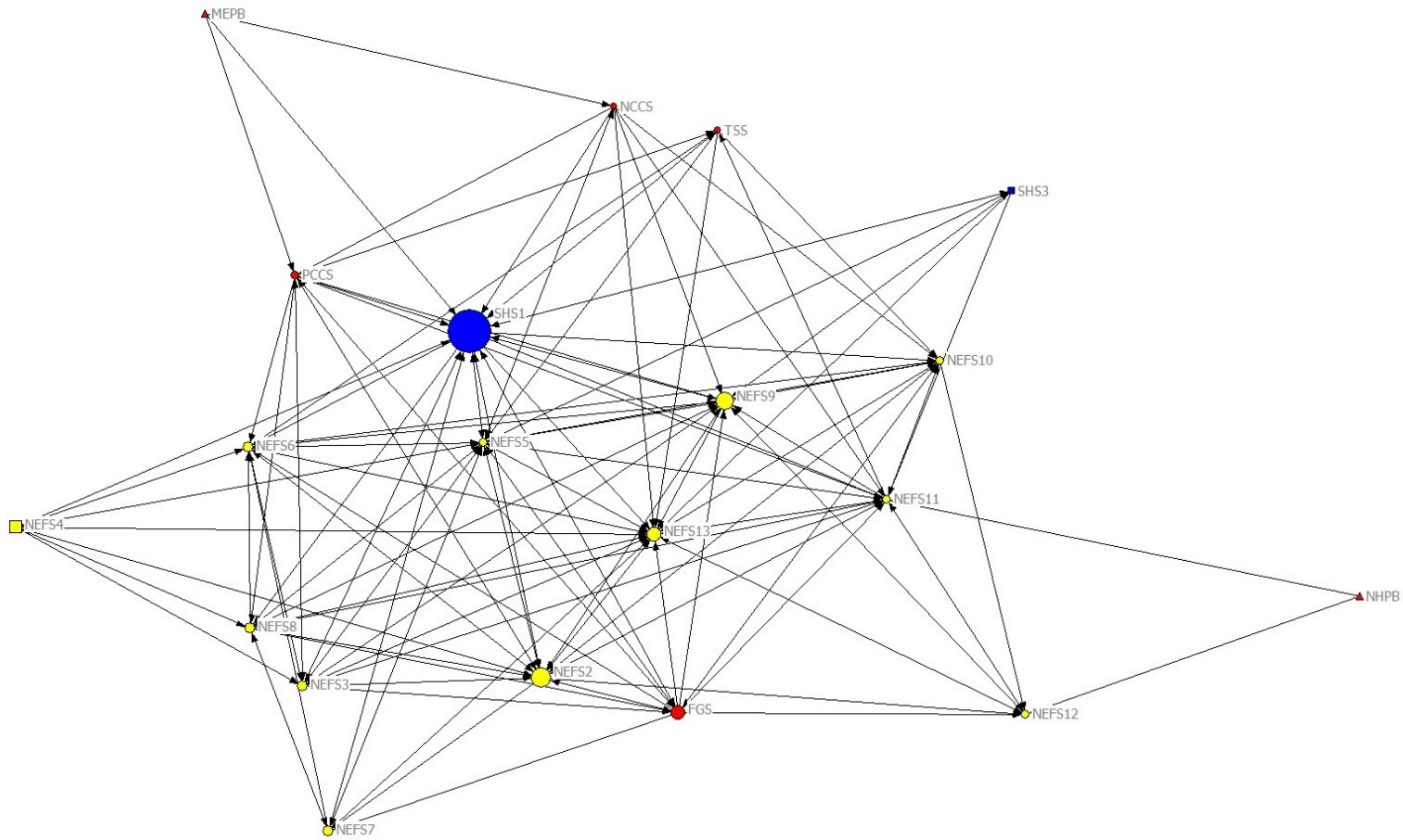

Figure 6 (continued). Sociograms of the annual groundfish ACE transfer network (2010 – 2015). Nodes are sized to reflect initial Annual Catch Entitlement (ACE) allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[15] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality.

[15] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

2013

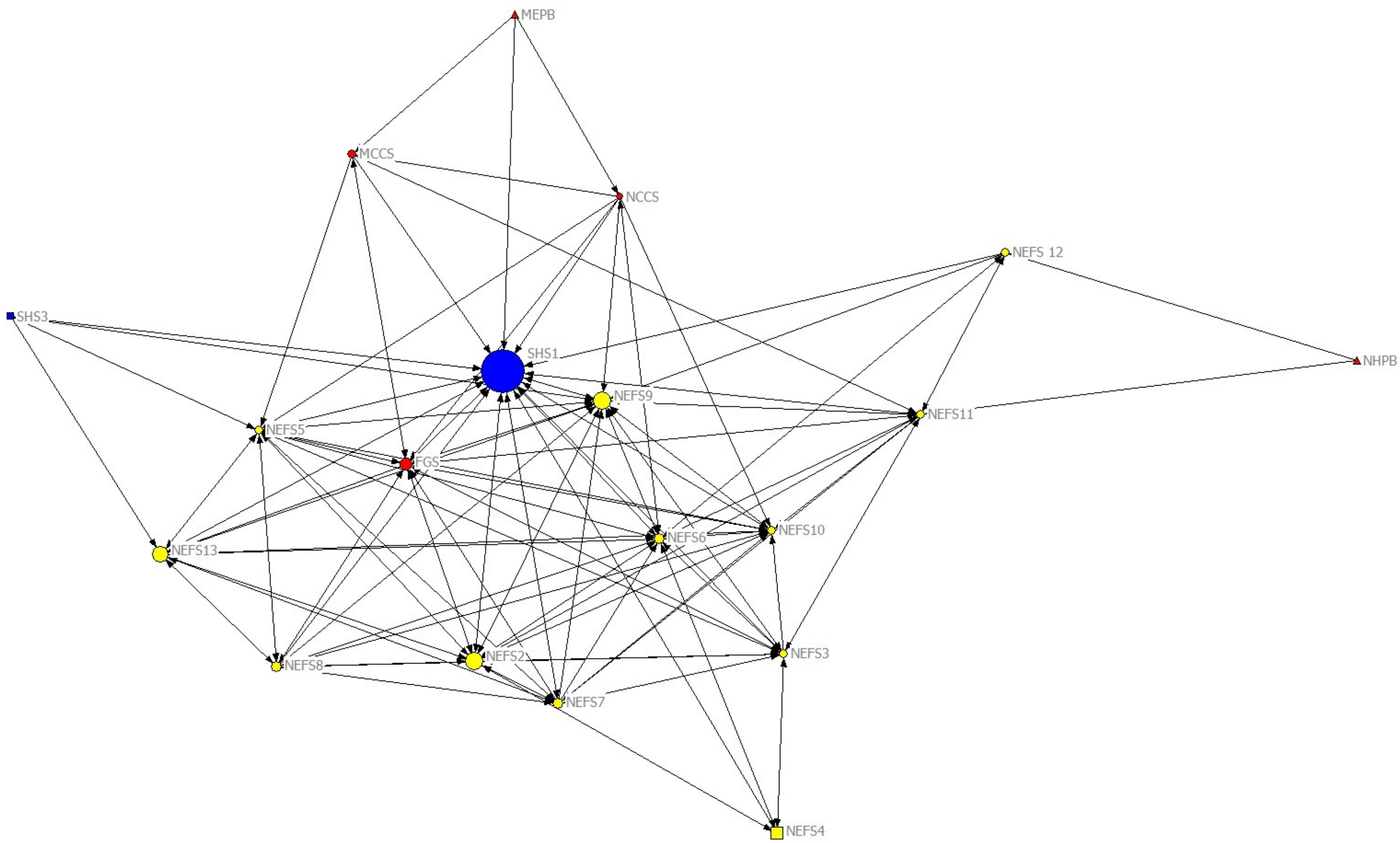

Figure 6 (continued). Sociograms of the annual groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Nodes are sized to reflect initial ACE allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[16] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality.

[16] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

2014

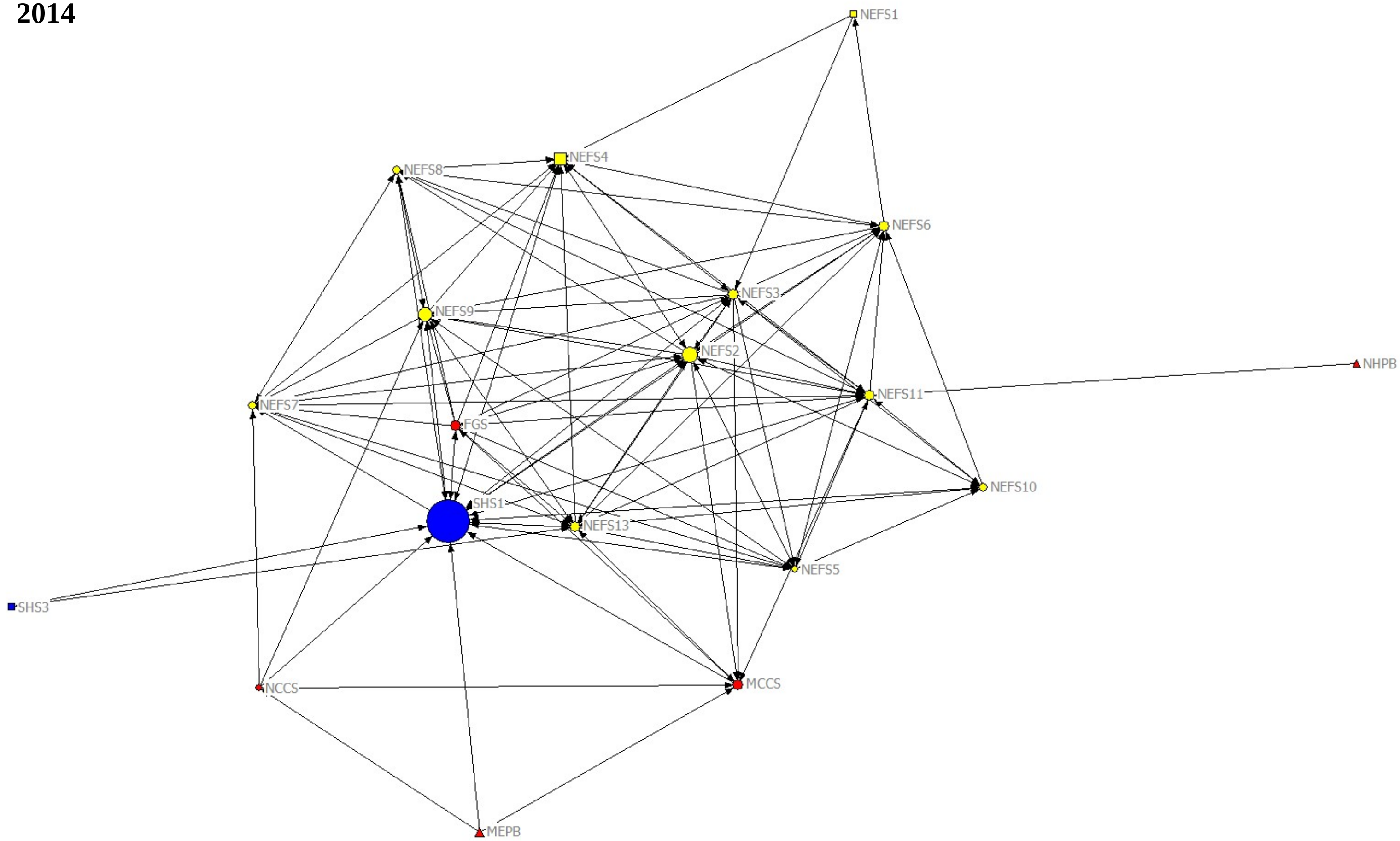

Figure 6 (continued). Sociograms of the annual groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Nodes are sized to reflect initial ACE allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[17] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality.

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2015

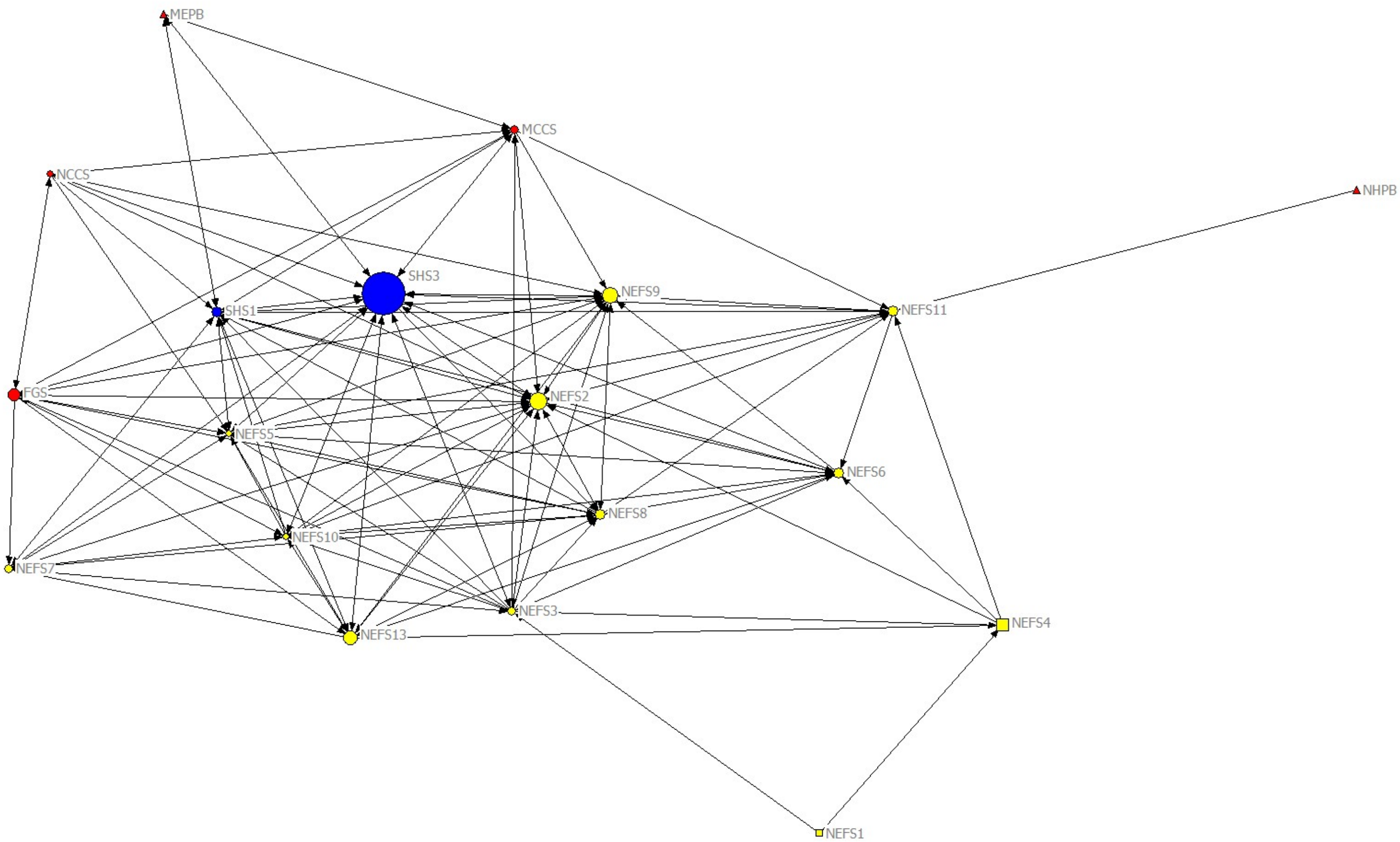

Figure 6 (continued). Sociograms of the annual groundfish Annual Catch Entitlement (ACE) transfer network (2010 – 2015). Nodes are sized to reflect initial ACE allocation and shaped to reflect classification as active sectors (circle), lease-only sectors (square), or permit bank sectors (triangle). Nodes[18] are color-coded to reflect related groups of sectors. Yellow nodes represent NEFS sectors, blue nodes represent SHS sectors, and red nodes represent all other sectors. Arrowheads indicate transfer directionality

[18] FGS = Fixed Gear Sector; PCCS/MCCS = Port Clyde Community Groundfish Sector/Maine Coast Community Sector; NCCS = Northeast Coastal Communities Sector; TSS = Tri-State Sector; NEFS 1 – 13 = Northeast Fishery Sector 1 – 13; SHS = Sustainable Harvest Sector; SHS 1 = Sustainable Harvest Sector 1; SHS 3 = Sustainable Harvest Sector 3; MEPB = Maine Permit Bank; NMPB = New Hampshire Permit Bank.

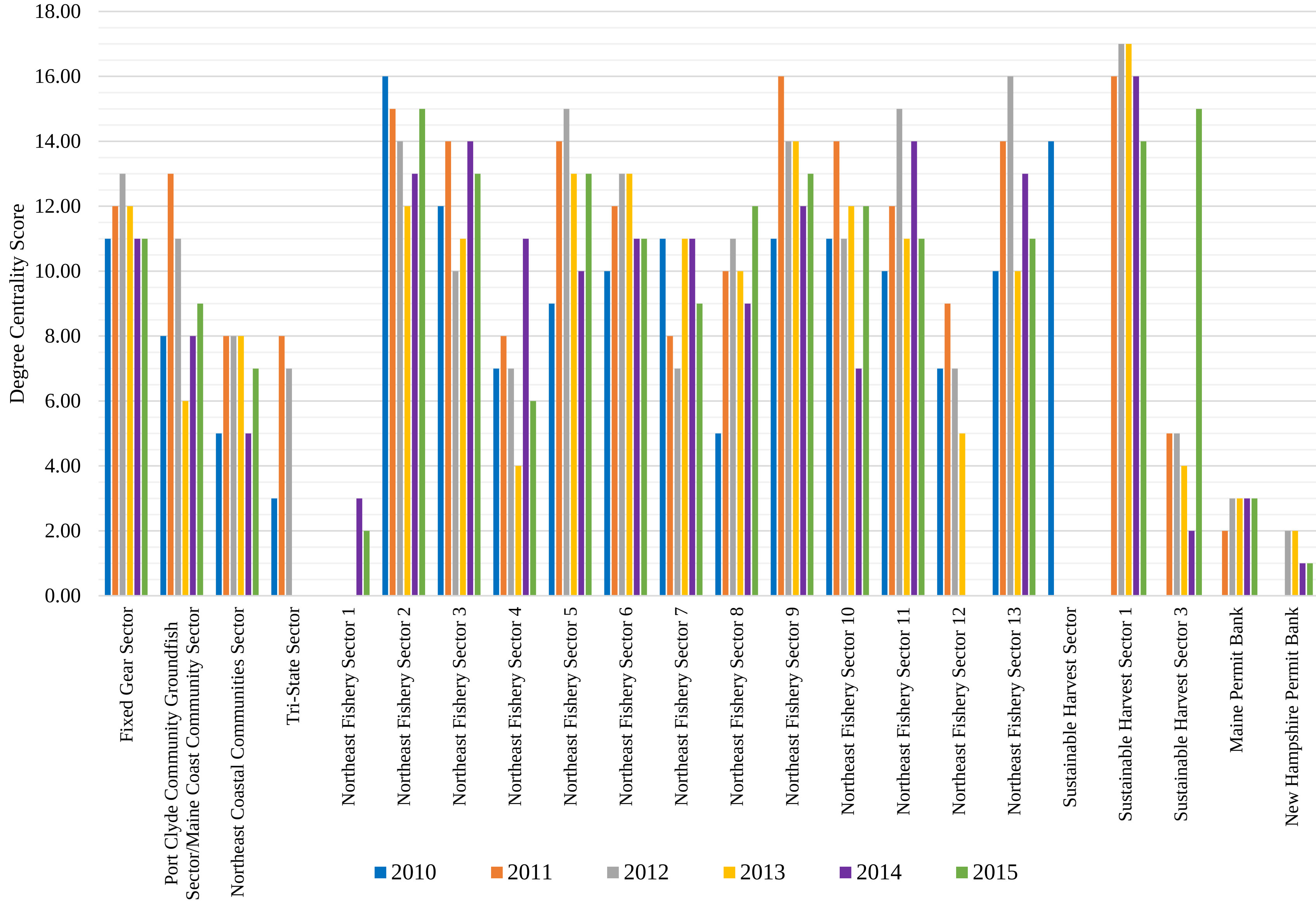

Figure 7. Annual overall (non-directional) degree centrality scores for all nodes, by fishing year (2010 – 2015).

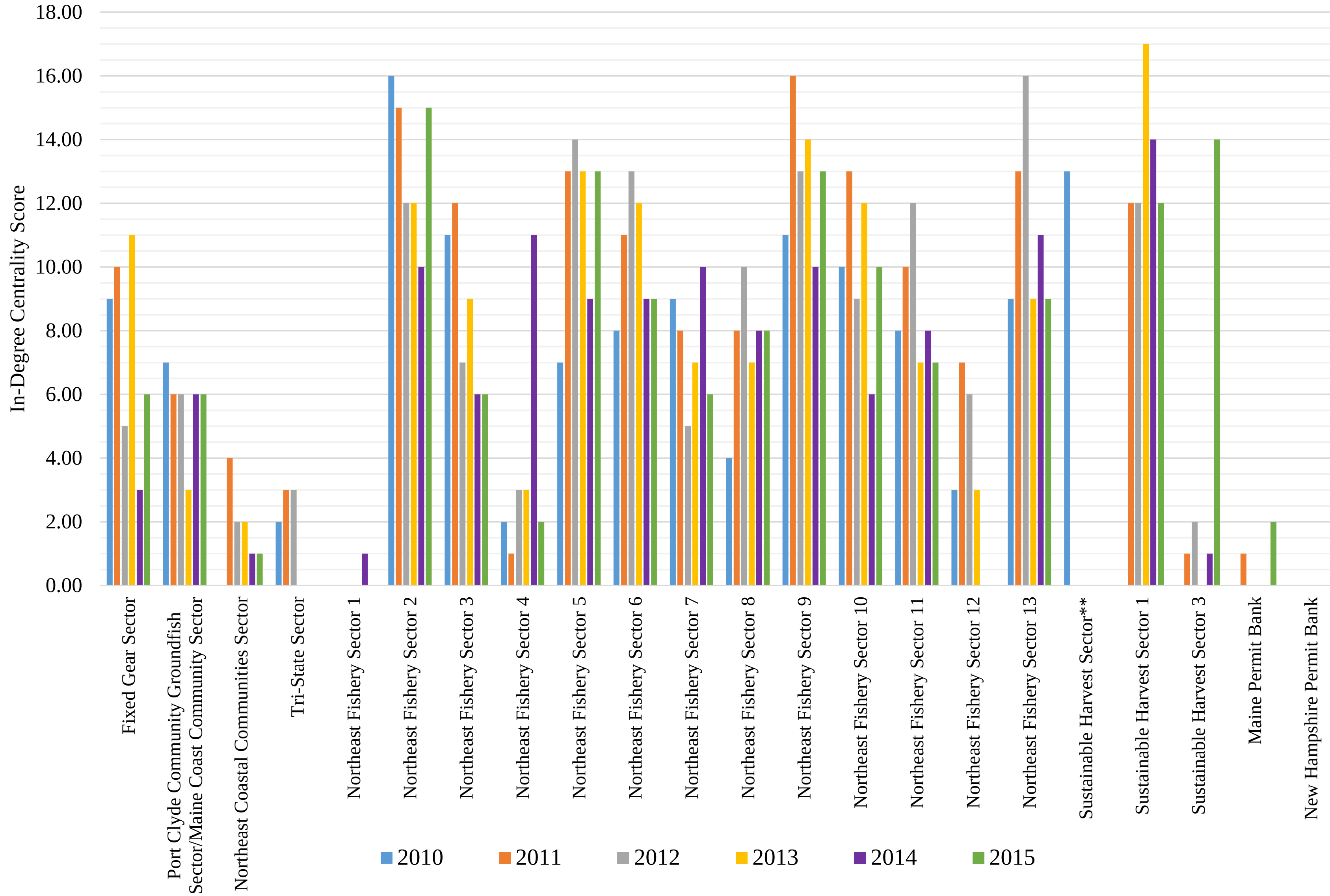

Figure 8. Annual in-degree centrality scores for all nodes, by fishing year (2010 – 2015).

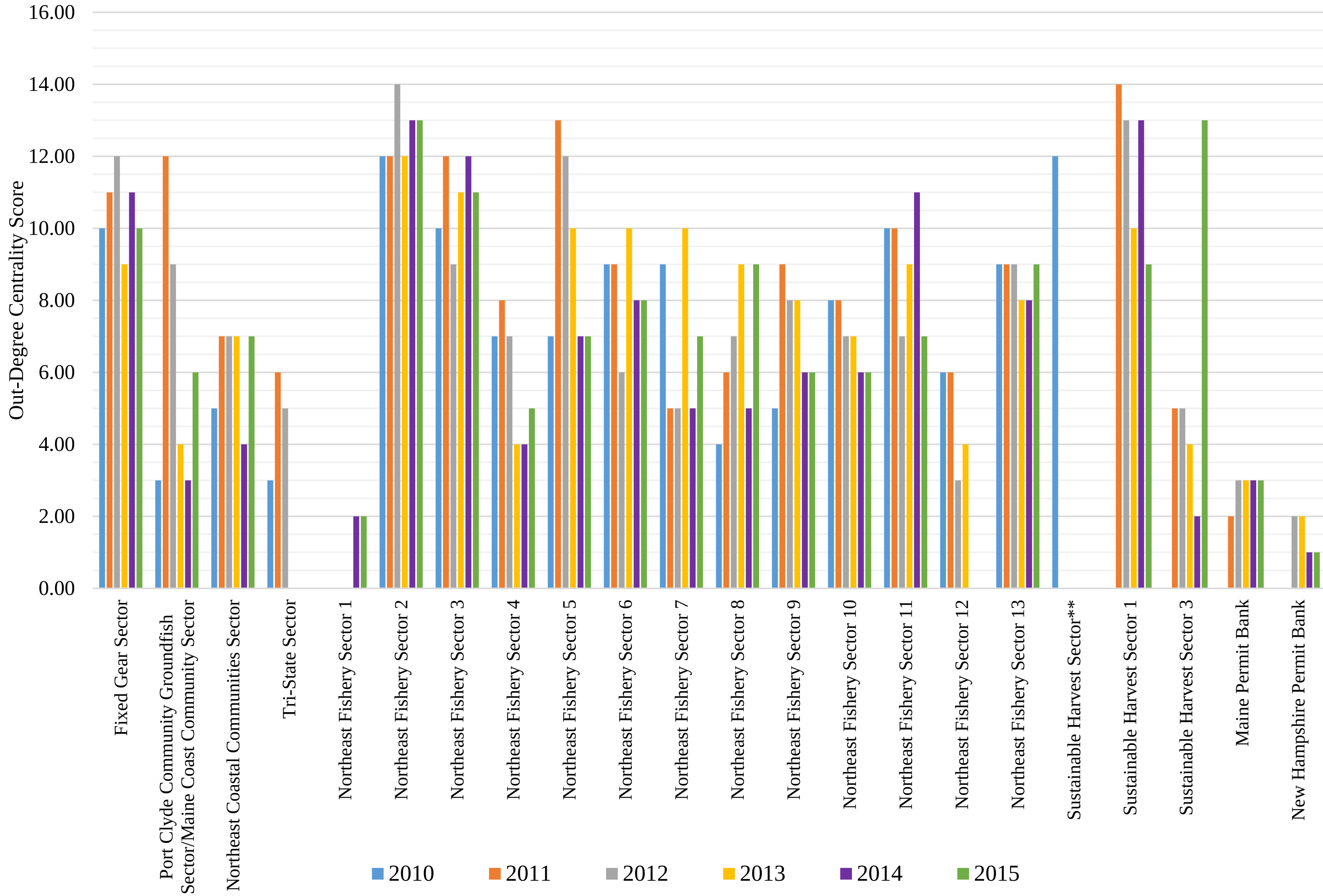

Figure 9. Annual out-degree centrality scores for all nodes, by fishing year (2010 – 2015).

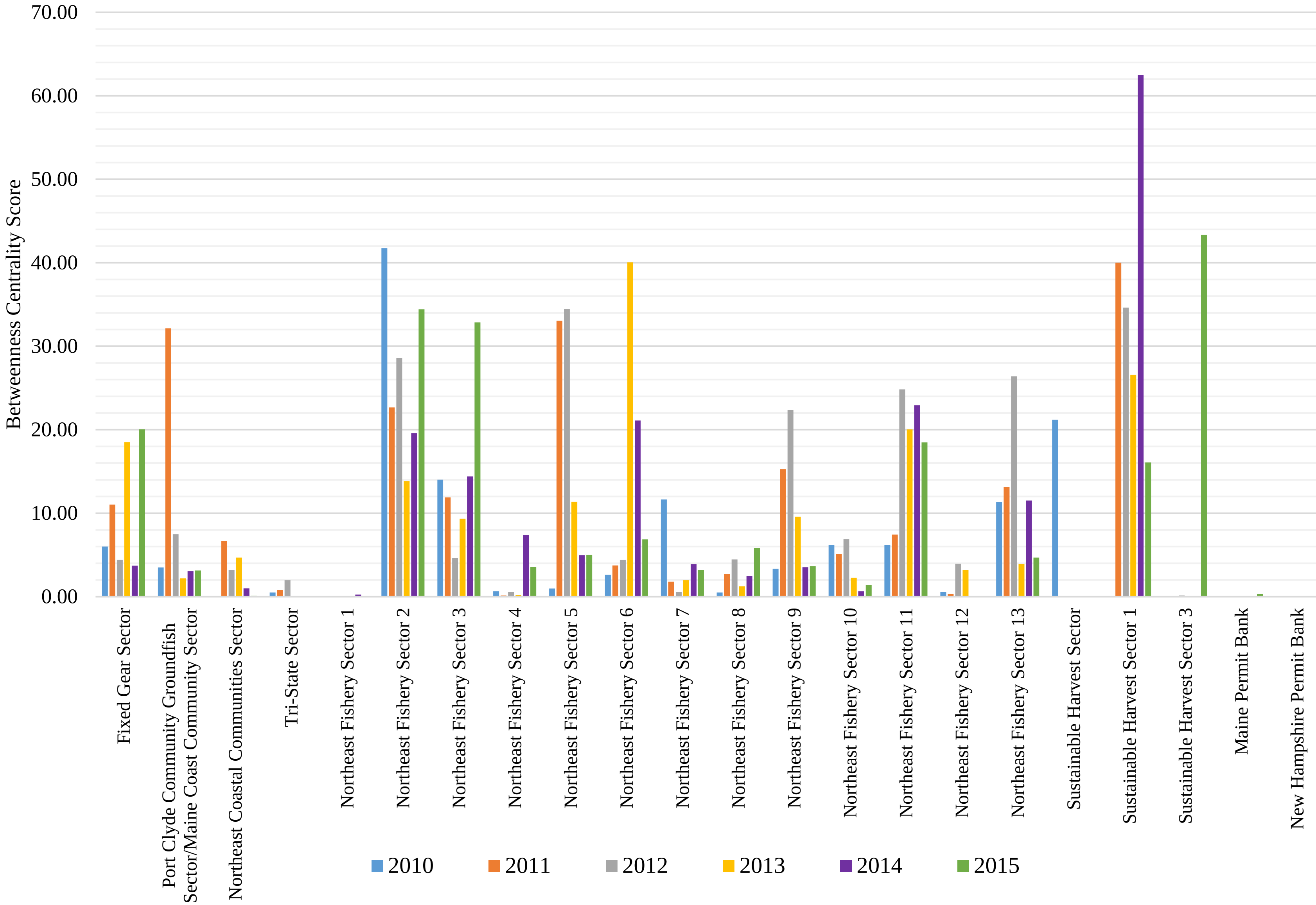

Figure 10. Annual betweenness centrality scores for all nodes, by fishing year (2010 – 2015).

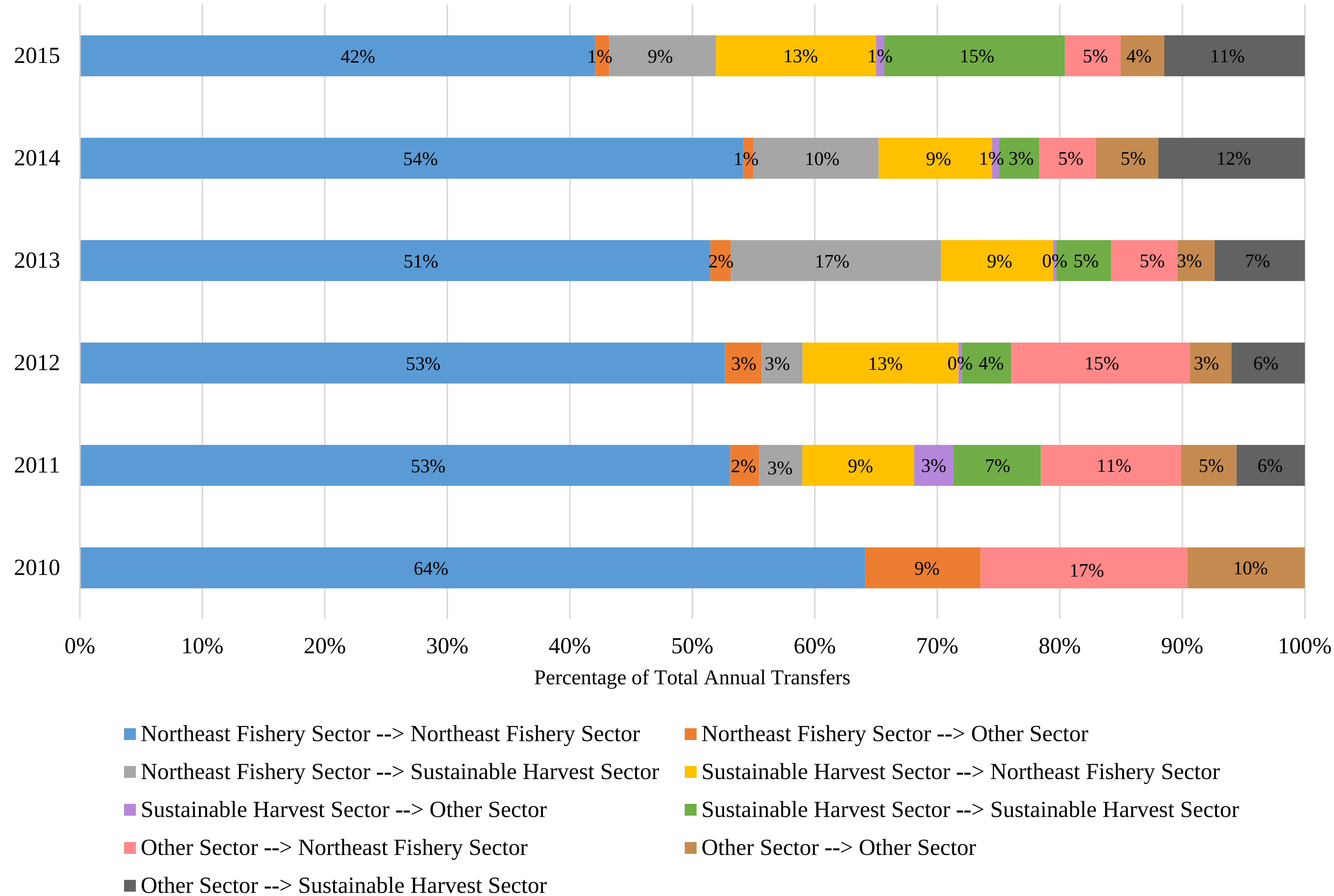

Figure 11. Percentage of transfers between groups of groundfish sectors, by fishing year (2010 – 2015).