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Science-to-management pathways in US Atlantic herring management: using governance network structure and function to track information flow and potential influence

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Atlantic herring (*Clupea harengus*) are crucial members of the ecosystem and economy of the Northwest Atlantic, and a challenging species for management, which in the United States is a multistakeholder process, involving commercial and recreational fishing interests, conservation organizations, state and federal governments, and other interested parties. Given the large number of stakeholders, fisheries management has been conceptualized as a governance network, through which multiple parties access the decision-making process and seek to influence the process or outcome. Network analysis is employed to assess the access pathways for scientific information, i.e. collaborative acoustic-survey data, into stock-assessment decisions and the development process for the fisheries management plan. The governance network map was constructed for US Atlantic herring management in 2006 and 2007. The pathways of information flow in the network showed that participants in the collaborative acoustic survey were well connected to the stock-assessment and fisheries-management processes and decision-makers, particularly through key individuals bridging between the industry, science, and management communities. Heavy reliance on those individuals serving a bridging role made the network connectivity vulnerable, however. The network structure also demonstrated significant influence potential for acoustic-survey information. Ramifications for science-to-management pathways in fisheries are discussed.

Keywords: herring management, influence, network analysis, science to management, stock assessment.

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Introduction

Atlantic herring (*Clupea harengus*) are crucial members of the ecosystem and economy of the Northwest Atlantic. They sustain a directed fishery and provide bait for the lucrative lobster fishery as well as essential food for marine mammals, birds, and other fish species. Consequently, they support extensive economic and community activity. In the Northwest Atlantic, herring are not currently in an overfished state and overfishing is not occurring. However, concerns for the potential of localized depletion and negative impacts on other fisheries and economic sectors have led to a sequence of management plans and amendments in recent years. Stock assessments have been vital in these management deliberations, and there are several sources of herring stock-survey data for the Gulf of Maine and Georges Bank, including government-administered trawl surveys and a collaborative industry–science acoustic survey. A joint US and Canadian technical committee of scientists conducts the stock assessment from these data, which in turn is used to set harvest allocations by the fisheries-management agencies in both countries.

Fisheries management in the United States is a multistakeholder process, involving commercial and recreational fishing interests, conservation organizations, state and federal governments, and other interested parties. It has been criticized for being slow, co-opted, and ineffective because of this structure (Heinz, 2000; Okey, 2003; Rosenberg, 2003), although others have concluded considerable success (Witherell, 2004; Hilborn, 2007). Given the large number of participating stakeholders, fisheries management has been conceptualized as a governance network (Gibbs, 2008), which is defined as non-hierarchical and self-organizing groups of individuals or organizations working together towards a common outcome [e.g. the generation of a fishery management plan (FMP)]. The networks use communication and organizational tools of coordination (e.g. regular meetings, formal communication procedures, coordinating staff or leaders), defined decision-making procedures, and division of labour or responsibilities and expectations (Agranoff, 2007). This multiparty network provides parties with access to fisheries-management decision-making and with opportunity to influence the process or outcome (Verschuren and Arts, 2004; Betsill and Corell, 2008).

Our research employed techniques of network analysis to map and analyse the access pathways for information from a collaborative industry–science acoustic stock survey (CASS or acoustic survey from now on) into Atlantic herring stock assessment and the FMP development processes. We briefly review the social-science literature on the science-to-management process, i.e. the flow of scientific information into the resource management process, how information influences decision-making, and give details for the Atlantic herring case study. The methods for conducting network analysis are discussed, and the resulting maps presented and analysed. We conclude by considering the ramifications for fisheries management and the science-to-management process.

Science-to-management and its influence in decision-making

The social process that integrates scientific information and knowledge into resource management and decisions is not well understood and has only recently been considered directly (McNie, 2007; Wilson, 2009). The literature consists primarily of tips emerging from individual case studies. In particular, research has shown the effectiveness of decision-support frameworks that define a systematic procedure for making science-based decision (Jacobs *et al.*, 2005; Liu *et al.*, 2008).

Scientific research is not always framed or conducted on a scale relevant to the jurisdictional scope of management, nor are findings often communicated in venues used by managers. Therefore, decision-support frameworks facilitate science-to-management by focusing discussion on management-relevant problem definitions and approaches to analyse the problem (Liu *et al.*, 2008). Decision-support frameworks reframe the scientific research questions to address a suite of pragmatic management and social needs, including the appropriate scale of the research, the perceived credibility of the information, and the realities of communicating the findings (Jacobs *et al.*, 2005). Lackey (1998) examined one type of fisheries-management decision-support framework (risk-assessment models) and concluded that they promoted science-to-management because they guided the policy debate towards narrow issues of risk.

The development process for the US FMP is convoluted, but it explicitly lays out a science-based decision framework (Heinz, 2000; Weber, 2002). The adequacy of the science, the responsiveness of management to scientific information, and the effectiveness of the interaction between science and fishery management in the United States have been hotly debated (Crockett, 2005; Witherell, 2005; Rosenberg, 2007). Although decision-support frameworks may lay the groundwork for a science-to-management process and seek to frame the public debate, fisheries management takes place within a human context of conflict among competing ideas, values, and knowledge and the application of political behaviour and negotiation in a governance system (Orbach, 1989; Hilborn, 2007). Nonetheless, Lee (1993) found that the interplay of science and politics can lead to the integration of science into resource management decisions, i.e. what he called a blending of scientific idealism and political pragmatism, although it is a long-term process of social learning. Depending on the temporal scale considered, therefore, science-to-management in multistakeholder fisheries management may be ineffective (short term) or effective (long term). Wilson (2009) found a similar situation when he considered science-to-management in the International Council for the Exploration of the Seas (ICES) science and advisory programmes.

Generally, therefore, fisheries management is undertaken through a science-based decision-support framework that remains inherently political, but over the long term likely facilitates the influence of scientific information through framing the problem and approaches to analysis, setting the agenda, and fostering social learning. However, influence is a challenging social phenomenon to study. Identifying the significance of one piece of information, or the actions of one individual or organization relative to others in a public decision-making process, has not been examined thoroughly by social scientists. Influence, which is a relational variable related to an incident of impact, is different from power, which is commonly associated with a capacity and a structural phenomenon, e.g. position in an organization, resources, and authority. Influence would arise from the use of power, not merely its possession. The science-based decision-support framework in fisheries management puts science in a position of power, but science and the individuals who possess scientific knowledge would influence a decision-making process only if their particular science is used by decision-makers.

Much current literature has sought to define and operationalize influence (e.g. Arts and Verschuren, 1999; Betsill and Corell, 2001). Verschuren and Arts (2004) segmented the process of influence into stages, starting with access to the decision-making process, i.e. a power-related factor considering the position of an individual in the decision-making structure. Once access is available, individuals need to make their information or preferences known to other participants, who need to be exposed to or hear the information and preferences. Last, participants need to understand the information and preferences in order for any action they take to be influenced by the information and preferences.

In this study of Atlantic herring management, network analysis is used to assess the potential for influence of scientific information by considering how the network structure and function observed contributes to each stage of the influence process.

The case of Atlantic herring

Atlantic herring are small, oily schooling pelagic fish that live along the North American Atlantic coast from Cape Hatteras, NC, USA, to the Canadian Maritime provinces. The Atlantic States Marine Fisheries Commission (ASMFC) reported that "herring may be the most important fish in the northeast United States because of its vast role in the ecosystem and its importance to the fishing industry" (ASMFC, 2007). Herring are the forage fish of the foodweb for marine mammals, seabirds, sharks, and >20 fish species throughout the Mid and Northeast Atlantic (NEFMC, 2003). They feed on zooplankton and occupy a critical position in the foodweb between lower and upper trophic levels.

Herring support an important commercial fishery and provide bait for the lobster, blue crab, and tuna fisheries. The fishery developed in the late 19th century, stimulated by the simultaneous development of a canning industry and a lobster fishery. In the early 1960s, a foreign fishery contributed to a collapse of the offshore herring industry in the United States, having increased the average annual landings from 60 000 t through the 1940s and 1950s to peak at 470 000 t in 1968 (ASMFC, 2007). The weir was the main gear used in the herring fishery until the 1940s, when stop-seines became more prevalent. Today, purse-seines and midwater trawls (mobile gears) are the gear of choice (ASMFC, 2007).

Herring management

The ASMFC and the New England Fishery Management Council (NEFMC) jointly regulate herring in state and federal waters in the United States, respectively. Table 1 lists the organizational entities and their functions. The US National Marine Fisheries Service (NMFS) in the National Oceanographic and Atmospheric Administration (NOAA) manages marine fish resources through

Table 1. US fisheries-management organizational entities and roles.

Organizational entity	Acronym	Function
National Marine Fisheries Service	NMFS	The lead US federal scientific and regulatory agency for fisheries, located in the NOAA
Fisheries and Oceans Canada	DFO	The lead Canadian federal scientific and regulatory agency for fisheries
New England Fishery Management Council	NEFMC	One of eight regional councils in the United States established under the Magnuson–Stevens Fishery Conservation and Management Act of 1976 to manage fisheries resources within the federal 200-mile limit offshore of Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut (www.nefmc.org)
Atlantic States Marine Fisheries Commission	ASMFC	The commission that serves as a deliberative body, coordinating the conservation and management of the states' shared nearshore fishery resources (marine, shell, and anadromous) for sustainable use. Member states are Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida (www.asmfc.org)
Transboundary Resources Assessment Committee	TRAC	Reviews stock assessments and projections necessary to support management activities for shared resources across the USA–Canada boundary in the Gulf of Maine–Georges Bank region (www.mar.dfo-mpo.gc.ca/science/TRAC/TRAC.HTML)
Collaborative Acoustic Stock Survey	CASS	The industry–science partnership conducting acoustic surveys of herring during fishing operations (fishery-dependent)
Joint NEFMC–ASMFC Plan Development Team	PDT	Consisting of scientific and technical experts, the PDT reviews available information and produces the FMP text
Advisory Panel	AP	Composed of stakeholder interest groups knowledgeable about the fishery, providing advice and input to the PDT and NEFMC for developing the FMP (there is also an ASMFC herring AP)
Oversight Committee	None	A subset of NEFMC members, the PDT reports to the oversight committee, which reports to the NEFMC

the Magnuson–Stevens Fishery Conservation and Management Act (MSFCM), which was first enacted in 1976 and amended in 1996 and 2007. In addition, NMFS applies the Marine Mammal Protection Act, the Endangered Species Act, the Coastal Zone Management Act, and National Marine Sanctuaries Action, along with international fisheries agreements, in managing fisheries, including that for Atlantic herring.

The MSFCM established eight regional management councils (one of which is the NEFMC), composed of voting representatives from state agencies and citizens representing recreational and commercial fishing interests, conservation organizations, and other stakeholder groups. They also contain non-voting representatives, often from coordinating agencies. The eight councils develop and recommend FMPs for the fish stocks they manage, including specific management measures (e.g. regulations for gear restrictions, fishing seasons, quota limits, and licensing strategies); NMFS has the final approval. FMPs need to comply with the ten national standards in the MSFCM, aimed at preventing overfishing, achieving optimal yields, making use of best scientific information, minimizing the bycatch of non-target species, and considering fishing communities.

The eight councils establish Plan Development Teams (PDTs) for particular species, consisting of scientists and staff from NMFS, council staff, state agencies, and research institutions. PDTs review stock assessment and other scientific findings before drafting regulatory measures and developing proposals for the species-specific oversight committee, which is a subset of the council members. Advisory Panels (APs) are formed for each fishery among recreational and commercial fishers, charter boat operators, buyers, sellers, consumers, and other knowledgeable and interested stakeholder groups to provide advice and input to their respective PDTs, an oversight committee, and the councils. The oversight committee presents management strategies and measures to the full council (for herring, the NEFMC), for the approval and formation of a final FMP, which is then presented to NMFS for approval.

In addition to the federal fisheries-management process, individual states in the United States are responsible for managing fisheries in state waters (within 3 miles of shore), although they must be consistent with federal rules. Established in 1942, the ASMFC has three Commissioners from each of 15 Atlantic coast states from Florida to Maine, specifically the director of each state's marine fisheries agency, a state legislator for each state, and an appointed knowledgeable and interested individual. Each state has a single vote. The ASMFC adopts FMPs for coastal fisheries, although with limited regulatory authority, and it works cooperatively with lead-state regulatory agencies on interstate fisheries management, research, and statistical analysis, fisheries science, habitat conservation, and law enforcement.

Atlantic herring are managed as one stock throughout their range in the Gulf of Maine and on Georges Bank. Nonetheless, there is evidence of three distinct stocks in the region, with different spawning times, locations, and biological characteristics, but the lack of quantitative data on relative stock sizes has led to difficulties in assessing individual stock status (ASMFC, 2006; Overholtz *et al.*, 2006).

A federal FMP became effective in January 2001, and it articulated a quota system with total allowable catches, i.e. when 95% of the annual quota is caught in a single management area, the area is closed until the start of the following fishing year. Four management areas were established, and the FMP required vessel, dealer, and processor permits. Further, the FMP established reporting requirements and restrictions on vessel sizes. Subsequent modifications in 2002 and a joint Federal/State modification in 2007 adjusted the management areas, established more gear restrictions, limited access to the fishery, and adjusted quota calculations (NEFMC, 2002, 2006).

For our work, we were interested in the 2007 FMP decision-making process. A joint NEFMC–ASMFC PDT was established with 15 members from the NMFS, state agencies, universities, and staff from both the NEFMC and the ASMFC. On the federal side, there was an eight-member oversight committee consisting of NEFMC members and one Commissioner from the Mid-Atlantic Fisheries Management Council, and a NEFMC AP consisting of 15 industry groups ranging from New Jersey to Maine. The ASMFC Atlantic herring AP consisted of 13 members, eight of whom also served on the NEFMC Atlantic herring AP.

Acoustic-survey data

There are multiple sources of data on Atlantic herring stocks in the Northwest Atlantic. Foremost, the US and Canadian federal governments support trawl surveys. The US federal government has conducted annual acoustic surveys offshore on Georges Bank and Nantucket Shoals for more than 40 years. Further, the herring fishing industry and scientists at a private research institution conduct collaborative acoustic-survey research inshore on spawning beds.

US and Canadian bottom-trawl surveys have been used to model herring stock trends and abundance, although challenges and limitations have been recorded. For example, environmental factors, altered herring behaviour, and changes in survey gear or timing have been associated with significant annual variability. Moreover, the US trawl-survey data from winter, spring, and autumn have proven difficult to interpret because during those seasons and in the areas sampled, the stock complex is mixed and disaggregation is difficult (Overholtz *et al.*, 2006).

In part to address some of these limitations, acoustic-survey designs for herring in the NW Atlantic have been discussed, refined, and implemented. The designs and protocols were developed in part through a series of workshops among state and federal agencies, academic and research institutions, and the fishing industry in the late 1990s and early 2000s (Michael and Yund, 2001). An acoustic research and monitoring survey was established in 1998 by the NMFS to assess prespawning herring offshore on Georges Bank, followed in 1999 by a industry–science CASS covering inshore, spawning components of the stock along the Maine–New Hampshire–Massachusetts coast.

To develop a collaborative research programme to collect fishery-dependent acoustic data, an initial feasibility project was conducted, and it revealed that relatively inexpensive scientific-grade acoustic systems could be added to commercial fishing vessels to collect substantial acoustic data in the course of normal fishing operations, i.e. fishery-dependent data. However, performing fishery-independent scientific surveys with commercial herring vessels proved substantially more difficult (Scheirer *et al.*, 2005). Therefore, a full-scale fishery-independent acoustic survey using commercial groundfish vessels was tested in 1999; it was more successful, and CASS has been implemented in this manner. Since its inception, the programme has experienced funding uncertainty, periodic staff turnover, inconsistent commercial vessel participation from groundfish and herring fisheries, and a shift in lead scientific responsibilities between a state marine resource agency and a private research institution. Further, new acoustic systems were tested and deployed. Nonetheless, nearly a decade of annual surveys covered coastal waters from eastern Maine to Cape Ann, MA, to assess distribution, abundance, and biomass of spawning Atlantic herring (Salerno, 2007). After the first 6 years of full-scale CASS, an independent peer review of the project was undertaken to certify the results and to receive recommendations for standardized design and operation (Scheirer *et al.*, 2005).

In March 2005, the Northeast Consortium funded and facilitated an independent peer review of the CASS. The review panel concluded that acoustic surveys are an appropriate way to survey herring in the area and recommended that the technique be continued in the inshore Gulf of Maine because of the lack of knowledge of the timing and locations of significant spawning events for herring there (Scheirer *et al.*, 2005). It also recommended that future surveys focus on estimating biomass using a broad-scale systematic survey approach, as well as developing an annual sentinel acoustic survey of the important spawning grounds. Results of the peer review were presented to the federal and state fishery-management entities (NEFMC and the ASMFC) in May 2005 and were adopted in subsequent acoustic surveys (Salerno, 2007).

Stock assessment and the use of survey data

A scientific panel converts survey data and analysis conducted by NMFS and DFO scientists into an overall stock assessment of abundance, geographic and temporal distribution, biomass, and scientific advice on quotas. Given the US–Canada transboundary nature of Atlantic herring and the fishery, there are joint US and Canadian stock-assessment processes in place. Since 1998, the Transboundary Resources Assessment Committee (TRAC) has reviewed stock assessments and the projections necessary to support management activities for shared resources across the US–Canada boundary in the Gulf of Maine and Georges Bank. These assessments provide advice to federal and state resource managers on the status of fish stocks and the likely consequences of management alternatives. The TRAC co-chairs (one DFO and one NMFS appointee) identify co-experts (one from DFO and one from NFMS) responsible for coordinating data preparation, leading the analysis, facilitating production and presentation of the working paper, and inviting independent peer review. The TRAC drafts scientific consensus stock-assessment reports and presents the results to US and Canadian fisheries managers (DFO, 2009).

The TRAC produced reports in 2003 (Overholtz *et al.*, 2004) and 2006 (O'Boyle and Overholtz, 2006), referencing several sources, including NMFS winter, spring, and autumn bottom-trawl surveys, Canadian winter bottom-trawl surveys, US and Canadian larval herring surveys (United States 1971–1994; Canada 1987–1995), the US acoustic surveys on Georges Bank, and the CASS (Overholtz *et al.*, 2004). The fishery-dependent data from the CASS have not been used regularly, although before its 2005 peer review, CASS data were cited by Overholtz *et al.* (2004) and in the NMFS Stock Assessment and Fishery Evaluation (SAFE) reports for Atlantic herring (Northeast Consortium, 2006). Since the 2005 CASS peer review, the survey could not be considered a consistent time-series of stock-assessment data, and the data have been used more qualitatively by the TRAC (Northeast Consortium, 2006). TRAC also produced a report in 2009 (Shepherd *et al.*, 2009), but because this study focused on the 2006/2007 time-frame when the network analysis was conducted, the 2008/2009 stock assessment is not considered here.

To evaluate the influence of CASS data on the stock-assessment process and fisheries management, we conducted a network analysis on the 2007 Atlantic herring FMP decision-making process. The resulting governance network map allowed us to examine the structure and function of the herring fishery-management network, and information pathways for acoustic-survey information from the CASS.

Methods

Social network analysis gathers and analyses data from individuals or organizations on the links or connections among the individuals or organizations, i.e. the actors. Social networks can assess a wide range of resources, authority, information, and levels of interdependence among actors, and it has utility in illustrating the structure of formal and informal networks and resource flow (Scott, 2000). The links and the relationships, rather than the actors, are of primary analytical interest. Communication network analysis is a social network analysis subfield that focuses on the characteristics of specific communication pathways and the patterns of connections that communication produce (Monge and Contractor, 2003). Rather than examining broader social structure, e.g. resources, authority, information, and the levels of interdependence among actors, communication network analysis concentrates on the flow of data, information, knowledge, images, symbols, and other forms of communication among network actors.

Social and communication network analyses have not been applied often to marine or coastal fisheries. Maiolo and Johnson (1989) conducted communication network analyses to identify opinion leaders and central figures in the communication network among southeastern US king mackerel fishers. Schneider *et al.* (2003) conducted comparative institutional mapping studies of estuaries with National Estuarine Programs (NEPs) sponsored by the US Environmental Protection Agency and of those that do not have NEPs.

Surveys and interview protocols are used to gather data for communication network analysis. Software (in this study, InFlow, www.orgnet.com) is readily available to analyse and graphically represent quantitative data on the relationships and interactions within and between individuals and stakeholder groups in a network. Communication is defined as any formal or informal communicative act or contact, i.e. e-mail, face-to-face, telephone, *ad hoc* meetings, etc.

A questionnaire was administered (web-based, hard copies mailed or provided directly to participants, and telephone interviews) among a list of 249 participants identified in the public records as participating in the Atlantic herring FMP process and confirmed as participants by key informants, i.e. lead government staff. The questionnaire asked respondents to indicate the frequency with which they communicated with each listed individual on a scale from 0 to 5, with 0 meaning never; 1, yearly; 2, quarterly; 3, monthly; 4, weekly; and 5, daily. A 1–5 scaled frequency of communication is a common network analysis measure (Scott, 2000; Monge and Contractor, 2003), and a critical factor in social capital (Putnam, 2000) and multiparty planning (Innes, 1998; Forester, 1999), although other measures are used also to assess the value and significance of connections. Further demographic information was gathered, including age, years of experience on the job, educational achievement, and discipline or profession. The individuals participating in the CASS and the TRAC stock-assessment process were identified based on a public record, so that they could be located in the network maps. Standard survey data-collection procedures and quality control standards were used in the design and administration of the questionnaire (Dillman, 1999).

In January and March 2007, we observed FMP public meetings and planning sessions, and throughout 2006 and 2007, we gathered case documentation from the public record and individual participants. We solicited respondents to the questionnaire through a series of e-mail and solicitation letters throughout 2007. In November 2007 and January 2008, we conducted face-to-face interviews with five key participants.

Data on the links (i.e. scaled frequency measures) and the nodes (i.e. demographic identifiers for the individuals) were entered into a database for importation into the InFlow software to generate communication network maps and to run the network connectivity measures. An algorithm from mathematical graph theory is applied by most network analysis software; the algorithm in InFlow spatially orientates nodes in a map based on their relationship with each other. Once the network was mapped, we calculated connectivity metrics. Several measures of network structure and operation are available, although this study focused on connectivity among individuals and specific pathways between those involved in the stock assessment and fisheries management processes. Hence, network size, density, and path lengths were analysed, along with measures of an individual's network centrality (degree, betweenness, closeness). Degree is defined as the total number of links an individual has with other nodes and is a measure of the activity level of the individual (Scott, 2000; Monge and Contractor, 2003). Betweenness is a core measure of centrality in a network, based on a position of shortest path between other nodes in a network (Freeman 1977). Someone with higher values of betweenness is most efficiently linking different individuals. For instance, an individual positioned between two clusters of nodes that are not otherwise connected would have a high value of betweenness. Closeness measures how close an individual is to everyone else; individuals with the highest values of closeness have the shortest path to everyone else and are in the best network position to monitor network information flow (Scott, 2000; Monge and Contractor, 2003). Preliminary findings and communication network maps were presented to and discussed with NEFMC staff in November 2007 and the Atlantic herring PDT in August 2008, aiding interpretation (e.g. further qualitative characteristics of communication links and network function) and allowing further gathering of data.

Results

The communication network map of Atlantic herring fisheries management (Figure 1) reflects a snapshot in time (winter/spring 2007) among 146 individuals communicating weekly, consisting of members of state agencies from Maine to North Carolina, US and Canadian federal fisheries agencies, several industry sectors (e.g. the directed herring fishery, the lobster fishery, the hook-and-line sector), and four non-governmental organizations (NGOs). The map represents individuals (referred to as nodes or actors) as the endpoints of lines, and (at least weekly) communication channels between two nodes as lines. The network's density was 1%. Density is a measure of network activity, and it reflects the number of linkages among members; if everyone was connected to everyone else, the network density would be 100%. At the same time, the weighted average path length of the entire network was 2.5, i.e. on average any two individuals in the network are fewer than three links away from each other.

The node located in the centre of the map (Figure 1) demonstrated on average four times more links to others than the next ranked member of the network. That individual's network position and function illustrated the highest overall activity level in

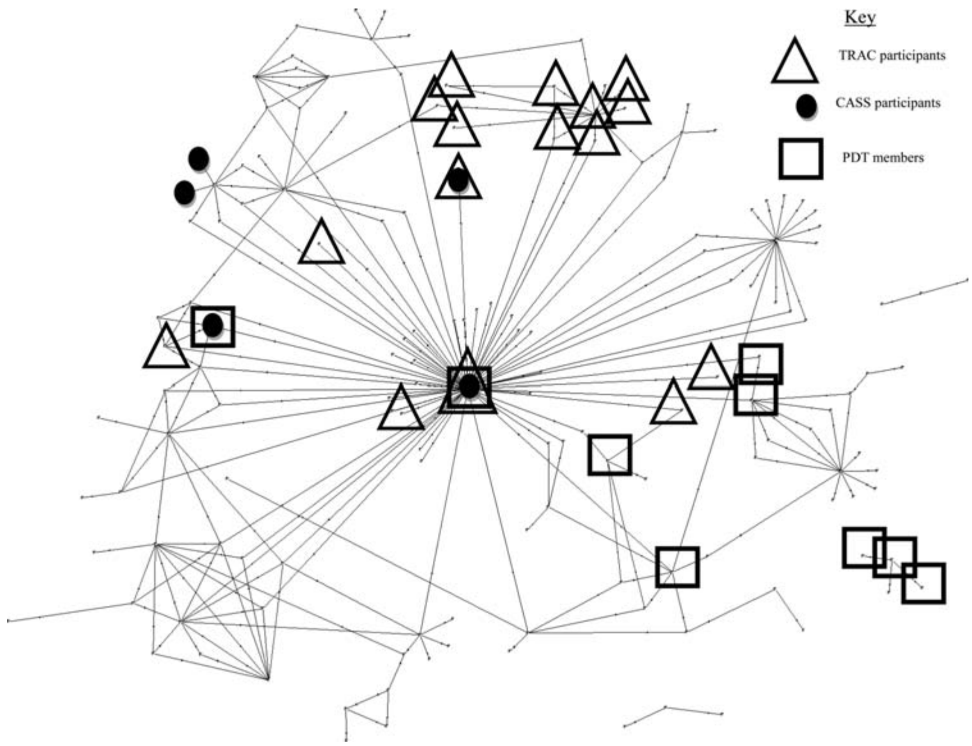

Figure 1. Atlantic herring FMP network map for weekly communication, with overlaid the TRAC, the CASS, and the PDT participants.

the network. He had the highest betweenness score (0.20), three times higher than the next ranked network member (0.06).

Lists were available in the public record of participants in the CASS, the TRAC stock-assessment process, and the PDT members; Figure 1 identifies these participants in the overall Atlantic herring FMP network. Two individuals participated in both the acoustic survey and the TRAC, i.e. one from industry (upper central in the figure) and one from a state regulatory agency (the central one in the figure), so bridged between those subgroups. The state regulatory agency member is the individual discussed above with the highest value of betweenness (0.20) and most overall links, i.e. degrees. In fact, that individual also participated on the PDT, so bridged all three subgroups. A second representative from the state regulatory agency participated in the acoustic survey and the PDT. Hence, the acoustic-survey subgroup had twice as many representatives on the PDT (two) as the TRAC (one), although the TRAC had more of its subgroup members (16 of the total of 28, or 57%) involved in the FMP process at a weekly frequency than the acoustic survey (5 of the total of 24, or 21%).

Nevertheless, the additional bridge between the acoustic survey and the PDT would be significant if, hypothetically, there was turnover in the most central individual, e.g. if he changed jobs, retired, or changed roles in the FMP network. Figure 2 below illustrates the resulting network map if that central individual was removed hypothetically. The resulting network would fracture into 5, disconnected subclusters, and 23 isolated individuals. However, the acoustic survey maintained two overlapping connections—one industry representative who also participated in the TRAC, and one state regulatory staff who served on the PDT—despite the loss of the most active, central network member.

Influence was segmented into stages to consider (Verschuren and Arts, 2004): access (i.e. a structural factor that provides access to decision-makers in the network); voice (i.e. an ability to articulate and/or present information in a manner that makes it available to the receiver); heard (i.e. the receivers who are exposed to information actually hear or acknowledge the information); understood (i.e. ability to have information correctly understood by others); and acted upon (i.e. ability to have information used to make decision). The objective of this study was not directly to measure these influence components, but rather to assess whether the network structure and function, as measured by the map and its centrality measures, provided direct evidence of the influence components. The network maintained a weighted average path length of 2.5, ensuring that on average individuals were less than three path lengths apart. The two individuals with direct bridging roles between the CASS and the TRAC, and between the CASS and the PDT, also illustrated direct access that could allow influence.

The network map illustrates weekly communication among the 146 individuals in the Atlantic herring fisheries-management process in early 2007. At a regular communicative interval, weekly, the opportunity existed for CASS information to be voiced and heard by others in the network. Coupled with the weighted average path length network value and the direct bridging connections, it is likely that acoustic-survey information was voiced and heard by members of the TRAC and PDT, although this study did not directly ask that question. Although the network structure as measured in this study could not determine whether information was understood, the bridgers who sat in both subgroups would likely understand information from both subgroups, because they had direct access to the information generated by both. A bridger is a common network analysis role,

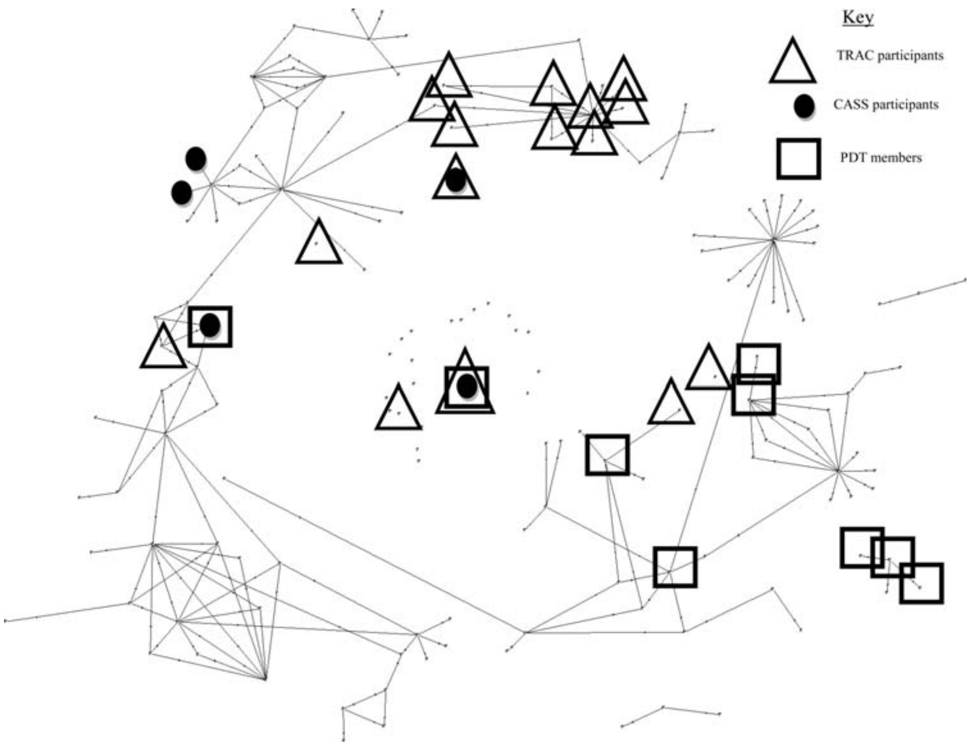

Figure 2. Atlantic herring FMP network map, with overlaid the hypothetical removal of one central bridging individual.

reflecting an individual who connects two or more otherwise disparate groups. It was not possible to determine whether the CASS information was acted upon in the TRAC or PDT, but the 2006 herring stock assessments acknowledged the CASS data (Overholtz *et al.*, 2006).

Discussion

The Atlantic herring FMP network displays substantial connectivity across a wide array of stakeholders, with a weighted average path length of 2.5 that is well within the connectivity thresholds from the literature. Friedkin's (1983) study of organizational behaviour in universities identified the threshold number of links beyond which an individual is unaware of another person's role and information. Information or resources within two links of someone is readily available and utilized in decisions. In the range 2–3 links away, decision-makers may be generally aware of others and their information; however, it becomes less clear and decision-makers are less conscious of its availability. Beyond three links away, the information is beyond a decision-maker's horizon of observability. Although there are significant differences between universities and public sector decision-making, e.g. public decisions often requiring and government officials proactively seeking public comment, a horizon of observability likely exists in public decisions too, although the threshold value may be different.

The low density (1%) of the Atlantic herring FMP network reflects limited weekly interactions overall among the diverse stakeholder groups involved, although individual bridgers forge strong connectivity between the subgroups. The bridgers connect otherwise disparate groups in the network and allow the network to share information efficiently, broadly, and quickly (within a week). One particular individual showed very high activity level and betweenness scores, i.e. his network position provided control over information flow across the network and facilitated connections between clusters of individuals that might otherwise not have been connected to each other. Coleman (1990) showed that the presence of many links in a network (high density) contributes to the sense of belonging and group identity. Bodin *et al.* (2006) suggested that density is an indication of the strength of trust and the potential of social control among a group. Therefore, the Atlantic herring FMP network was less likely to form a strong sense of group identity or belonging. The stakeholders will remain independent, and the network structure illustrated the disparate subgroups. Fisheries management in the United States is often characterized as a competitive public deliberation among disparate interest groups (Orbach, 1989; Hilborn, 2007; Gibbs, 2008), consistent with the network structure findings in this study.

The network positions of CASS participants within the TRAC demonstrated sufficient access to ensure that the information and data were available to the stock-assessment scientists. Document review confirmed that the TRAC scientists were aware of the availability of the CASS data (Overholtz *et al.*, 2006). Further, two individuals, one industry leader and one state regulatory agency scientist, participated in both the TRAC and the CASS, helping to bridge and integrate these two informational and decision-making domains. The effectiveness of the bridgers is enhanced by the potential credibility of an industry representative and a marine scientist in the state agency, i.e. they both have access to and likely credibility with their respective stakeholder groups. Networks with bridgers to diverse resources function more adaptively and creatively than networks with high density and many tight links (Newman and Dale, 2005). Bridgers can synthesize a large pool of knowledge and learn about the organizational dynamics and interests of those subgroups, so provide advantages in identifying whom to connect to and how (Burt, 2003). Hence, effective bridgers who span the boundary between the industry and the regulatory communities provide greater capacity for the Atlantic herring stock-assessment process to be creative and to address the challenges that have been acknowledged in the stock assessment (Overholtz *et al*., 2006).

Not all communication is equal; some has more significance in transmitting particular types of information or resources (Granovetter, 1983), so pathways to the PDT are important for potential influence and for facilitating the science-to-management process. Both TRAC and CASS members have access to the PDT through their members participating directly on the PDT. The institutionalized role of the TRAC gives it preferential weight in the stock assessment over the CASS. However, the CASS had twice as many individuals serving bridging roles as the TRAC, which in turn provide opportunities for more communication pathways to access the PDT. Consequently, the CASS may not be disadvantaged by not being as institutionalized as the federal trawl surveys.

In terms of influence, the network structure provided evidence of three initial stages (i.e. access, voice, and heard), but did not fully address whether the information from CASS was understood or acted upon. The network structure and function demonstrated that the CASS had access to both the stock-assessment and the fisheries-management processes. The most central individual bridge was facilitating information flow among the CASS, the TRAC, and the PDT, so promoting the voice stage of influence and the opportunity to ensure that the information was heard. The potential and opportunity for influence was clear, but actual influence remained uncertain. More research is needed to assess whether decisions were made based on the CASS and TRAC information.

Overall, the Atlantic herring FMP network structure and function demonstrated a level of connectivity to provide CASS participants with access to and awareness of their information in both the scientific stock-assessment process and the management process. Although the CASS is not fully institutionalized in the decision-support framework as a source of information to the TRAC or the PDT, bridgers served critical roles of establishing potential influence. The dependence on bridgers introduces vulnerability to a network function. If bridgers leave the network, considerable connectivity would be temporarily lost. This is particularly true in the Atlantic herring network, because one bridger was simultaneously a participant of the CASS, the TRAC, and the PDT. Turnover would lead to replacement or reassignment of another staff member to the CASS, the TRAC, and the PDT role, but time would be needed to re-establish the links and effectiveness of the network should that eventuate.

We have shown that fisheries management can be analysed as a network, as Gibbs (2008) suggested. In fact, the Atlantic herring fisheries-management network was more sophisticated than the structured decision-support framework laid out in the US fisheries-management procedures. The network could share information broadly and quickly, particularly with the significant role of the bridgers that sit in multiple subgroups within the network and provide information channels between stakeholder groups (Goldsmith and Kettl, 2009). However, the Atlantic herring network was not dense, which would lead to a sense of group identity and belonging. Instead, the network contained disparate subgroups, corroborating the view that US fisheries management is a public deliberation among competing interests. This has ramifications for understanding the science-to-management process: significant scientific information can move outside the structured decision-making procedures, and bridgers may serve critical roles in facilitating this information flow. The CASS in particular had different pathways from those defined by the institutionalized decision-support framework to access the stock-assessment and fisheries-management decision-makers, and these alternative pathways provide opportunities for potential influence. Wilson (2009) concluded from his review of the ICES Science and Advisory Programmes that constructive tension exists around the boundary between science and advisory responsibilities. The tension allows creativity and promotes an adaptive, learning institution. However, Wilson (2009) also underscores the importance of maintaining clear boundaries to maintain the required salience, credibility, and legitimacy of science, which are necessary to have influence in policy. The CASS blended the science and management decision-making subgroups in the Atlantic herring FMP network, blurring the boundaries between science and non-science.

Taking insights from the corporate sector (e.g. Aries and Trout, 1981; Njuguna, 2009), NGOs think about their strategic position and the niche of their organization within a broader network to enhance their realm of influence (McLaughlin, 2006). Further research could examine whether CASS participants were acting strategically, seeking out positions in the broader network relative to the TRAC and PDT participants; the literature hypothesizes that they were.

Other participating groups, including government managers, could think about the network in a similar strategic positioning manner. Managers and stakeholder groups could attend to the role and tools of bridging, e.g. what communication and information management capacity do bridgers need, and what organizational recognition and credit do they receive for serving this network role in addition to their organizational responsibilities. The decision-support framework could integrate the role of these bridgers more explicitly. However, serving as a bridge can be complicated, and bridgers hold multiple roles and responsibilities for the network and for their stakeholder groups. Hence, bridgers are likely presented with situations where multiple interests of their multiple subgroup membership may be in conflict. They need either to choose one interest over another or to elect to act strategically and aim to advance one interest at the expense of another.

Further, heavy reliance on bridgers for network function also requires managing for change, given the potential for turnover. Stakeholders, including government and science, may need to ensure a sufficient number of connections to enough different bridgers and stakeholder groups to adapt to turnover. This will become even more significant for government agencies in the United States in coming years, because large numbers of the workforce are due to retire (US Department of Commerce and US Department of Education, 2008). The network map provides guidance on to whom to make new connections most effectively and efficiently to access the subgroups and decision-makers of interest; individuals with higher centrality measures will provide more efficient access to the breadth of the network.

Although the network structure and function provided evidence into the influence that information sources might have, those insights were limited to the first three stages of influence (access, voice, and being heard), rather than to the final two critical steps (whether the information is understood by others, and whether others acted upon that information). More research is needed here, including exploring other features of network links that will suggest how important for resource management decision-making that link might be, e.g. the usefulness and credibility of information, the trustworthiness of the source, and the perceived weight or significance of the source's opinion.

Finally, networks are non-hierarchical and self-organizing, although they are guided by prescriptive decision-making procedures, such as FMP development frameworks. Managing a network to advance the science-to-management process, to maximize influence, or more broadly to achieve public and societal value is not easy (Goldsmith and Eggers, 2004; McGuire, 2006), but understanding how the network is structured and functions is an important first step.

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