Evaluating aquaculture as a diversification strategy for Maine's commercial fishing sector in the face of change

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Declaration of Interest

JSS has a standard aquaculture lease and raises American Oysters in Georgetown, Maine. JSS is also a member of the Maine Aquaculture Association.

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Abstract

Aquaculture represents an increasingly significant share of the global supply of freshwater and marine resources. The distribution of benefits from aquaculture development will largely depend on who has the resources necessary to participate in the sector and how the sector is governed. We investigate the extent to which aquaculture is being utilized by commercial fishermen to expand and diversify their livelihoods in Maine, USA. Here, a network approach is used to delineate individuals' participation in aquaculture and wild-capture fisheries. Results show that while some fishermen are starting aquaculture businesses, aquaculture has had a limited effect on livelihood diversification for those engaged in the commercial fishing sector to date. These findings raise questions about who will benefit from aquaculture and how the continued growth will compete with existing marine resource sectors, including wild-capture fisheries. We argue that the extent to which aquaculture can foster livelihood diversification in the long term and fit within existing coastal economies will largely depend on the institutions that are established to govern the sector.

1. Introduction

Aquaculture production is increasing worldwide (Troell et al., 2014). Production for human consumption now accounts for 44% of total fish supply and is expected to surpass wild-caught fish capture within the next ten years (FAO, 2016). Growth in the sector is being catalyzed by significant public and private investments in the science, technology, and infrastructure aimed at improving husbandry practices and expanding production capacity. Many nations are institutionalizing this growth with strategic policy directives that include ambitious production goals within their Exclusive Economic Zones (Baines and Edwards, 2018; Gonzalez-Poblete et al., 2018; Grist, 2002; Fairbanks 2018; Sandersen and Kvalvik, 2015).

Central to the promotion of aquaculture development is its potential to contribute to the global food supply, lower seafood trade deficits, alleviate poverty and hunger, reduce pressure on wild stocks, and diversify coastal economies and marine resource users' livelihood strategies (Grist, 2002; Hamouda et al., 2005; Marshall, 2001; Martínez-Novo et al., 2017; Ramos et al., 2015; Renwick, 2018). Recent mapping exercises that model production capacity identify untapped aquaculture potential and make these benefits seem well within the realm of possibility (Gentry et al., 2017).

In this moment of increasing aquaculture optimism, greater attention to the suite of benefits that aquaculture provides in practice and to whom is needed. The need for this type of critical assessment and rigorous scholarship on the human dimensions of aquaculture more broadly is underscored by the history of aquaculture development, which has in some instances negatively impacted coastal communities by triggering resource consolidation, destabilizing traditional land tenure systems, displacing small-scale resource users, and causing conflict with other marine resource uses (see, for example: Belton et al., 2018; Ellis et al., 2016; Gonzalez-Poblete et al., 2018; Knott and Neis, 2017; Marshall, 2001; Pitchon, 2015; Rosendal et al., 2013; Wiber et al.,

2012). Such cases are not necessarily reason to curb or abandon aquaculture development efforts or dismiss its potentially beneficial contributions to society, but they highlight a paradox. Krause et al. (2015:45) eloquently articulate the paradox, pointing out that efforts to expand aquaculture and capitalize on the blue economy can result in the "exclusion of society from a revolution initiated for its very own benefit."

One reason that the benefits of aquaculture are sometimes decoupled from the places where it is occurring is because aquaculture development tends to be evaluated on performance metrics related to technological innovation, production capacity, gross output, number of jobs created, and total area farmed (Alexander et al., 2015; Ellis et al., 2016; Gentry et al., 2017), rather than on social parameters associated with the quality of work, distribution of project, and the general well-being of the people who live in coastal communities where aquaculture is implemented (Bailey, 1988; Blythe et al., 2017; Galappaththi and Berkes, 2014; Natale et al., 2013; Pitchon, 2015). While the former may resonate at regional, national, or global scales, the type and quality of social interactions that underlie aquaculture development are also important, especially at scales relevant to the lived experiences of individuals and coastal communities. We posit that the degree of autonomy that coastal communities have in shaping the trajectory of aquaculture and other coastal development; who has the financial resources and technical skills to capitalize on aquaculture (and who does not); how benefits of aquaculture development are dispersed long-term and how intergenerational transfer of farmers occurs; and the extent to which aquaculture augments or competes with existing marine resource uses matter because these issues have direct implications for the well-being of individuals and coastal communities where aquaculture occurs (Bailey, 1988).

The research presented in this paper focuses on the relationship between the commercial fishing sector in the state of Maine, USA, and the burgeoning aquaculture sector in the region. We begin by describing the recent development of aquaculture in the state and then use a network analysis to better understand who is participating in aquaculture, with a focus on understanding the role it is playing as a diversification strategy for those engaged in Maine's wild-capture fisheries. In particular, our analysis focuses on the subset of people who hold access rights to participate in wild-capture and aquaculture fisheries, as opposed to those who work in the two sectors as crew, contractors, or other types of employees. The extent to which commercial fishermen[1] are adopting aquaculture in practice has not been thoroughly evaluated, even though livelihood and coastal economy diversification are among the stated reasons that it is promoted in the state and for which public and private investments are being made (e.g., Smith, 2017). Focusing on this relationship presents an opportunity to evaluate the extent to which aquaculture achieves these social benefits at multiple levels, and, simultaneously, to respond directly to continued calls in the literature for more attention to the human dimensions of aquaculture (Bailey, 1988; Blythe et al., 2017; Galappaththi and Berkes, 2014; Natale et al., 2013; Pitchon, 2015).

We focus specifically on the state of Maine and the relationship between wild-capture fisheries and aquaculture because changing ocean and coastal conditions are raising concerns about the long-term viability of fisheries in the state, and there is a perceived need for economic

[1] Our use the term 'fishermen' is intended to be gender neutral. We use it here because most people in the commercial fishing sector in Maine prefer this term over 'fisher'.

alternatives (Stoll et al., 2016). At the same time, aquaculture is being framed as an important economic alternative for fishermen and coastal communities, and major investments are being made in the science, technology, and infrastructure to improve husbandry practices and catalyze aquaculture-related activities (ARI, 2017). With this investment has come growth in the sector, as we describe in more detail below. While the specifics of this case are undoubtedly unique to Maine, the general pattern (i.e., changing fisheries, community dependence on natural resources, and increasing aquaculture activity) is not uncommon. Therefore, it represents a useful case to explore how people are interacting with aquaculture and what these social interactions mean in terms of benefits to individuals and communities.

1.1 Background and Study Area

The current Public Law that supports commercial aquaculture in Maine was established in 1978 (PL 1997, c. 661) and builds off previous legislation that can be traced back to at least the mid-1950s. The legal system, which has continued to be refined through time, includes three types of permits, each with a unique set of features (Table 1). Standard Leases are the largest of the three types of aquaculture permits and can be up to 100 acres. Standard Leases have a 20-year lease period and are transferable, which means they can be bought, sold, or traded with the approval of the Maine Department of Marine Resources (DMR). The second type of aquaculture permit that the state issues is for Experimental Leases, which cannot exceed four acres. One defining feature of Experimental Leases is that they are non-renewable, except in cases where they are being used for scientific purposes. Limited Purpose Aquaculture licenses (LPAs) are the smallest type of aquaculture permit (400 ft^2) and need to be renewed annually. Unlike Standard and Experimental Leases, LPAs cannot be issued to corporations, and individuals who hold them are required to participate in an annual training, which is intended to ensure that people have a minimum level of knowledge about aquaculture production and public health[2].

[Please insert Table 1]

In 1975, Ed Myers obtained the first DMR lease to raise cultured oysters on the Damariscotta River Estuary at Abandoned Farm in South Bristol (Hendrix, 2004). Ocean Products, Inc. is credited with being the first successful commercial-scale operation for salmon in Maine. Lease records maintained by DMR show that the company was granted a 45-acre lease in Cobscook Bay in 1985 to raise Atlantic salmon in net pens (Lease # COB-BC). The Maine-based company then sold the operation to Connor's Brothers, Ltd., which later transferred its lease to Heritage Salmon and then to Phoenix Salmon, Inc. Later, Phoenix Salmon changed its name to Cooke Aquaculture, which is the sole marine-based salmon aquaculture company active in the United States today.

Salmon farming is the largest (by volume and value) aquaculture sector in the state. According to DMR, which is responsible for managing wild-capture fisheries and aquaculture in state waters (0 to 3 nm), salmon production alone exceeded $55 million in 2010 (the last year these data were reported[3]). In addition to salmon, numerous other species are or have been farmed or are in

[2] People that hold either of the two larger types of leases are not required to take a training.

[3] DMR does not reported data on fisheries with three or few participants to protect businesses' confidentiality.

experimental phases of development throughout Maine, including American lobster, blue mussels, Atlantic halibut, polychaete worms, green urchins, American oysters, American eels, sea scallops, and a variety of sea vegetables.

Public investments by way of direct funding, science and technical support, and policy reform have played a critical role in facilitating the growth and sustainability of the aquaculture sector in Maine. The University of Maine's Darling Marine Center (est. 1965), Maine Sea Grant (est. 1971), Maine Aquaculture Association (est. 1976), University of Maine's Fisheries and Aquaculture Research Group (est. 1985), Downeast Institute (formally Beal's Island Regional Shellfish Hatchery) (est. 1987/2000), Maine Aquaculture Innovation Center (est. 1988), Center for Cooperative Aquaculture Research (est. 1999), and Aquaculture Research Institute (est. 2009) played a particularly pivotal role in helping Maine's nascent aquaculture industry in its early years. These organizations and institutions have made major investments in health monitoring programs and technology for disease diagnosis and treatment for both finfish and shellfish, working on amoebic gill disease, host-pathogen interactions (including for the MSX parasite and sea lice), and basic immunology for farmed species. Similar investments were also made to improve basic husbandry techniques, upweller technology for juvenile oysters (Baldwin et al., 1995), integrated multi-trophic aquaculture farming (Pietrak et al., 2012), blue mussel rafts (Riley and Morse, 2001), and site selection (Snyder et al., 2017).

As interest in aquaculture in Maine has grown, many other organizations have invested in the sector. There are at least 85 institutions or programs within existing organizations that are actively engaged in promoting the development of aquaculture through education and outreach, research, and funding, including the aforementioned groups as well as numerous newcomers (Appendix 1). These efforts were catalyzed, in part, by a $20 million National Science Foundation Track 1 Experimental Program to Stimulate Competitive Research (EPSCoR) grant awarded to the University of Maine in 2014 to create the Sustainable Ecological Aquaculture Network. These resources were intended to leverage the resources and capacity in the state to "help advance sustainable ecological aquaculture" (SEANET, n.d.).

Together, these investments have contributed to the growth of Maine's aquaculture sector. Growth has been particularly rapid in recent years with an influx of new participants starting farms (Fig. 1). A report by the Aquaculture Research Institute (2017), for example, found that, as of 2017, 24% of growers in Maine started operating in the past two years and 45% started in the past five years. These new farmers have invested a combined $10.8 million in the sector in the last three years alone (ARI, 2017), beyond the public investments that have been made. Growth has been further catalyzed by several aquaculture training programs designed to help interested parties start aquaculture businesses and legislative changes enacted to reduce the regulatory constraints on aquaculture [e.g., L.D. 1438 (128th Legis. 2017)]. Focus Maine, a coalition of state business leaders, predicts that with continued investment, Maine's aquaculture exports could increase by an additional $230 to $800 million by 2025 (Focus Maine, 2016).

Maine does not have a comprehensive management plan to guide the growth of aquaculture, but there have been a number of previous policy reports and four efforts between 1990 and 2010 to articulate a vision for aquaculture in the state and identify key impediments to growth. Of these, three were developed through formal state planning processes and one was spearheaded by the

Maine Aquaculture Association, a private trade association that promotes the sector. These documents include a set of arguments that have been used to justify and support aquaculture development. One of the reoccurring justifications is that aquaculture provides a critically important opportunity for coastal communities to strengthen their economies. This perspective, for example, is articulated in the 2004 *Governor's Task Force on the Planning and Development of Marine Aquaculture in Maine* (2004:3), which states: "Marine aquaculture offers the potential to bring substantial economic value and diversity to the state and its communities." Similar logic is echoed in the executive summary of the Maine Aquaculture Association's publication, *Directing the Future of Maine's Aquaculture Cluster*. Here, the authors note that if aquaculture is not embraced as a diversification strategy, "[t]raditional coastal communities and their year-round working waterfronts will slowly erode" (Belle et al., 2010:4).

The process by which aquaculture will help to diversify coastal communities' economies in practice are not always stated explicitly, but one argument is that it will happen when commercial fishermen enter the sector. This is evident, for example, in the rhetorical questions used to frame the introduction of the *Aquaculture Development Strategy for the State of Maine* (1990:8):

> Maine's fishing industry is undergoing dramatic change. Pressures on traditional fisheries are mounting. Concerns about overharvesting rise, at the same time that demand for seafood increases. Can aquaculture help fishermen meet this demand? Can the State help sustain small-scale fishing operations by making it easier for them to supplement traditional harvesting with aquaculture?

While the *Governor's Task Force on the Planning and Development of Marine Aquaculture in Maine* directly challenges[4] this perspective, the narrative that aquaculture provides a diversification strategy for commercial fishermen has been persistent and continues to be used to motivate aquaculture development. Evidence of this is captured in the media with claims that it is "one of the best parts of the story" (Smith 2017), as well as in the public testimony on legislative bills. For example, during a proposed bill to establish a legislative task force on aquaculture in 2019 [L.D. 1420 (129th Legis. 2019)], one representative explained: "the record shows that aquaculture is an important tool that will help coastal communities… and working waterfront families continue their maritime heritage." Another person reflected a similar viewpoint, commenting that "LPAs have been a great tool for traditional, commercial fishermen to diversify." The extent to which aquaculture is leading to greater diversification among commercial fishermen, a key constituency in coastal communities, is the focus of this paper.

[Please insert Figure 1]

[4] The authors of the *Governor's Task Force on the Planning and Development of Marine Aquaculture in Maine* write that the "state's original vision of finfish aquaculture as a major economic development strategy … that would provide fishermen a new economic activity to supplement declining wild fisheries revenues has not been realized… While they have not remained farmers, local fishing families have been able to diversify their economic base by developing service companies such as contract diving and fish and feed transport vessels" (2004:29).

2. Methods

2.1. Data Collection and Analysis

The research presented in this paper draws on licensing and leasing data for wild-capture fisheries and aquaculture in Maine as well as the authors' combined experiences working in and around these sectors for more than a decade. Individuals who are engaged in wild-capture fisheries in Maine are responsible for obtaining commercial fishing licenses for the species they target from the DMR. These licenses must be renewed annually or fishing privileges will be revoked. The details of this licensing system are beyond the scope of this paper (see Stoll et al. 2016 for a detailed description), but, in general, licenses are issued by species or gear and individuals are required to hold a separate license for each fishery s/he targets. Similarly, individuals who own aquaculture operations are required to obtain a license or a lease from DMR. Licenses for aquaculture are issued to individuals with small-scale operations that are no more than 400 square feet. Those who start larger scale aquaculture farms are required to obtain a lease. Unlike the licenses for wild-capture fisheries or LPA sites, leases can be issued to corporate entities and can be held for up to twenty years before requiring renewal. These leases, as previously mentioned, also differ from LPA sites and commercial fishing licenses in that they are transferable. DMR is responsible for maintaining records of all individuals and enterprises that hold licenses and leases for wild-capture fisheries and aquaculture. These data are maintained by separate units within DMR, and are publicly available upon request. In this paper, we refer to both licenses for LPAs and leases as licenses for simplicity, except in cases where the distinction is of material relevance[5].

To understand the extent to which commercial fishermen are diversifying into the aquaculture sector and how the patterns have changed through time, aquaculture license data were merged with wild-capture fishing license data across Maine using R (version 3.3.3) and then cross-checked manually. Data were analyzed for the most recent calendar year in which data were available (2017) and also for 2012, to provide a five-year comparison. The data included information on nearly ten thousand individuals with licenses for wild-capture fisheries or aquaculture in each year. Data dating back to 1995 also were used to confirm individuals' licensing histories to determine if those involved in aquaculture had participated in wild-capture fisheries in Maine in the past.

DMR does not have a unifying system to track all types of marine resource users, so the wild-capture and aquaculture data were integrated using a two-step process: First, matrices for wild-capture fisheries and for aquaculture licenses were generated with information about each individual and the marine species s/he harvests or grows. Second data were merged into a single database using first name, middle initial, last name, and suffix along with mailing addresses. These data were then cross-checked manually to make a determination as to why an individual was holding their license(s). Individuals who obtained one or more fishing licenses on the same year or after s/he started farming were designated as farmers and anyone who held a fishing

[5] In 2018, DMR started issuing aquaculture licenses that are required in order to harvest product from a farm. These licenses are separate from the licenses issued for LPA sites.

licenses before acquiring a lease was designated a commercial fisherman. This latter step was necessary because until 2018, DMR required aquaculture growers to hold commercial fishing licenses to sell product they grew on their leases, thereby making it difficult to distinguish farmers from fishermen who also farmed. For example, if an individual had an oyster farm, s/he would be required to buy a commercial shellfish license to sell the oysters. This is the same license that a fisherman would need to harvest most wild-caught clam species.

Merged licensing data were analyzed using a network approach to evaluate the relationships between those engaged in wild-capture fisheries and those engaged in aquaculture. Network science has been used to study a range of fisheries issues, such as differences in local ecological knowledge (Farr et al., 2018), social-ecological dynamics (Bodin, 2017), leadership (Stoll, 2017), seafood trade (Stoll et al., 2018), power dynamics (Crona and Bodin, 2010), sociocultural grouping (Barnes-Mauthe et al., 2014), and adaptive capacity (Stoll et al., 2017). But, to our knowledge, it has not been deployed to date to investigate questions about the interplay and interactions between wild-capture fisheries and the aquaculture sector. The relationship between those engaged in wild-capture fisheries and aquaculture was evaluated using degree centrality scores for each license type. In cases where a farm listed multiple owners, all names were included in the analysis. Centrality is a common network measure that is used to calculate the relative importance of particular nodes in a network based on the number of connections they have to each other (Wasserman and Faust, 1994). In this case, nodes are represented as different license types and the connections represent the number of times individuals hold a particular pair of licenses. License types with high centrality scores are those which tend to be held as part of a portfolio of other licenses, while those with lower centrality scores tend to be relatively disconnected from other fisheries and do not represent a common license that is used to diversify livelihood strategies. A cluster analysis was also performed using the license data to evaluate subgroupings within the fisheries-aquaculture network to further understand intra- and interconnections between aquaculture and wild-capture fisheries. Specifically, we used a random walk algorithm called a Walktrap because it is a robust method for identifying clusters within complex network environments that have numerous connections (Pons and Latapy, 2005).

One limitation of the method used here is that it does not account for crew, processors, drivers and other individuals that may be employed in aquaculture or wild-capture fisheries, because DMR does not require these types of operators to hold licenses for most wild-capture fisheries or in the aquaculture sector. One exception to this rule is for those that work on LPA sites as assistants. While this constrains our ability to fully assess the interplay between wild-capture fisheries and aquaculture, there is a material difference between being the owner of a farm and working on one as an employee or contractor (Pollnac and Poggie 2006). Nonetheless, we report on the number of LPA assistants that hold fishing licenses. Another limitation is that the data are specific to Maine and as such anyone that holds a fishing or aquaculture license outside the state was not included in our analysis. Finally, the analysis assumes that having a license is the equivalent of participating in a fishery or aquaculture and that all licenses are equivalent. However, latency is a known phenomenon in both sectors, since the cost of maintaining a license is relatively low compared to the cost of acquiring one. Further, some commercial fishing licenses are associated with very small fisheries and therefore unlikely to contribute materially to a person's livelihood. Not accounting for latency or low-value fisheries likely inflates the overall

extent of overlap. These limitations combined suggest that the results should not be used as definitive numbers, but rather as qualitative estimates that show relative relationships.

3. Results

Aquaculture in Maine has steadily increased in the last decade (Fig. 1). In 2017, DMR issued 466 Limited Purpose Aquaculture licenses and leased 1,379 acres via Standard or Experimental leases to 219 individuals or corporations. This represents a 588% increase in the number of LPAs and an 18% increase in the total acreage since 2010. More than 1,000 acres are situated in the eastern third of the state, where ocean conditions are conducive for salmon farming. LPAs are more broadly distributed across the state.

Twenty-six percent (n = 57) (Fig. 2) of aquaculture license-holders held one or more commercial fishing licenses during the 2017 fishing season (mean = 1.9, SD = 1.2), which represents 0.58% of the commercial fishing sector licenses (n = 9,750). This constitutes a 104% increase in participation the last five years (n = 28 more aquaculture licenses were held in 2017 vs 2012), but an overall decrease in percentage of lease holders with commercial fishing licenses (29%, based on the comparison between 2012 and 2017). During 2017, those who diversified into aquaculture most commonly held shellfish (n = 26) or lobster (n = 36) licenses (Table 2). The third most common commercial fishing license held by those who have an aquaculture license was the state's general category license, which allows fishermen to target a suite of low value species such as periwinkles (n= 15). Several farmers (n = 6) did not hold any fishing licenses during the 2017 fishing season, but had one or more licenses between 1990 and 2015. Presumably, these individuals transitioned from wild-capture fisheries to aquaculture, but are no longer actively engaged in wild-capture fisheries. While data does not exist to evaluate the full extent to which fishermen are diversifying into aquaculture as contractors, employees, or volunteers, 64 of the 339 assistants on LPA sites also have fishing licenses (19%).

Degree centrality scores for each license type in Maine provide further information about the role aquaculture is playing in diversifying fishermen's livelihood strategies. In this context, degree centrality provides a measurement of the total number of times a person holds any combination of licenses. For example, if a person has an aquaculture and lobster license, the degree centrality between aquaculture and lobster would be one. The analysis shows the diverse connections commercial fishermen have to different fisheries and aquaculture (Fig 2.). Aquaculture (all species combined) has a lower degree centrality score (n = 110) than twelve of the eighteen most economically significant commercial fisheries in Maine, including relatively small wild-capture fisheries such as the scallop diver fishery (n = 175) and the wild harvest of seaweed (n = 232) (Fig. 2). By comparison, the degree centrality of lobster is more than twenty times higher (n = 2895). The low degree centrality score for aquaculture is suggests a relatively tenuous socioeconomic relationship between aquaculture and wild-capture fisheries at this point[6].

[Please insert Figure 2]

[6] Separating aquaculture by species or type (i.e., finfish, shellfish, seaweed) makes the relationship between aquaculture appear even weaker. These results are not shown here for brevity and because the results in aggregate provide adequate information.

The Walktrap cluster analysis (Pons and Latapy, 2005) further illustrates the division between aquaculture and wild-capture fisheries (Fig. 3). The analysis shows four semi-discrete subgroups of marine resource users based on the suite of licenses that any one individual holds. Three of these subgroups include all but two of the wild-capture or farm-raised species. The fourth includes only eel and mussels. If there were strong connections between certain wild-capture and aquaculture fisheries, subgroupings would include a combination of wild-capture and aquaculture-raised species. However, the results show that subgroups 1 and 2 include only aquaculture-raised species, while subgroup 3 and 4 are exclusively made up of wild-capture fisheries (Fig. 3). This indicates that, while some fishermen also farm, there is a stronger association among wild-capture fisheries than between wild-capture fisheries and aquaculture-raised species and vice versa.

[Please insert Table 2)

[Please insert Figure 3]

4. Discussion and Conclusion

Aquaculture has been offered as an important tool for economic development in coastal communities, and as a way for commercial fishermen to diversify their livelihoods during a time of increasing socioeconomic and environmental change. There are a number of programs and community-based initiatives geared towards helping commercial fishermen start aquaculture businesses in Maine. A new oyster farm in the island community of Georgetown, Maine provides an illustrative example. Started in 2017, the farm was created to help clam diggers and other commercial fishermen on the island diversify their livelihoods in the face of prolonged declines in the softshell clam fishery (Fig. 4). As part of this project, seven new farmers with backgrounds in commercial fishing started raising oysters with the support of several community leaders and a range of technical service providers, including the University of Maine. At the time of writing this paper, the group was in the process of forming a cooperative to coordinate its activities. A primary objective of the effort is to provide the group with a new revenue stream to supplement the money they earn from commercial fishing.

[Please insert Figure 4]

While examples like this show there is potential for commercial fishermen to use aquaculture to diversify their livelihoods and the number of commercial fishermen involved in aquaculture is increasing, the results presented in this paper suggest that by and large those who are entering the aquaculture sector in Maine are not commercial fishermen. By our estimates, 26% (n = 57) of those that hold LPAs and aquaculture leases in 2017 were fishermen, which represents 0.58% of

the individuals active in the commercial fishing industry overall (n = 9,750). Understanding the reasons why more commercial fishermen are not diversifying into aquaculture or are doing so as assistants and not owners (n = 64) represents an important area of future research as is a better understanding of who these newcomers are. We hypothesize that these patterns may be a function of multiple factors, including the cost of starting an aquaculture business, the time it takes to maintain an aquaculture operation, delayed returns on investment, cultural differences between wild-capture fisheries and aquaculture, or the fact that Maine's primary fishery, lobster, remains highly valuable. Importantly, these findings complicate the existing narrative that aquaculture is helping fishermen diversify their livelihoods.

The extent to which this pattern will change depends, in part, on the accessibility of aquaculture to new entrants in the future. Presently, regulatory barriers to aquaculture remain comparatively low to most wild-capture fisheries in Maine. Indeed, most wild-capture fisheries are closed to entry (e.g., shrimp), based on lottery systems with low odds (e.g., elver or scallop), or require enrolling in costly training programs and being placed on a wait list (e.g., lobster) (Stoll et al., 2016). However, the bar to enter and maintain aquaculture operations is starting to increase as the regulatory hurdles to entry creep up[7]. This process of "enclosure" is common in fisheries (Carothers, 2015; Murray et al., 2010) and signs of it happening in the aquaculture sector in Maine are starting to become evident. In 2017, for example, the Maine State Legislature passed a bill requiring LPA license holders to participate in a mandatory training program administered by the state. Farmers are now also required to purchase a new aquaculture-specific license as opposed to the shellfish license that was required previously. These new requirements are far from insurmountable, but they do start to raise the bar to participation and may be a sign of future restrictions on the horizon.

Beyond *de jure* rules that may be making it more challenging for commercial fishermen to shift into the aquaculture sector, there are also *de facto* constraints that make aquaculture less feasible for new entrants. Among these is the reality that there is public opposition to aquaculture in some areas, which makes it difficult for prospective aquaculture businesses to start (Hanes, 2018). Such resistance has stemmed from concerns about the aesthetics of aquaculture, fears about pollution, and conflict with other users. New entrants into the aquaculture sector also will likely face increasing competition with those who were early adopters and already have established businesses. Some predict the influx of new growers in Maine will put downward price pressure on aquaculture-raised species like clams and oysters (The Hale Group, LTD, 2016). If this happens, it will likely create a dynamic that will favor the most efficient enterprises that are able to produce product at the lowest cost. Such efficiency will likely come from those who can scale up production and have the most experience (Rivera et al., 2017). Commercial fishermen entering the sector likely will be at a disadvantage.

Regardless of whether or not these challenges will constrain future uptake of aquaculture by commercial fishermen, the results of this research complicate the narrative that aquaculture provides a diversification strategy for the commercial fishing sector and highlight the need for greater attention to the social interactions of aquaculture when making claims about the potential

[7] Other potential regulatory barriers may also emerge as new barriers are proposed, including a citizen petition to place a moratorium on aquaculture leases over 10 acres that was initiated in 2019.

benefits that it provides. While there are instances where individuals have added aquaculture to their repertoire and diversified their livelihood strategies, these occurrences appear to be exceptions to the rule, rather than the norm. This does not mean that aquaculture cannot play an important role in diversifying coastal economies, just that the diversification that appears to be occurring is not happening at the individual level among commercial fishermen.

More scholarship is needed to understand who the newcomers entering aquaculture are, and more broadly, how aquaculture is contributing to the diversification of coastal economies. Is aquaculture adding to the resilience and durability of waterfront businesses? How does the wealth that is generated from aquaculture get distributed and to whom? To what extent is it changing community demographic structures? As questions like these are further probed, attention should be given to the governance systems that underlie aquaculture and the role they play in shaping the aquaculture landscape long term. Notably, key governance provisions that have shaped Maine's commercial fishing sector (Acheson 2003) are not being implemented in the aquaculture sector. In particular, the owner-operator requirements and prohibition on transferability that have helped keep Maine's iconic lobster fishery made up of many small-scale operations are not being applied to aquaculture. These policy differences may be warranted and are not necessarily problematic (e.g., Walters 2007), but it is important to recognize that they could put aquaculture on a different development path than the one that wild-capture fisheries have been on in Maine to date. It is a path that has allowed the salmon sector to consolidate in Maine (Conkling 2000), and it is one that has led similar outcomes in other cases where transferability is allowable (Bennett et al. 2015; Brinson and Thunberg 2016). Therefore, the distribution of benefits from aquaculture within and across communities likely will change through time as Maine's aquaculture sector continues to mature and first-generation farmers begin to seek exit strategies and retire. The implications of these dynamics for coastal communities and economies have yet to be fully understood and warrant further research. If aquaculture is to serve a tool for diversification at the individual or community-scale long term, governance strategies will likely need to be designed to specifically achieve this outcome.

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Institution / Organization
Aquaculture Research Institute (University of Maine)
Audubon Expedition Institute (Lesley University)
Audubon Seabird Restoration & Education Program
Bigelow Laboratory
Boothbay Sea and Science Center
Bowdoin College
Brunswick High School
Brunswick Junior High School
Camp CaPella
Camp Susan Curtis
Center of Cooperative Aquaculture Research
Chebeague Island School
Chewonki Foundation
Children's Museum of Maine
Coastal Encounters
Coastal Enterprises Inc.
Cobscook Community Learning Center
College of the Atlantic
Darling Marine Center (University of Maine)
Davis Family Foundation
Deer Isle-Stonington High School
Downeast Institute for Applied Marine Research & Education
Eagle Hill Institute
Economic Development Administration
Edna Drinkwater School
Falmouth High School
Financial Authority of Maine
Frank H. Harrison Middle School
Friends of Casco Bay
FocusMaine
Gulf of Maine Research Institute
Herring Gut Learning Center
Hurricane Island Foundation
Island Institute
Long Island School
Maine Aquaculture Association
Maine Aquaculture Innovation Center
Maine Community Foundation

Maine Department of Agriculture, Conservation & Forestry
Maine Department of Economic and Community Development
Maine Department of Environmental Protection
Maine Department of Marine Resources
Maine Maritime Academy
Maine Philanthropy Center
Maine Sea Grant
Maine Technology Institute
Marine Environmental Research Institute
Maine Campus Compact (University of Maine)
Maine Discovery Museum
Maine State Aquarium
Maine State Museum
National Oceanic and Atmospheric Administration
National Park Service (Acadia National Park)
National Science Foundation
NOAA Sea Grant National Strategic Investments
Ocean Adventure!
Ocean Farm Technologies
OceanWide
Peaks Island Elementary School
Penobscot Marine Museum
Ripple Effect
Rural Aspirations Project
Schoodic Institute
Sedgwick Elementary School
Southern Maine Community College
St. George School
St. Joseph's College
Sustainable Aquaculture Research & Education
The Ecology School
Unity College
University of Maine (multiple colleges and departments)
University of Maine at Machias
University of Maine at Presque Isle
University of Maine Fish Vet Group
University of New England
University of Southern Maine
US Army Corp of Engineers

USDA Agriculture & Food Research Initiative
USDA Farm Service Agency
USDA National Cold Water Marine Aquaculture Center
USDA Small Business Innovation Research Program
Vine Street Elementary School
Washington County Community College
Wells National Estuarine Research Reserve

Table A1. List of institutions or programs within institutions involved in aquaculture research, education, development, or management in Maine. List compiled by Paul Anderson and is not intended to be exhaustive.

Figure 1. Number of Limited Purpose Aquaculture licenses (Left) and acres leased (Right) has increased through time. Data source: Maine Department of Marine Resources.

Figure 2. (Left) Relationships between wild-captured fisheries and aquaculture are based on individuals' participation in different fisheries and aquaculture and suggest that few fishermen are using aquaculture as a diversification strategy. Width of line between license types represents relative number of links between node pairs. Thicker lines denote stronger linkages. (Right) Degree centrality of aquaculture (all species combined) relative to wild-capture fisheries. Lower scores reflect weaker ties to other fisheries.

Figure 3. Substructure within the license network indicate clear distinctions among those engaged in the aquaculture and wild-caught fisheries sectors. Orange nodes depict aquaculture-raised species; blue nodes depict wild-captured species; grey shaded areas (n = 4) depict clusters. Fisheries with 'D' denote those associated with trawl gear; fisheries with 'H' denote hand-gear fisheries.

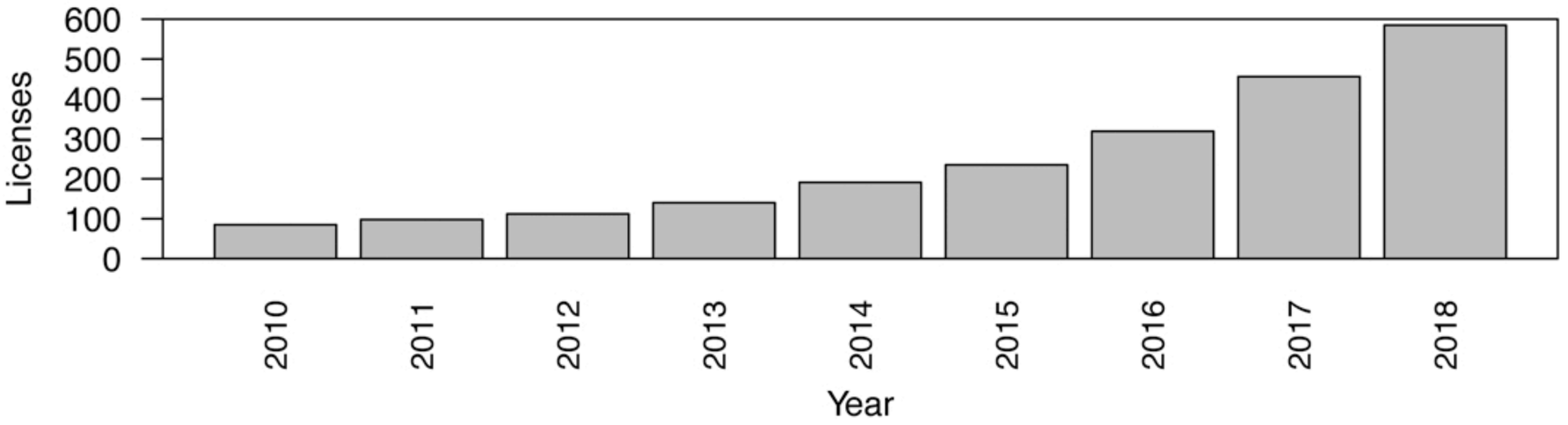
Figure 4. Commercial fishermen on Georgetown working together in the summer of 2017 to launch newly built oyster cages as part of a community-based oyster farm in mid-coast Maine.

	Standard Lease	Experimental Lease	Limited Purpose Aquaculture License
Established	1976	1997	2000
Maximum size	100 acres	4 acres	400 ft^2
Total allowable area leased by individual or corporation	1,000 acres	NA	1,600 ft^2
Time frame	20 years	3 years	1 year
Application fee	$1,500	$100	$50 ($300 non-resident)
Annual lease fee	$100/acre	$100/acre	None
Renewable	Yes	No (unless for scientific research)	Yes
Applicant	Individual or corporation	Individual or corporation	Individual
Transferability	Yes	No	No
Escrow	$5,000	$5,000	No
Training requirement	No	No	Yes

Table 1. Types of aquaculture permits issued in Maine and their associated features.

License Type	Total	Standard or Experimental Lease	Limited Purpose Aquaculture License	Both
Lobster	36	10	21	5
Elver	3	1	2	0
Eel	2	1	1	0
General category	15	3	11	1
Green crab	5	0	4	1
Mussel (D)	1	1	0	0
Mussel (H)	4	0	4	0
Surf clam	0	0	0	0
Pelagic / Anadromous	4	1	3	0
Quahog	0	0	0	0
Scallop (D)	7	5	2	0
Scallop (H)	1	0	1	0
Urchin (H)	2	0	2	0
Urchin (D)	2	1	0	1
Seaweed	2	1	1	0
Sea cucumber	0	0	0	0
Shellfish	26	3	18	5
Worm	0	0	0	0
	110	27	70	13

Table 2. Number of commercial fishing licenses held by individuals with aquaculture licenses. Note that less than one percent of those with commercial fishing licenses also have aquaculture permits (see text for details). Fisheries with ‘D’ denote those associated with trawl gear; fisheries with ‘H’ denote hand-gear fisheries.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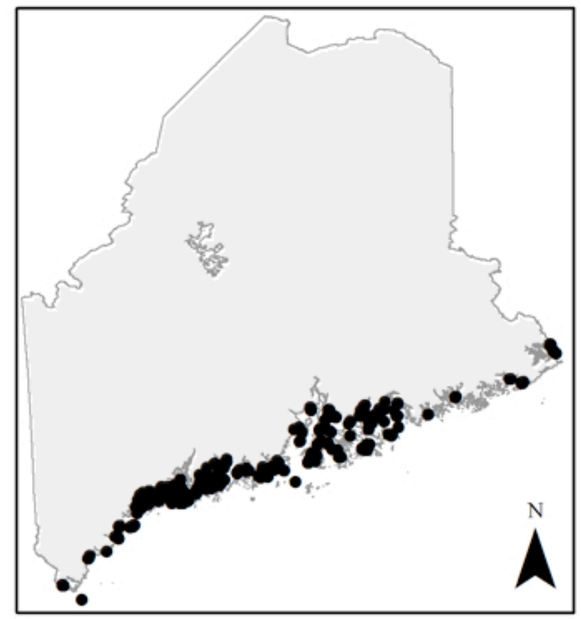
Year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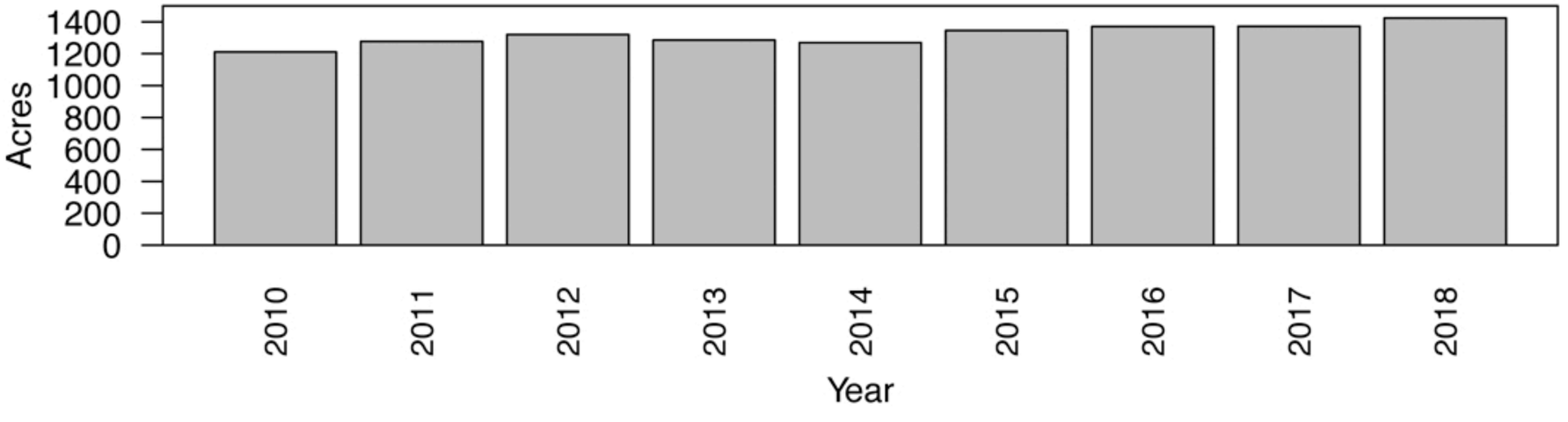
Acres
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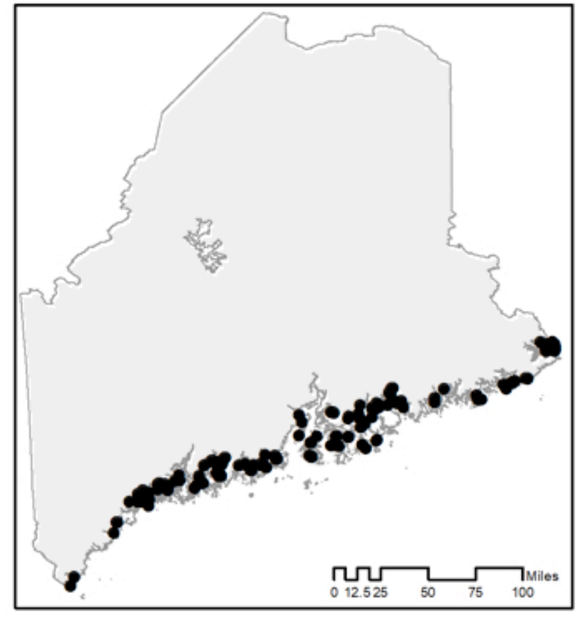
Miles
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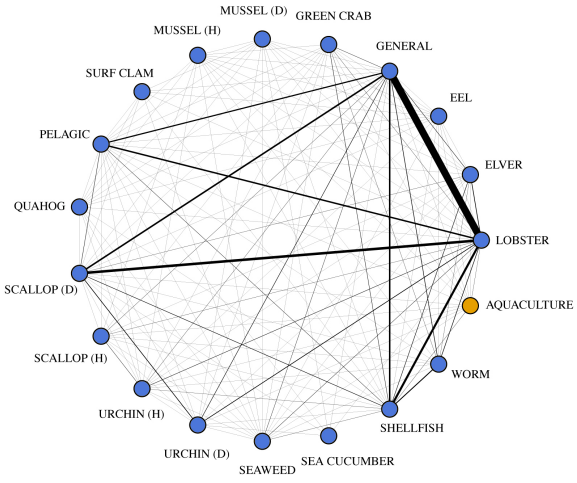
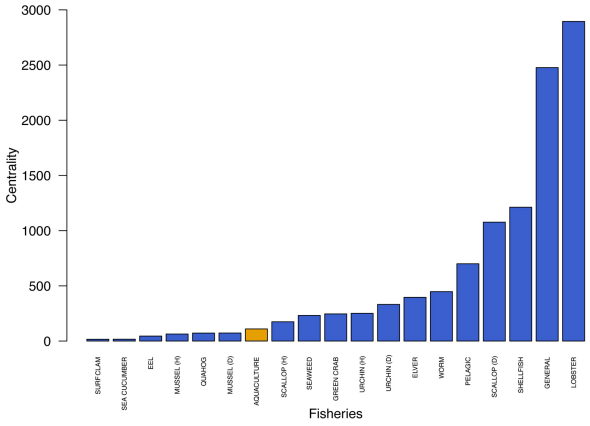

MUSSEL (D)
GREEN CRAB
MUSSEL (H)
GENERAL
SURF CLAM
EEL
PELAGIC
ELVER
QUAHOG
LOBSTER
SCALLOP (D)
AQUACULTURE
SCALLOP (H)
WORM
URCHIN (H)
SHELLFISH
URCHIN (D)
SEA CUCUMBER
SEAWEED


3000
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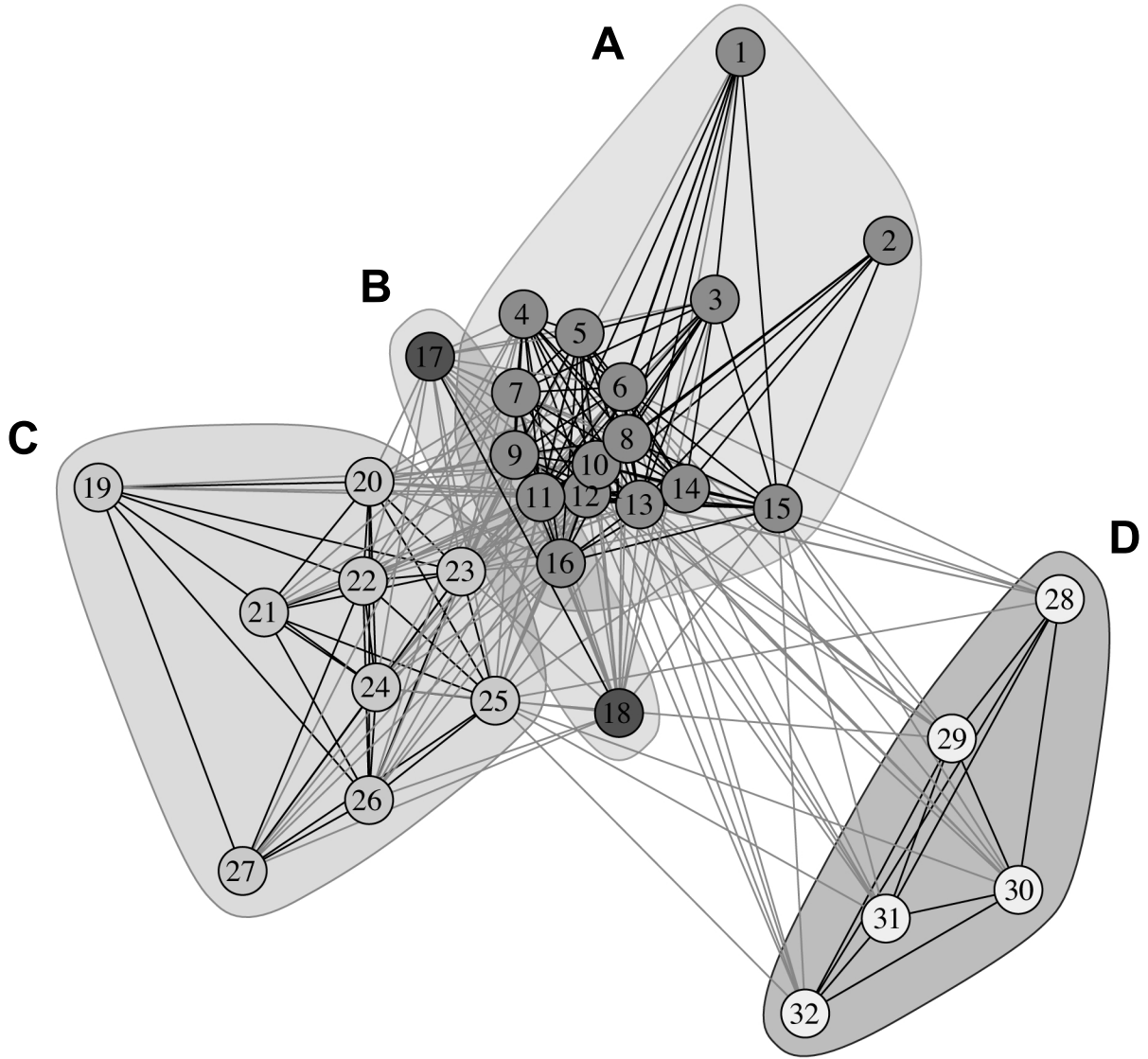
Centrality
SURF CLAM
SEA CUCUMBER
EEL
MUSSEL (H)
QUAHOG
MUSSEL (D)
AQUACULTURE
SCALLOP (H)
SEAWEED
GREEN CRAB
URCHIN (H)
URCHIN (D)
ELVER
WORM
PELAGIC
SCALLOP (D)
SHELLFISH
GENERAL
LOBSTER
Fisheries



Subgroup	ID	Target Fishery	Type
A	1	Surf clam	Wild-capture
	2	Sea cucumber	Wild-capture
	3	Quahog	Wild-capture
	4	Scallop (Hand)	Wild-capture
	5	Urchin (Hand)	Wild-capture
	6	Seaweed	Wild-capture
	7	Green crab	Wild-capture
	8	Pelagic/Anadromous	Wild-capture
	9	Marine worm	Wild-capture
	10	General category	Wild-capture
	11	Shellfish	Wild-capture
	12	Lobster	Wild-capture
	13	Scallop (Drag)	Wild-capture
	14	Urchin (Drag)	Wild-capture
	15	Mussel (Drag)	Wild-capture
	16	Eel	Wild-capture
	17	Sea urchin	Wild-capture
B	18	Elver	Wild-capture
	19	Mussel (Hand)	Wild-capture
C	20	Sea vegetable	Aquaculture
	21	Bay scallop	Aquaculture
	22	Sea scallop	Aquaculture
	23	Oyster	Aquaculture
	24	Quahog	Aquaculture
	25	Blue mussel	Aquaculture
	26	Softshell clam	Aquaculture
	27	Surf clam	Aquaculture
D	28	Cod	Aquaculture
	29	Halibut	Aquaculture
	30	Haddock	Aquaculture
	31	Trout	Aquaculture
	32	Salmon	Aquaculture

Highlights

- A common goal of aquaculture development is to support livelihood diversification;
- The extent to which fishermen are adopted aquaculture in Maine is evaluated;
- Counter to the prevailing narrative, relatively few people in the fishing sector are participating;
- Greater attention to the human dimensions of aquaculture is needed to evaluate its societal potential.