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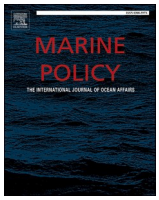

Combining social network analysis and ethnography to better understand fishers' organization and promote sustainable small-scale fisheries in St. Croix, US Virgin Islands

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ABSTRACT

Given the importance of coral reef ecosystems to not only the health, livelihoods, and well-being of individuals and communities throughout the world, but also to global biodiversity, it is critical to improve our understanding of coral reef small scale fisheries (SSF) as social-ecological systems (SES). When examined using a SES approach, SSF operate within coupled-feedbacks with their surrounding marine ecosystems, and environmental outcomes depend upon interactions among a variety of social, ecological, and institutional factors. In a SES context, social network analysis (SNA) can illuminate how structure and process contribute to governance successes or failures among actors and natural resource systems. To address gaps in understanding what factors impact community cohesion, the flow of information, and potential for collective action in SSF, SNA was combined with rich ethnographic data focused on fishers in St. Croix, U.S. Virgin Islands. Results suggest that fishers in St. Croix are not organized into one cohesive group, and that demographic and fishing-related attributes influence group membership in non-uniform ways. These findings align with and build on recent work on SSF, but further demonstrate that the processes that influence the formation and maintenance of ties among fishers are complex and potentially site-specific. This makes it challenging to come to meaningful conclusions related to the potential for collective action based on SNA alone, but highlights the important role that in-depth ethnographic and other qualitative data can play.

1. Introduction

Globally, small-scale fisheries (SSF) play a critical role, supplementing and supporting livelihoods, contributing to food security, and combating poverty [46,65]. SSF are defined as traditional or artisanal fisheries involving fishing households (as opposed to commercial companies), using relatively small amounts of capital, and relatively small fishing vessels (if any). Fishers often make short fishing trips, remain close to shore, and the fish caught are mainly for local consumption [31]. Many SSF depend on coral reef ecosystems and are found throughout the tropics. Although coral reefs are some of the most biodiverse and productive ecosystems globally, they are also more vulnerable to climate change impacts such as bleaching [70], storm intensity [34], ocean acidification [20], and sea level rise [59]. In addition, many reef SSF are found in small islands and developing countries, and often suffer from poor governance and conservation [7,9,42]. Research suggests several factors contribute to this, including lack of funding and capacity to monitor and enforce regulations, lack of data available to managers, complexities due to multi-gear and multi-species approaches, and lack of coordination among multi-scale management institutions [9,13,36].

Given the importance of coral reef ecosystems to not only the health, livelihoods, and well-being of individuals and communities throughout the world, but also to global biodiversity, it is critical to improve our understanding of coral reef SSF as social-ecological systems (SES). When examined using a SES approach, SSF operate within coupled-feedbacks with their surrounding marine ecosystems. Environmental outcomes depend upon interactions among a variety of social, ecological, and

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institutional factors [24,37,47], and scholars have used a SES framework to explore how management institutions influence behavior and environmental outcomes [57]. SES studies of SSF have emphasized the importance of factors such as leadership, enforcement, social capital, and protected areas [37], participatory rulemaking [24,25], and the existence of community incentives to invest in long-term management [6,25,58] in helping groups to overcome collective action problems to more effectively manage fisheries resources [41].

Social Network Analysis (SNA) is an analytical approach focused on the patterns of relationships among individuals and groups. In a SES context, SNA can illuminate how structure and process contribute to governance successes or failures among actors and natural resource systems [14]. While SNA is often viewed primarily as a method for analysis of social networks data, recent applications to natural resource management emphasize its utility for expanding on theoretical concepts regarding systemic-level interactions, such as how social network structures influence the potential for collective action [10,16,49,60]. These recent applications identify social networks as important characteristics of SESs that can function in a variety of ways to facilitate or hinder natural resource management initiatives. Social networks can improve collaborative management processes by facilitating the diffusion and exchange of knowledge and information [27,39,63], enabling access to and sharing of important financial and social resources [21,52], and facilitating the resolution of conflicts [38]. However, not all networks function in the same way, and the structural pattern of relations of a network can significantly influence how actors in a particular resource management context behave and interact [3,29,48,69].

1.1. Cohesion and fragmentation

SNA research suggests several factors contribute to the structure of fishers' networks and cohesion (the degree to which individuals are held together through social relationships, [33]) among fishers, such as ethnicity [8,10], kinship and friendship [62], and gear type [26,27] (See [4] for a comprehensive review). Community cohesion plays an important role in supporting effective governance of natural resources, particularly in contexts with limited institutional capacities and/or limited management authority and enforcement, as is often the case with SSF [4,11]. Measuring cohesion among a group of fishers can be important in tracing trust as well as shared values and norms important to management outcomes [3]. Low cohesion or fragmentation in fisheries systems may constrain avenues of social influence, limiting opportunities for broader collective action, particularly for fisheries operating under resource limited or highly localized management contexts [3,4].

Building on this body of work, our research seeks to understand how demographic and other factors contribute to network group membership among small-scale commercial fishers on the island of St. Croix, U.S. Virgin Islands (USVI). Valdes Pizzini et al. [68] provide a historical conceptual model to describe how complex processes such as colonialism, slavery/Emancipation, migration, and urban development have shaped coastal and fishing communities throughout the Caribbean, including in St. Croix. Declining economic conditions and government policies (e.g., homesteading) contributed to the islands' gentrification, and the fishing communities shifted from place-based communities (where social and economic life is located in a place, an identifiable settlement where kin, neighbors, and friends live and are engaged in fishing activities) located along the water to network-based communities in which fishers are connected to one another via social and economic relationships ([68]: 132–133). Results from recent censuses of USVI fishers support this shift, indicating fishers live scattered throughout the island, trailer their boats on a daily basis to boat ramps, and sell their catch on an individual basis (not in a central, common location such as a market) [43–45]. Additionally, [45] reported a large decline in the number of licensed commercial fishers on St. Croix (a decrease of 36.8% between 2004 and 2016, p.112), likely due to factors such as a moratorium on the issuance of new commercial fishing licenses that has been in place since 2001 and fishers allowing their licenses to lapse without renewing them. Lastly, Hurricane Maria devastated St. Croix in September 2017, critically impacting fishers via lost or destroyed fishing gear and lost revenue [67,71]. These factors contributed to the structure and status of the fishers' network leading up to the data collection period.

Today, such historical, cultural, and social factors continue to impact when and how fishers interact with one another and how they exchange information, but to date no researchers have used SNA to examine the structure of the fishers' network in St. Croix. Previous research found that, despite several attempts to establish a fishing cooperative and a fishermen's organization in St. Croix, these attempts consistently fail [35,45]. Grace-McCaskey [35] found that although the vast majority (85%) of fishers interviewed in St. Croix felt that fishers were not "well organized," nearly the same percentage of fishers felt that it would be beneficial for them if they were. The study described in this paper was conducted as a follow-up, using SNA to explore what factors influence how fishers are grouped. The overarching goal is to describe the structure and composition of fishers' social networks in St. Croix, and relate that structure and composition to the potential for fishers to organize for collective action. To do so, this exploratory analysis is guided by two research questions: 1) Are fishers grouped into one cohesive group, or are there clearly distinguishable subgroups? 2) If there are clearly distinguishable subgroups, what are the defining attributes of those groups (e.g., ethnicity, place of residence, primary fishing gear used)? This examination contributes to the growing body of literature geared toward better understanding the factors that bring and hold communities together in the SSF context, and what that means for the management of SES. For example, recent research highlights how social cohesion among fishers (and which factors facilitate or impede cohesion) plays an important role in promoting effective adaptation to climate change and other environmental stressors [64], as well as the connection between social cohesion and improved ecological conditions [7].

Collecting social networks data related to contentious issues (such as fisheries management in the USVI), in small, close-knit communities can be challenging. In this case, it was vital to pair SNA with ethnographic data and an understanding of the island's fisheries and the wider sociopolitical context of fishing on the island. Although most networks studies of fishers have larger sample sizes, much can be learned from the study of smaller, island-based fishing communities, such as St. Croix. In these cases, the ethnographic context is imperative. The results presented here build on extensive ethnographic research regarding fisheries management previously conducted in St. Croix over the past fourteen years [35,36], and findings from those studies were used to assist in the study design, as well as the analysis and interpretation of the networks data. Therefore, this study not only contributes to our understanding of the relationship between the structure of SSF networks and potential for collective action in SES, but also provides a case study highlighting the utility of a mixed methods research approach combining SNA with long-term, in-depth, qualitative methods such as ethnography [5,16].

2. Materials and methods

2.1. Description of St. Croix

St. Croix is the largest of the three main USVI and is located in the eastern Caribbean Sea. It has a land area of 215 km^2 and lies 145 km east of Puerto Rico. Fishing has played an important role in St. Croix throughout the island's history, not only providing the island's residents with a fresh source of dietary protein, but also playing an important role in the island's culture. The island's commercial fishery is a SSF, and fishers typically use small boats that they keep at home and trailer to the island's various launch sites and boat ramps, deciding where to fish on a daily basis depending on weather and sea conditions. It is a multi-gear,

multi-species fishery, with fishers typically using several types of fishing gears and targeting multiple species on a single trip ([36,68]). The primary fishing gears used include pots/traps, tank diving (SCUBA) or freediving with spearguns, and handlines. Primary species landed include reef fish (e.g., snapper, grouper, parrotfish), coastal pelagics (e.g., jacks, mackerels), spiny lobster, and conch. Nearly 100% of landings are sold on island [22].

2.2. Social network analysis

2.2.1. Data collection

Social networks data were collected via structured interviews with commercial fishers during fieldwork from July 2019 through February 2020 (n = 59). Commercial fishers in St. Croix are difficult to locate, partly because they operate at an individual scale, keeping their boats at their homes and transporting them by trailer to various ramps when they go out to fish. The island also lacks a formal marketplace where multiple fishers gather to sell their fish. For this reason, and following previous successful survey and interview data collection efforts targeting St. Croix's commercial fishers [36,45], the primary effort to interview fishers occurred during a week in July 2019 when fishers visited local government offices to renew their fishing licenses. A total of 48 fishers were interviewed via this method. Additionally, attempts to locate and interview fishers occurred throughout the fieldwork period by visiting boat ramps and sites across the island where fishers sell their catch, often out of the back of their trucks (e.g., along the roadside). Additional fishers were also contacted via snowball sampling strategies [12], when their contact information was provided by interviewees. A total of 59 commercial fishers were interviewed, which represents about 60% of the commercial fishers on the island who renewed their commercial fishing license for the 2019–2020 year (personal communication, DPNR personnel, 2020). A coverage of 60% falls within the ranges of other SNA studies in similar contexts (e.g., Alexander 2018), although it falls at the lower end of the spectrum.

The first part of the structured interview included a combination of open- and closed-ended questions related to demographic data, fishing activities and behaviors, and perceptions about fisheries management in St. Croix. The networks data were collected during the second part of the structured interview, using a name generator with free-recall [19]. In this case, fishers were asked, "What other fishers do you talk to about fishing?" Information-sharing name generators are a common choice to capture social networks of fishers throughout the literature on collective action and resource management (e.g., [3,4,26,28]). This body of work sees information exchange between fishers as a prerequisite for achieving cooperation and collective action. Through information sharing, actors increase their trust in each other, can learn from each other, and are able to develop shared understandings, norms, agreements, and conflict resolution mechanisms [15,17,55]. Thus, there is reason to believe social connections between actors who harvest the same resource might help prevent overharvesting. As interviewees responded to the prompt, the interviewer wrote down the names of each fisher nominated by the interviewee, along with the type of relationship tie (e.g., family member, friend, know through fishing, etc.) and frequency with which they communicate (i.e., often, sometimes, rarely). There was no limit to the number of fishers nominated by an interviewee.

2.2.2. Network construction

A network of fishers was constructed where ties are given by the sharing of information about fishing between two nodes (fishers). The constructed network is directed [19]. This means that if Person A indicates they talk with Person B, but Person B does not indicate they talk with Person A, there would be a tie pointing from A to B but not from B to A. Network ties were weighted by the frequency with which a node talks to another about fishing: 1 = rarely, 2 = sometimes, 3 = often.

2.2.3. Analytical strategy

Throughout the analyses, a descriptive approach is used to obtain a set of measures related to the goals guiding the study. First, a general description of the network and the characteristics of the sample are determined. Then, the connectivity of the entire network and its substructures is analyzed to assess whether fishers form one cohesive group or demarcated subgroups. Next, cohesive subgroups are identified through community detection, and the defining attributes of the subgroups ("communities") are explored. Each of these steps is described in more detail below.

General Descriptive Statistics. Descriptive statistics were calculated to gain a general understanding of the characteristics of our sample, and to develop an understanding of the network's basic structure. Basic network metrics calculated include network size, the types of relationships present within the network, the distribution of frequency of interaction among respondents, and the average and median number of nominations sent and received.

Cohesion. To assess the network's cohesion, connectivity was measured, which refers to the extent to which nodes in a network are directly or indirectly connected to each other. Because no single measure of connectivity can fully capture the patterns of connections within a network, multiple measures of the number of ties and their arrangement at different levels must be considered [53]. This strategy aligns with the recognition that cohesion is a multidimensional construct, better assessed through multiple indicators [33]. At the network level, connectivity was assessed by calculating the density, components, reachability of nodes, and assortativity. At the substructure level (i.e., in small regions of the network), the connectivity of groups of nodes ranging from those with a high number of nodes to those of individual nodes was assessed. To do this, a clique census was conducted and measures of transitivity, reciprocity, and articulation points were calculated.

Community Detection. Community detection techniques allow for the identification of subsets of nodes that are well-connected among themselves (internally cohesive) and well-separated from other nodes. Internally cohesive groups of nodes are called clusters or communities in the community detection literature. The community detection technique we employ selects the partition into communities that maximizes modularity. Modularity is a popular index of the extent to which partitions reflect clusters internally well-connected but having few ties with other clusters. Higher values of modularity are achieved in partitions where the proportion of observed ties within clusters is higher than the expected proportion of ties we would observe if nodes' connections within and between clusters were random [51]. While the maximum possible value of modularity is 1, modularity values between 0.3 and 0.7 are more commonly observed in networks that have a community structure (i.e., networks comprised of internally cohesive groups with few ties with other groups) [51].

The community detection algorithm "optimal" was employed, implemented in the package igraph of R software using the undirected version of the original network, keeping two undirected ties for the cases in which directed ties were reciprocated in the original network (the "optimal" community detection algorithm does not allow for the use of directed graphs). The algorithm calculates the value of modularity over all possible partitions and chooses the partition with the highest modularity value. The community detection procedure results in: (1) a partition by which each node is assigned to a community, and (2) the modularity value obtained by the partition.

Once the community detection procedure has been finalized, we conduct a permutation test to assess whether the resulting partition represents a significant subgroup structure. To perform the test, we generate 1000 random networks with the same degree distribution as the observed network. Then, we conduct the community detection procedure for each of the 1000 networks. Finally, we obtain a distribution of modularity scores for the 1000 networks and determine the location in the distribution where the modularity of the observed

Table 1
Sample characteristics (N = 59). In cases where the categorical variables do not add to 59, the remaining observations were missing.

Continuous Variables	Min	Max	Mean	sd
Age	23	81	55.05	15.84
# of years fishing	2.00	65.00	26.32	14.06
% of household income from fishing	0	100	62.1	40.8
Number of fishing trips per month	0	31	15.4	8.09
Categorical Variables	**Count**	**%**		
Race/Ethnicity				
Black/African American/West Indian	15	25.42%		
Hispanic/Puerto Rican	27	45.76%		
White	8	13.56%		
Mixed/Other	9	15.25%		
Place of birth				
St. Croix	34	57.63%		
Other	24	40.68%		
Place of residence				
Christiansted	14	23.73%		
Frederiksted (West area)	17	28.81%		
Mid-island	18	30.51%		
Northside	8	13.56%		
Level of education				
Some college or more advanced degree	12	20.34%		
Gender				
Male	58	98.31%		
Gear				
Trap	14	23.73%		
Line	53	89.83%		
Net	13	22.03%		
SCUBA diving	33	55.93%		
Freediving	7	11.86%		
Species				
Reef	38	64.41%		
Deep water snapper	39	66.10%		
Lobster	25	42.37%		
Conch	24	40.68%		
Coastal pelagics	24	40.68%		
Dolphin/wahoo	42	71.19%		
Deep water pelagics	39	66%		
Whelk	4	7%		
Bait sold	4	7%		
Launch site				
Altona Lagoon	30	51%		
Molasses Pier	25	42%		
Frederiksted	18	31%		
Gallows Bay	9	15%		
Salt River	5	8%		
Green Cay (Moored/Docked)	3	5%		
Christiansted	6	10%		
Other	4	7%		

network falls. If the modularity score in the observed network falls far from the center of the distribution, it suggests that the observed modularity has a small probability of being observed just by chance.

Subgroup characterization. To identify the attributes of the groups resulting from the community detection procedure, descriptive statistics for each of the groups were calculated. The proportion of members of each group that falls into relevant attribute categories were calculated. For the attributes launch site and gear type, bar graphs (Figs. 2 and 3) were created to visualize the launch sites and type of gear towards which different groups tend to gravitate.

3. Results

3.1. Description of participants

Table 1 provides summary data regarding the demographic and fisheries-related characteristics collected via interviews with 59 fishers.

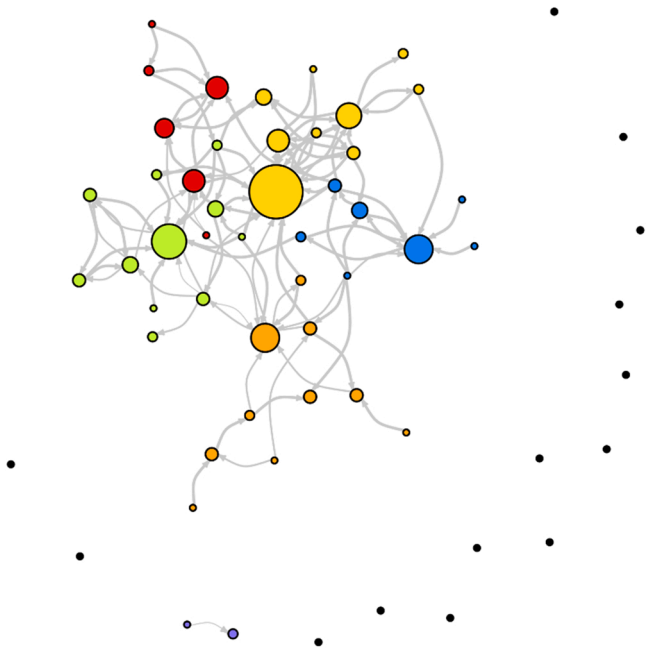

Fig. 1. St. Croix fishers' network. Nodes sizes are proportional to their indegree. Black, unconnected nodes are isolates. Arrows at the end of each tie point to nominees and indicate the direction of the tie. Tie weights are represented in the thickness of the lines connecting two nodes. Communities are named by the color of their nodes as follows: Community 1 = orange, Community 2 = blue, Community 3 = green, Community 4 = yellow, Community 5 = purple, and Community 6 = red. Figure produced using the igraph package – R software.

Table 2
Network statistics for cohesion (N = 59).

Density		0.03
Components		
	Largest component	43 (73%)
Reachability		
	Diameter (directed)	12
	Diameter (undirected)	7
	Average shortest path (directed)	3.78
	Average shortest path (undirected)	2.88
Number of cliques		
	Triangles	38
	Size four	5
Dyad census		
	Mutual ties	24 (0.7%)
	Asymmetric ties	80 (2.3%)
	Null ties	3238 (96.88%)
Transitivity		0.24
Reciprocity		0.13
Number of articulation points		6 (10%)

3.2. Basic network descriptives

The resulting network has 59 nodes and 104 edges (see Fig. 1 and Table 1). We followed a complete network design, focusing on the ties among respondents only. Ties to non-respondent fishers were dropped. Complete network designs are a common choice in the literature on fisheries social networks and social-ecological networks [7,61]. Most of the ties in the network (77%) represent frequent communications between fishers, 17% represent less frequent communications, and 4% represent rare communications. The network presents a mix of relational ties: 13% of the ties were identified as ties between family members, 46% were based on fishing activities, 21% based on friendship, 18% based on work ties, and less than 1% were acquaintance ties. Fishers sent and received, on average, 1.76 ties. The median number of ties sent and

Table 3
Assortativity by selected attributes.

Attribute	*r*
Ethnicity	0.18
Having a college degree	0.18
Age	0.30
Years fishing	0.30
Being born in St. Croix	-0.03
Number of trips	0.29
Percentage income from fishing	0.24
Launch site (first choice only)	0.05
Place of residence	0.06

received equals 1.

3.3. Cohesiveness and fragmentation

An analysis of the number and size of components reveals that a single component contains the majority of the nodes in the network (43 nodes – 73%) (see Table 2). One component of size two and 14 isolates (nodes that do not have any connection with the rest of the network) are also observed. The fact that about a quarter of the nodes are isolates, along with a low density score (0.03), indicates a lack of cohesion in the overall network.

We also obtain measures of reachability within the largest component. In the directed version of the network, a diameter of size 12 is observed, meaning information would have to travel through 12 nodes to connect the two most distant nodes in the network. In the undirected version of the network (if it is assumed that all ties are reciprocated), the diameter is seven nodes. An average shortest path of 3.78 in the directed version of the network indicates a piece of information would have to travel, on average, 3.78 steps to travel from one node to another. In the undirected version of the network, the average shortest path is 2.88. The reachability metrics we obtain (average shortest path and diameter) indicate a pattern of indirect communication between nodes and the presence of bridging (weak) ties.

At the level of the network, assortativity coefficients were calculated for a wide range of fishers' attributes to measure the extent to which connected nodes have similar characteristics. As shown in Table 3, assortativity coefficients indicate the network is moderately assortative with respect to age, number of years fishing, average number of fishing trips per month, and percentage of household income that comes from fishing. The network is slightly assortative with respect to ethnicity and level of education. These results suggest these factors may play a role in the formation of connections between fishers. The assortativity coefficients for all other attributes indicated a non-assortative network (see supplementary material).

Several measures at the substructure level further reveal patterns of connectivity. The fishers' network presents a high number of null and asymmetric ties and a low number of mutual ties. The high proportion of asymmetric ties indicates nominations tend to be one-sided. More cohesive structures tend to be more reciprocal and highly knitted [32, 50]. In addition, about 10% of the nodes are articulation points.

3.4. Community detection

The community detection procedure resulted in six connected substructures (i.e., excluding isolates) and a modularity score of 0.468 for the partition. Following others (e.g., [28]), we conduct a permutation test, which indicated this modularity score falls in the 96.9 percentile of the distribution of modularity scores obtained from 1000 randomly generated networks (i.e., $p < 0.05$). This suggests that the partition into six substructures detected via community detection is unlikely to occur due to chance alone.

3.5. Characterizing subgroups

Each subgroup ("community") profile is characterized based on its composition in terms of selected attributes. Communities are distinguished by the color of their nodes in Fig. 1. These attributes were chosen based on whether they were salient features of communities and include: age, years of fishing, ethnicity, whether they hold a college degree, number of fishing trips per month, percentage of household income that comes from fishing, relationship type, gear type, and launch site. Community members' perceptions regarding fisheries management in St. Croix are also discussed when relevant. To better assess communities' profiles in terms of the gear type and launch site, Figs. 2–4 present the proportion of fishers in each community who use each gear type and each launch site. Table 4 presents descriptive statistics regarding the composition of each community for selected attributes, and Table A1 in Appendix A shows the composition of communities regarding additional attributes. Such additional attributes are not discussed in this section because differences are less marked.

Community 1 – Orange (10 nodes): Fishers in Community 1 tend to be older than most fishers in the network. The average age in

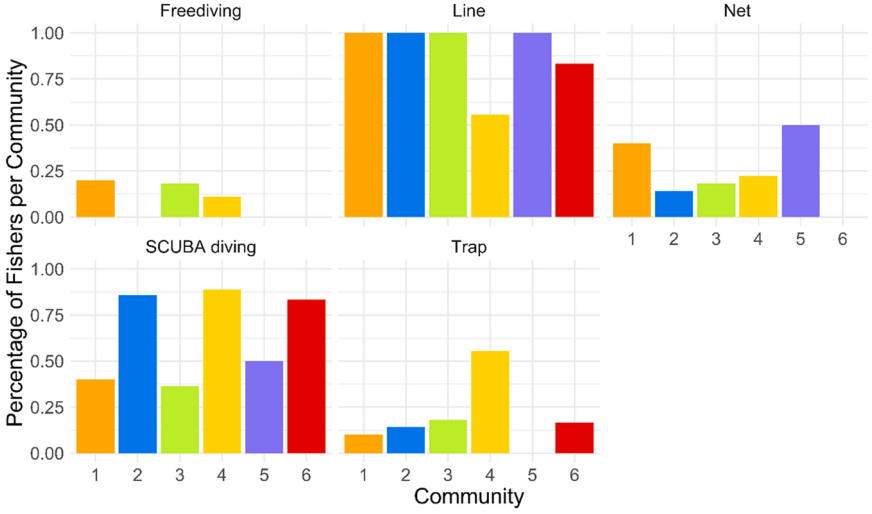

Fig. 2. Percentage of fishers in each community that use each type of gear. Communities follow the same color scheme employed throughout this article: Community 1 = orange, Community 2 = blue, Community 3 = green, Community 4 = yellow, Community 5 = purple, and Community 6 = red. Figure produced using R software.

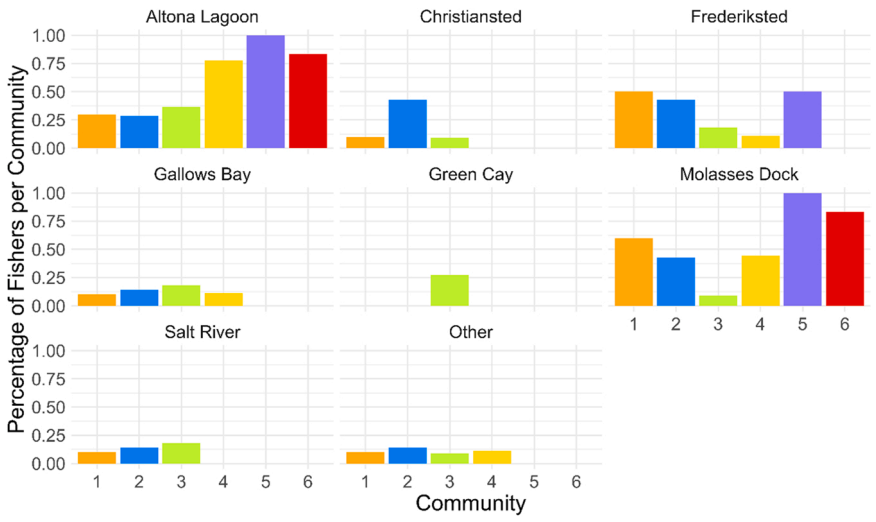

Fig. 3. Percentage of fishers in each community that use each launch site. Communities follow the same color scheme employed throughout this article: Community 1 = orange, Community 2 = blue, Community 3 = green, Community 4 = yellow, Community 5 = purple, and Community 6 = red. Figure produced using R software.

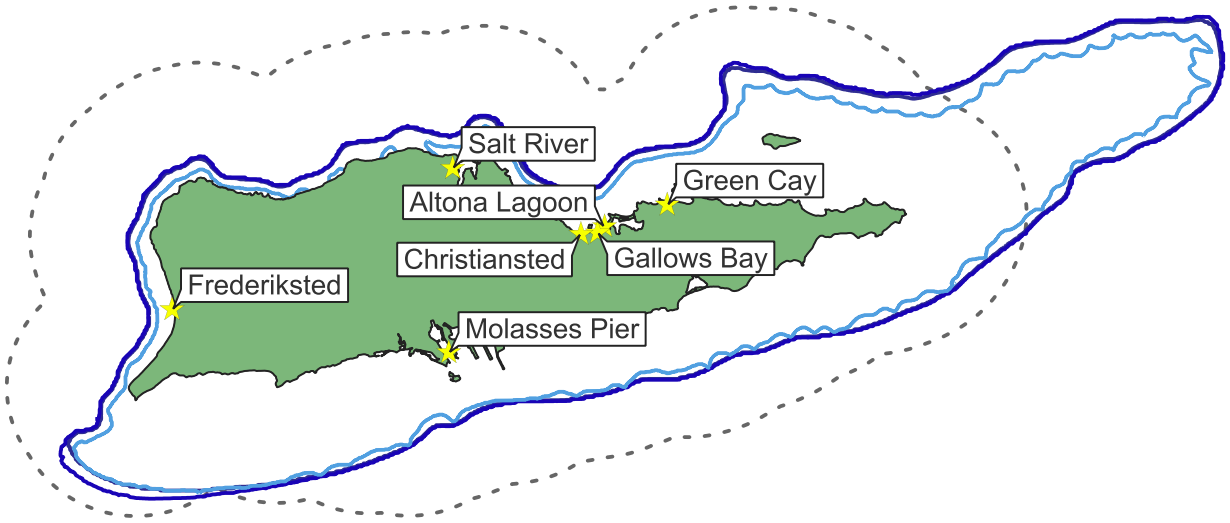

Fig. 4. Map of St. Croix, showing launch sites. Map courtesy of Dr. Ethan Deyle, Dept of Biology, Boston University.

Community 1 is 59.4 years compared with the overall mean of 51.1 years. Likewise, Community 1 fishers have, on average, more years of fishing experience (mean = 33.1 years) compared with the rest of the network (overall mean = 23.32 years). Regarding ethnicity, this community is composed of fishers who identify as Hispanic/Puerto Rican and mixed/other. Like most other communities, Community 1 has a low proportion of fishers with a college degree (10%). The number of fishing trips per month (mean = 12.6) and percentage of household income that comes from fishing (mean = 45%) are low compared to the rest of the network (overall mean = 62.1). Income from fishing accounts for 50% or less of the total household income for the majority of these fishers. In terms of relationship types observed, the community presents a combination of kinship ties (5 out of 11) and friendship ties (6 out of 11). As depicted in Fig. 2, all fishers in Community 1 (10 out of 10) reported they use line fishing. In fact, most fishers in Community 1 (8 out of 10) selected line fishing as the type of fishing that generates them the most revenue. Fig. 3 reveals that, while there is some diversity in the launch sites these fishers use, most of their fishing trips leave from Molasses Pier and Frederiksted. Fishers in this community reported a high level of (self-reported) knowledge of fisheries management, and though the majority of the fishers in this group reported they attend fisheries management meetings "often/always," most of them indicated they never actively participate in the meetings (e.g., by providing public comments).

Community 2 – Blue (7 nodes): Similar to Community 1, Community 2's fishers are older than average, though there is more heterogeneity in age. This community is composed of a mix of fishers who identify as Black/African American/West Indian and as Hispanic/Puerto Rican. While most ties in this community are based on friendship (64%), there are also a couple of fishing ties, one acquaintance, and one family tie. For all fishers in this community, income from fishing accounts for a large percentage (50% of more) of their household incomes. In terms of fishing gears used, these fishers focus almost equally on line and SCUBA diving (Fig. 2), and they launch their boats from numerous sites (Fig. 3). Most of the fishers in this community do not find it easy to participate in fisheries management.

Community 3 – Green (11 nodes): This community is characterized by having the strongest presence of White fishers in the network; 86% of fishers who identify as White (6 out of 7) are in this community. Fishers in Community 3 have fewer years of fishing experience (mean = 20.3

Table 4
Descriptive statistics for St. Croix partitions after community detection procedure.

	Communities											
	1. Orange		2. Blue		3. Green		4. Yellow		5. Purple		6. Red	
	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd
Size (number of nodes)	10		7		11		9		2		6	
Race/Ethnicity												
Black/African American/West Indian	1	10%	3	43%	2	18%	1	11%	1	50%	1	17%
Hispanic/Puerto Rican	4	40%	4	57%	3	27%	7	78%	1	50%	4	67%
White	0	0%	0	0%	6	55%	0	0%	0	0%	1	17%
Mixed/other	5	50%	0	0%	0	0%	1	11%	0	0%	0	0%
College degree	1	10%	1	14%	6	55%	1	11%	0	0%	0	0%
Age	59.4	13.49	56.14	19.29	50.64	12.13	46.44	13.66	48.5	7.78	40.33	12.56
Years fishing	33.1	13.6	27.6	16.2	20.3	11.7	25.0	16.3	30.5	6.36	16.5	10.1
Number trips per month	12.6	6.02	19.0	5.20	14.4	9.95	21.3	6.5	14.0	14.1	15.8	11.9
% Income from fishing	45.0	38.4	82.9	23.6	45.5	45.4	86.7	33.2	25.0	35.4	63.7	49.2
Gear												
Trap	1	10%	1	14%	2	18%	5	56%	0	0%	1	17%
Line	10	100%	7	100%	11	100%	5	56%	2	100%	5	83%
Net	4	40%	1	14%	2	18%	2	22%	1	50%	0	0%
SCUBA diving	4	40%	6	86%	4	36%	8	89%	1	50%	5	83%
Freediving	2	20%	0	0%	2	18%	1	11%	0	0%	0	0%
Launch site												
Altona Lagoon	3	30%	2	29%	4	36%	7	78%	2	100%	5	83%
Molasses Pier	6	60%	3	43%	1	9%	4	44%	2	100%	5	83%
Frederiksted	5	50%	3	43%	2	18%	1	11%	1	50%	0	0%
Gallows Bay	1	10%	1	14%	2	18%	1	11%	0	0%	0	0%
Salt River	1	10%	1	14%	1	9%	1	11%	0	0%	0	0%
Green Cay (Moored/Docked)	0	0%	0	0%	3	27%	0	0%	0	0%	0	0%
Christiansted	1	10%	3	43%	1	9%	0	0%	0	0%	0	0%
Other	1	10%	1	14%	2	18%	0	0%	0	0%	0	0%
Relationships												
Number of edges	11		11		19		20		1		9	
Family	5	45%	1	9%	0	0%	5	25%	0	0%	2	22%
Work	0	0%	0	0%	4	21%	0	0%	1	100%	3	33%
Friend	5	45%	7	64%	3	16%	1	5%	0	0%	0	0%
Fishing	1	9%	2	18%	12	63%	14	70%	0	0%	4	44%
Acquaintance	0	0%	1	9%	0	0%	0	0%	0	0%	0	0%
Perceptions												
Knowledgeable about fisheries management	3.6	1.26	3.43	1.51	3.27	1.42	4	1	2.5	0.7	2.83	1.17
Satisfaction with fisheries management	3.1	1.1	2.57	0.98	2.55	1.04	2.67	1.58	4.0	1.41	3.0	1.26
Ease of participation	3.4	0.97	2.57	1.27	3.45	0.82	3.44	1.13	4.5	0.7	3.2	0.75
Meeting attendance												
Never	1	10%	1	14%	0	0%	0	0%	0	0%	0	0%
Sometimes	3	30%	4	57%	6	55%	2	22%	0	0%	3	50%
Often/always	6	60%	2	29%	5	45%	7	78%	2	100%	3	50%
Meeting involvement												
Never	5	50%	3	43%	2	18%	3	33%	1	50%	3	50%
Sometimes	4	40%	2	29%	3	27%	3	33%	1	50%	2	33%
Often/always	1	10%	2	29%	6	55%	3	33%	0	0%	1	17%

years) and are younger than average (median = 46 years). The percentage of household income coming from fishing (mean = 45.5%; median = 25%) is low compared to that of the other communities. Fishing represents 50% or less of the total household income for the majority of these fishers, but there are some fishers that rely on fishing as their sole source of income. Most ties in this community are work-related (e.g., connections through non-fishing work) or fishing ties (74%). The remaining 16% of the ties (3) are friendship ties. This community has a bimodal distribution in terms of fishing trips per month with some of the fishers having very few trips per month (e.g., 2, 4) and some fishers with many more trips per month (e.g., 20, 30). The fishers in this community are mostly focused on line fishing: all of these fishers use line fishing (Fig. 2) and 9 out of 11 fishers selected it as the gear that generates them the most income. They use a diverse set of launch sites for their fishing trips (Fig. 3). The fishers in this community report a higher tendency to speak publicly at fisheries management meetings than the rest of the communities, and they are more dissatisfied with fisheries management.

Community 4 – Yellow (9 nodes): Like Community 3, the fishers in Community 4 are also younger than average (median = 46 years). This community is composed mostly of Hispanic/Puerto Rican fishers (7 out of 9), who are connected to each other primarily via fishing (70%) and kinship (25%). Only one of the ties is based on friendship (5%). Nearly all the fishers in this community (7 out of 9) rely 100% on fishing for their household income. Fishers in this community focus primarily on SCUBA diving, with 90% ranking it as the most (or one of the most) revenue generating gear they use. Many of them, however, ranked multiple gears as equally important, and a third of the fishers selected traps as (one of) their most revenue generating gears (Fig. 2). Most fishers in this community (7 out of 9) launch their boats from Altona Lagoon (Fig. 3). Fishers in Community 4 believe themselves to be knowledgeable of fisheries management processes. Most of the fishers reported attending fisheries management meetings more frequently than those in other communities, but only three of them reported participating in the meetings regularly. In terms of self-reported knowledge of fisheries management processes, in most communities, a mix of responses is observed: some fishers report they only know a little or nothing about the process, and some report they are more knowledgeable about the process. Fishers in Community 4, however, present higher scores regarding their (self-reported) knowledge of fisheries management processes.

Community 5 – Purple (2 nodes): Both fishers in this dyad are close to the mean age. One fisher identifies as Black/African American/West Indian and one identifies as Hispanic/Puerto Rican. The tie that connects them is a work tie. These fishers have more experience than average fishers (mean = 30.5 years), and they both report they attend management meetings. One person does not rely on fishing at all as a source of income and fishing accounts for 50% of the household income of the other. These fishers report using different gears (nets vs. SCUBA diving) and different launch sites.

Community 6 – Red (6 nodes): Community 6 is composed of younger fishers when compared to the rest of the communities (mean age = 40.3 years), and fishers with fewer years of experience (mean = 16.5 years; overall mean = 25.2 years). This community is diverse in terms of race/ethnicity, having members who identify as Black/African American/West Indian, Hispanic/Puerto Rican, and White. This community is based on a combination of fishing and work ties (77%) and also has the presence of two family members. Like Community 3, this community also has a combination of fishers reporting a wide range of number of fishing trips per month and the extent to which they rely on fishing for their household income. In terms of fishing gear, the fishers in this community primarily use lines or SCUBA diving (Fig. 2), and they reported using only Molasses Pier or Altona Lagoon for launching their boats (Fig. 3). The fishers in Community 6 are particularly interested in learning about fishing regulations; while most communities have a mix of "I'm somewhat interested" and "I'm always interested and try to be aware" responses, everyone in Community 6 says they are always interested in learning.

The overall network structure also suggests that there are key people in important "brokering" positions, meaning that they could have a great deal of influence in how information flows through the network [18]. For example, very few nodes concentrate a high number of nominations; one fisher received 10 nominations and another one received 15 nominations. As shown in Fig. 1, node sizes reflect the number of nominations fishers received. The majority of fishers in the network, however, received only one nomination, and 14 fishers received no nominations. This is suggestive of a disparity in the popularity of nodes and a hierarchy within the network.

4. Discussion

Returning to the guiding research questions, these results suggest that fishers in St. Croix are not grouped into one cohesive group, which reiterates findings from previous ethnographic research [36]. Although 75% of the nodes in the network are included in the largest component, the network has a low density score and a relatively high number of fishers who are isolated (14 out of 59), meaning they are not connected to any other fishers in the network. During the interviews, these fishers indicated they did not talk to any other fishers about fishing. It is important to note, however, that while these fishers could in fact be true isolates in the network, it is also possible that they were suspicious of the intentions of the research and purposely chose not to provide any names, or they were not able to recall the names of anyone at the time of the interview. These are common issues researchers face when collecting and analyzing networks data (e.g., [2,23,30]), but such missing data can have important implications for the overall network structure and our findings. Further research into this point is needed to determine if they are true isolates.

These findings suggest that while there seem to be six substructures (Communities 1–6) within the connected components, there does not appear to be any single attribute that is clearly driving the existence of all clusters. Instead, there seem to be multiple attributes and factors that influence the groupings, and may influence different groups of fishers in varied ways. For example, Community 3 is unique in several ways. First, nearly all of the White fishers (6 out of 7) are in Community 3, while those who identified as Black or Hispanic are mixed throughout the other communities. They also reported speaking at public fisheries management meetings more frequently than the fishers in other communities, as well as greater dissatisfaction with fisheries management.

Although the differences between Community 3 and the other communities are only slight, when these findings are paired with ethnographic data and the larger historical and political context of fisheries management in St. Croix (i.e., [36]; Yandle, Sweeny Tookes, & Grace-McCaskey 2020), the findings are more meaningful. As described in detail in [36], St. Croix's complex history of colonialism, migration, and status as a United States territory continues to influence demographic differences among social groups today. The vast majority of White individuals in St. Croix were not born there. Instead, they typically grew up and were educated in the continental United States, then moved to the island as adults, pursuing a career in the diving industry or environmental conservation. Often, they fish for enjoyment, subsistence, and to supplement their earnings from other occupations. Even though many White residents, including those who are fishers, have lived in St. Croix for twenty or thirty years, because of their skin color, they are still perceived as "outsiders" by most fishers and other non-White island residents [36]. Therefore, it is not surprising that the SNA results suggest ethnicity influences some community groupings.

When examining the type of relationships present in different communities, it is clear that some communities (i.e., Communities 1 and 4) have a higher proportion of family ties. Thirteen of the 14 family ties in the entire network are within (rather than between) communities, suggesting family ties are an organizing factor in the community structure of the network. More specifically, Community 4 is made up primarily of Hispanic/Puerto Rican fishers who are connected to one another via fishing and kinship ties. These fishers report a high dependence on fishing for their household income, consider tank diving to be their highest revenue-generating gear, and report being highly knowledgeable about fisheries management processes. Again, these results align with previous findings about the importance of commercial fishing to a few Puerto Rican families that migrated to St. Croix from Vieques [35,36]. For these families, fishing plays a primary role in their livelihoods, and fishers from the same family often fish together in pairs or trios. It is also important to note that this community is the most central in the network (Fig. 1), and the fisher who received the most nominations is part of this community. The influential positions of individuals such as this and the role they play regarding information and knowledge sharing in the network will be explored in future analyses.

The results also do not indicate any clear patterns of primary fishing gear or launch site used influencing community membership. Each community has fishers who use multiple types of fishing gear and various launch sites. This likely reflects the specific characteristics of St. Croix's small-scale commercial fishery mentioned previously, including that boats are kept at home, allowing fishers to choose on a daily basis on which side of the island to fish depending on weather, sea conditions, and other factors. This flexibility, however, also means that launch sites are not spaces for repeated social interactions among fishers, a contrast to findings in previous research [4]. Likewise, the lack of clear patterns in the communities related to gear use reflects the multi-method and multi-species characteristics of St. Croix's fishery, but also suggests findings different from those related to other SSF (e.g., [26,27]).

Results related to fishers' perceptions of and participation in fisheries management processes also show a lack of consensus within and between groups regarding perceptions of the current status of fisheries. While 37% of the fishers believe the current state of fishing is about the same as 5 years ago, 47% believe it has gotten worse. This lack of a shared understanding about the status of fisheries resources and varied perspectives on the extent to which the island's fisheries are threatened might hinder collective action related to management and conservation measures [56]. Additionally, only 25% of the fishers stated they participate in fisheries meetings (territorial and/or federal) often, and 39% stated that they never participate. These findings are similar to those from previous survey results [36]. Interestingly, however, ethnographic and observational data at territorial and federal fisheries

management meetings contradict these results, indicating that only a very small number of fishers from St. Croix (< 5) participate in and are actively engaged in management processes. One potential explanation for fishers reporting they participate more than they do is they wanted to be seen by the researchers as interested in fisheries management issues (social desirability bias). While a full analysis and explanation of the cause of the discrepancy is beyond the scope of this paper, these data regarding perceptions of and participation in management processes indicate that although managers design public meetings to be spaces that encourage the sharing of knowledge and information about the status of marine resources and discussion of management strategies, it is clear they are not fulfilling this role. If, instead, information and knowledge related to fishing and marine resources is being shared through ties via the network described here, then it may signal the need for managers to develop specific communication and outreach strategies that take into account the important and influential positions held by key members of the fishers' network.

5. Conclusions and future directions

As is common with many exploratory studies, these findings lead to more questions than answers. Data collection is ongoing (temporarily stalled in 2020–2021 due to the COVID-19 pandemic and associated travel and research restrictions), and the results presented here are only the first step of many geared toward examining the role that social networks play in a small scale fishery SES such as that in St. Croix. Social networks data have also been collected from individuals who are not fishers but are involved in the local and federal fisheries management processes. Future analyses will focus on the structure of the larger fisheries management network in St. Croix, including fisheries scientists, managers, and other marine resource stakeholders. Building on the results reported here, an examination of the larger network structure will allow us to examine cross-scale interactions to understand how social structure may facilitate or hinder flows of knowledge and resources between fishers and other fisheries management stakeholders.

Three important caveats should also be mentioned here. First, as stated in Section 2.2.1 (Data Collection), our sample includes 60% of the commercial fishers on the island who renewed their commercial fishing license for the 2019–2020 year (personal communication 2020). While a coverage of 60% does fall within the range of other SNA studies in similar contexts (e.g., Alexander 2018), we acknowledge it is at the lower end of the spectrum, which must be taken into consideration when forming conclusions based on our analyses. A higher response rate would provide a more accurate picture of the network topology and of the shared attributes of connected nodes. Second, as stated in Section 4 (Discussion), nearly one-fourth of the fishers we interviewed were isolates in the network, and stated that they did not talk to any other fishers about fishing. If they are indeed isolates in the network, then future research must seek to better understand factors that may contribute to the isolated positions (e.g., personal choice to not interact with others), the extent to which the relatively large number of isolates impacts how information and knowledge flow through the network, and the impacts on management outcomes. If, on the other hand, some or all of the isolates in our study chose not to disclose the names of fishers to whom they were connected, then we must acknowledge the possibility that important ties are omitted from the network. Lastly, we must note that the social networks data included in this analysis were collected only a few months prior to the start of the COVID-19 pandemic. Research indicates that, across the globe, the pandemic has impacted when and how individuals interact with one another, and that many social ties have changed permanently [40,66]. It is rational to assume that the fishers' network in St. Croix has also been permanently altered due to the pandemic and its impacts. While we do not believe this point renders our findings any less valid or important, it does mean that future research that builds on what is presented here must take into consideration that the network may have changed significantly since these data were collected.

Overall, the fact that multiple attributes influence community membership among St. Croix fishers aligns with and builds on recent work on SSF [4] but reiterates the fact that the processes that influence the formation and maintenance of ties among fishers are complex and potentially site-specific. This makes it challenging to come to meaningful conclusions related to the potential for collective action based on SNA alone, but highlights the important role that in-depth ethnographic and other qualitative data can play, particularly in the SSF context.

Related to the potential for collective action among the fishers, future research could examine the extent to which fishers' individual attributes or positions within the network and connections to the larger fisheries management network influence individual or group perceptions of "us" versus "them." Such perceptions could impede the flow of information throughout the network. Additionally, because kinship and friendship ties appear to play a role in community membership, how knowledge and perceptions are distributed within families could be examined. If greater consensus within family and friendship ties is observed, it might suggest the importance of socialization processes in forming beliefs and perceptions related to fisheries in resource-dependent contexts. This, in turn, can provide important information regarding what may encourage consensus and cooperation among fishers in St. Croix, which recent research shows plays an important role in promoting effective adaptation to climate change and other environmental stressors [64], and may contribute to improved ecological conditions [7]. Therefore, our findings, and the results of future research, can make valuable contributions to the management and policy contexts in St. Croix and the USVI as the islands' fishers, managers, and residents more broadly continue to recover from the devastating impacts of Hurricanes Irma and Maria, and work toward developing management strategies that allow for the continued catch of marine species that support the livelihoods of fishers and the nutrition of island residents without leading to ecological collapse (Stoffle et al., 2022; [1,71]).

This research has contributed preliminary social data under a mixed SNA and ethnographic framework, in the interest of expanding applicability to the wider field of SES and the management of SSF sustained by coral reef ecosystems. Critiques of SES often highlight the potential to overlook subtleties and interactions across various social and ecological sub-systems [54]. As our preliminary findings have indicated, there is considerable heterogeneity among fisher communities in St. Croix. Future research can apply similar detailed quantifiable social groupings and their potential for collective action to appropriately scaled ecological data. For example, with regards to collective action, future research could more directly assess specific knowledge that fishers share about local ecological processes. Understanding how knowledge is diffused and adopted through networks into specific practice such as good fishing locations, or fishing gear modifications, may suggest areas of possible resource depletion. In turn, it may illuminate barriers to collective action resulting from absence of consensus regarding knowledge of ecological processes, or harmful practices being conducted by specific subgroups of the network. Overwhelmingly, developing better baseline social and ecological data in SSF contexts can support detection of interactions between individual actors and natural resource systems, to facilitate improved management and system-wide adaptive capacity. This is particularly vital in SSF which remain data poor yet support the livelihoods of small island communities throughout the world.

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CRediT authorship contribution statement

Cynthia A. Grace-McCaskey: Conceptualization, Methodology,

Table A1
Descriptive statistics for St. Croix partitions after community detection procedure (additional attributes).

	Communities											
	1. Orange		2. Blue		3. Green		4. Yellow		5. Purple		6. Red	
	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd	Freq/ Mean	%/sd
Size (number of nodes)	10		7		11		9		2		6	
Born in St. Croix	8	80%	3	43%	6	55%	6	67%	2	100%	5	83%
Place of Residence												
Frederiksted (West area)	5	50%	1	14%	3	27%	2	22%	1	50%	2	33%
Mid-island	5	50%	3	43%	1	9%	4	44%	0	0%	0	0%
Christiansted	0	0%	2	29%	3	27%	1	11%	1	50%	3	50%
Northside	0	0%	0	0%	4	36%	2	22%	0	0%	0	0%
Species												
Reef	6	60%	4	57%	3	27%	9	100%	1	50%	5	83%
Deep water snapper	8	80%	4	57%	7	64%	4	44%	2	100%	1	17%
Lobster	4	40%	2	29%	4	36%	7	78%	1	50%	4	67%
Conch	4	40%	1	14%	4	36%	7	78%	1	50%	3	50%
Coastal pelagics	4	40%	2	29%	3	27%	4	44%	1	50%	4	67%
Dolphin/wahoo	6	60%	7	100%	10	91%	4	44%	2	100%	5	83%
Deep water pelagics	6	60%	6	86%	10	91%	5	56%	1	50%	4	67%
Whelk	1	10%	0	0%	0	0%	1	11%	0	0%	2	33%
Bait sold	1	10%	1	14%	0	0%	1	11%	1	50%	0	0%
Point of sale												
Home	6	60%	1	14%	1	9%	0	0%	0	0%	0	0%
La Reine	1	10%	3	43%	2	18%	5	56%	0	0%	0	0%
Frederiksted Pier	0	0%	0	0%	1	9%	0	0%	0	0%	0	0%
Restaurants	2	20%	2	29%	6	55%	4	44%	0	0%	4	67%
Hotels	2	20%	1	14%	0	0%	0	0%	0	0%	1	17%
Supermarkets	0	0%	0	0%	1	9%	0	0%	0	0%	1	17%
Along the road	3	30%	4	57%	2	18%	3	33%	1	50%	4	67%
Private customer	2	20%	1	14%	3	27%	1	11%	1	50%	2	33%
Does not sell	0	0%	0	0%	1	9%	0	0%	0	0%	1	17%
Other	0	0%	0	0%	2	18%	1	11%	0	0%	0	0%
Perceptions												
Scientists and managers listen to fishers	3	1.33	2.43	1.4	2.73	1.19	3	1.5	3	0	2.83	1.47
Need for management	3.5	0.97	3.6	0.38	4.45	0.52	3.89	0.78	4.5	0.71	3.83	0.98
R's collective orientation	3.56	1.01	3.67	0.82	3.55	1.13	4	1.15	4.5	0.71	4.2	0.45
R's individual orientation	3.5	1.07	3.67	0.82	3.64	1.12	3.71	1.25	4.0	0	4.2	1.30
Third order belief fishers' collective orientation	3.12	1.25	3.0	1.10	2.55	0.82	3.29	1.5	3.0	1.41	2.83	1.33
Third order belief fishers' individual orientation	3.89	0.33	3.67	0.82	3.64	0.81	3.75	1.28	4.0	0	4.0	0.63
Current status of fishing vs. 5 years ago												
Better	1	10%	1	14%	0	0%	2	22%	0	0%	0	0%
About the same	3	30%	2	29%	6	55%	2	22%	2	100%	4	67%
Worse	6	60%	4	57%	5	45%	4	44%	0	0%	2	33%
Fishermen are well-organized (Yes)	1	10%	1	14%	0	0%	2	22%	1	50%	0	0%
Fishermen being better organized would help R (Yes)	7	70%	6	86%	6	55%	8	89%	2	100%	6	100%

Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Maria C. Ramos:** Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Anja Sjostrom:** Investigation, Writing – original draft, Writing – review & editing. **Sarah Page:** Investigation, Writing – review & editing.

Data Availability

The data that has been used is confidential.

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Appendix A

See Table A1.

References

[1] J.J. Agar, C.S. Fleming, F. Tonioli, The net buyback and ban in St. Croix, US Virgin Islands, Ocean Coast. Manag. 167 (2019) 262–270.
[2] F. Agneessens, G.J. Labianca, Collecting survey-based social network information in work organizations, Soc. Netw. 68 (2022) 31–47.
[3] S. Alexander, D. Armitage, A. Charles, Social networks and transitions to comanagement in Jamaican marine reserves and small-scale fisheries, Glob. Environ. Change 35 (2015) 213–225.
[4] S. Alexander, Ö. Bodin, M. Barnes, Untangling the drivers of community cohesion in small-scale fisheries, Int. J. Commons 12 (1) (2018).
[5] C. Avenarius, J. Johnson, Adaptation to new legal procedures in rural China: integrating survey and ethnographic data, in: S. Dominguez, B. Hollstein (Eds.), Mixed Methods Social Networks Research: Design and Applications, Cambridge University Press, New York, 2015.
[6] A.L. Ayers, J.N. Kittinger, Emergence of co-management governance for Hawai 'i coral reef fisheries, Glob. Environ. Change 28 (2014) 251–262.
[7] M.L. Barnes, E. Mbaru, N. Muthiga, Information access and knowledge exchange in co-managed coral reef fisheries, Biol. Conserv. 238 (2019), 108198.
[8] Barnes, M.L., Lynham, J., Kalberg, K., & Leung, P. (2016). Social networks and environmental outcomes. Proceedings of the National Academy of Sciences, 113 (23), 6466–6471.

[9] M.L. Barnes, Ö. Bodin, T.R. McClanahan, J.N. Kittinger, A.S. Hoey, O.G. Gaoue, N. A.J. Graham, Social-ecological alignment and ecological conditions in coral reefs, Nat. Commun. 10 (1) (2019), https://doi.org/10.1038/s41467-019-09994-1.

[10] M. Barnes-Mauthe, S. Arita, S. Allen, S. Gray, P. Leung, The influence of ethnic diversity on social network structure in a common-pool resource system: implications for collaborative management, Ecol. Soc. 18 (1) (2013) 23, https://doi.org/10.5751/ES-05295-180123.

[11] M. Barnes-Mauthe, K.L. Oleson, B. Zafindrasilivonona, The total economic value of small-scale fisheries with a characterization of post-landing trends: an application in Madagascar with global relevance, Fish. Res. 147 (2013) 175–185.

[12] H.R. Bernard, Research Methods in Anthropology: Qualitative and Quantitative Approaches, Rowman & Littlefield, 2017.

[13] K.K. Bhavnah, M. Carlo, S. Marcus, Barriers to effective monitoring and evaluation of small-scale fisheries in small island developing states: an example from Mauritius, Mar. Policy (2020), 103845.

[14] Ö. Bodin, B. Crona, The role of social networks in natural resource governance: what relational patterns make a difference? Glob. Environ. Change 1 (2009) 366–374.

[15] O. Bodin, J. Norberg, Information network topologies for enhanced local adaptive management, Environ. Manag. 35 (2) (2005) 175–193.

[16] O. Bodin, C. Prell, Social Networks and Natural Resource Management, Cambridge University Press, Cambridge, 2011.

[17] O. Bodin, M. Tengö, Disentangling intangible social–ecological systems, Glob. Environ. Change 22 (2) (2012) 430–439.

[18] S.P. Borgatti, Centrality and network flow, Soc. Netw. 27 (1) (2005) 55–71.

[19] S.P. Borgatti, M.G. Everett, J.C. Johnson, Analyzing Social Networks, Sage, 2018.

[20] R.W. Buddemeier, D.R. Lane, J.A. Martinich, Modeling regional coral reef responses to global warming and changes in ocean chemistry: Caribbean case study, Clim. Change 109 (3) (2011) 375–397, https://doi.org/10.1007/s10584-011-0022-z.

[21] Carlsson, L., & Sandstrom, S. (2008) Network governance of the commons. International Journal of the Commons, 2: 33–54.

[22] CFMC, Caribbean Fisheries Management Council. (2019). Comprehensive Fishery Management Plan for the St. Croix Exclusive Economic Zone. https%3A%2F%2Fmedia.fisheries.noaa.gov%2Fdam-migration%2Fcarib_fmp_st_croix.pdf&usg=AOvVaw0_clLY-LiLCNMOlguzMQ_b.

[23] D. Christopoulos, F. Aubke, Data collection for social network analysis in tourism research. Knowledge Networks and Tourism, Routledge, 2014, pp. 140–156.

[24] Cinner, J.E., T.R. McClanahan, M.A. MacNeil, N.A.J. Graham, T.M. Daw, A. Mukminin, D.A. Feary, A.L. Rabearisoa, A. Wamukota, N. Jiddawi, S.J. Campbell, A.H. Baird, F.A. Januchowski-Hartley, S. Hamed, R. Lahari, T. Morove, and J. Kuange. (2012). Comanagement of coral reef social–ecological systems. Proceedings of the National Academy of Sciences USA, 109: 5219–5222.

[25] J.E. Cinner, C. Hutchery, M.A. MacNeil, N.A.J. Graham, T.R. McClanahan, J. Maina, E. Maire, J.N. Kittinger, C.C. Hicks, C. Mora, E.H. Allison, S. D'Agata, A. Hoey, D.A. Feary, L. Crowder, I.D. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. Edgar, R.D. Stuart-Smith, S.A. Sandin, A.L. Green, M.J. Hardt, M. Beger, A. M. Friedlander, S.J. Campbell, K.E. Holmes, S.K. Wilson, E. Brokovich, A.J. Brooks, J.J. Cruz-Motta, D.J. Booth, P. Chabanet, C. Gough, M. Tupper, S.C.A. Ferse, R. U. Sumaila, D. Mouillot, Bright spots among the world's coral reefs, Nature 535 (2016) 416–419.

[26] M. Cox, M. Wilson, T. Pavlowich, The challenges of local governance: gear-based fragmentation in the Dominican fishery of Buen Hombre, Mar. Policy 63 (2016) 109–117.

[27] B. Crona, Ö. Bodin, What you know is who you know? Communication patterns among resource users as a prerequisite for co-management, Ecol. Soc. 11 (2) (2006) 7. ⟨http://www.ecologyandsociety.org/vol11/iss2/art7/⟩.

[28] B. Crona, Ö. Bodin, Friends or neighbors? Subgroup heterogeneity and the importance of bonding and bridging ties in natural resource governance, in: Ö. Bodin, C. Prell (Eds.), Social Networks and Natural Resource Management: Uncovering the Social Fabric of Environmental Governance, Cambridge University Press, 2011.

[29] A. Degenne, M. Forse, Introducing Social Networks, Sage Publications, London, 1999.

[30] E.R. Ellison, R.D. Langhout, Sensitive topics, missing data, and refusal in social network studies: an ethical examination, Am. J. Community Psychol. 60 (3–4) (2017) 327–335.

[31] FAO 2014. The State of World Fisheries and Aquaculture. Food and Agricultural Organization of the United Nations, Rome.

[32] K.A. Frank, J.Y. Yasumoto, Linking action to social structure within a system: Social capital within and between subgroups, Am. J. Sociol. 104 (3) (1998) 642–686.

[33] N.E. Friedkin, Social cohesion, Annu. Rev. Sociol. 30 (1) (2004) 409–425.

[34] Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., & Watkinson, A.R. (2005). Hurricanes and Caribbean Coral Reefs: Impacts, Recovery Patterns, and Role in Long-Term Decline., 86(1), 174–184.

[35] Grace-McCaskey, Cynthia A. (2012). Fishermen, Politics, and Participation: An Ethnographic Examination of Commercial Fisheries Management in St. Croix, U.S. Virgin Islands. Ph.D. dissertation, University of South Florida.

[36] C.A. Grace-McCaskey, Multi-scale fisheries management in St. Croix, United States Virgin Islands: what influences participation? Hum. Organ. 77 (2) (2018) 157–171.

[37] N.L. Gutierrez, R. Hilborn, O. Defeo, Leadership, social capital and incentives promote successful fisheries, Nature 470 (2011) 386–389.

[38] T. Hahn, P. Olsson, C. Folke, K. Johansson, Trust-building, knowledge generation and organizational innovations: the role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden, Hum. Ecol. 34 (2006) 573–592.

[39] M.E. Isaac, B.H. Erickson, S.J. Quashie-Sam, V.R. Timmer, Transfer of knowledge on agroforestry management practices: the structure of farmer advice networks, Ecol. Soc. 12 (2007) 32.

[40] J.K. Jo, D.A. Harrison, S.M. Gray, The ties that cope? Reshaping social connections in response to pandemic distress, J. Appl. Psychol. 106 (9) (2021) 1267.

[41] S.D. Jupiter, Epstein Graham, C.Ban Natalie, Mangubhai Sangeeta, Fox Margaret, Cox Michael, A social–ecological systems approach to assessing conservation and fisheries outcomes in fijian locally managed marine areas, Soc. Nat. Resour. 30 (9) (2017) 1096–1111.

[42] Kittinger, J.N., Finkbeiner, E.M., Glazier, E.W., & Crowder, L.B. (2012). Human Dimensions of Coral Reef Social-Ecological Systems. Ecology and Society, 17(4). JSTOR. ⟨https://www.jstor.org/stable/26269232⟩.

[43] Kojis, B. 2004. Census of the marine commercial fishers of the U.S. Virgin Islands. U.S. Virgin Islands, Department of Planning and Natural Resources (DPNR), St. Thomas.

[44] Kojis, B.L. and N.J. Quinn. March 27, 2012. Census of the Marine Commercial Fishers of the U.S. Virgin Islands 2011. USVI Dept. of Planning and Natural Resources, Division of Fish and Wildlife.

[45] B. Kojis, N. Quinn, J. Agar, Census of licensed fishers of the U.S. Virgin Islands (2016) NOAA Tech. Memo. NMFS-SEFSC 715 2017 160 doi: 10.7289/V5/TM-SEFSC-715.

[46] Leslie, H.M., Basurto, X., Nenadovic, M., Sievanen, L., Cavanaugh, K.C., Cota-Nieto, J.J., Erisman, B.E., Finkbeiner, E., Hinojosa-Arango, G., Moreno-Báez, M., Nagavarapu, S., Reddy, S.M.W., Sánchez-Rodríguez, A., Siegel, K., Ulibarria-Valenzuela, J.J., Weaver, A.H., & Aburto-Oropeza, O. (2015). Operationalizing the social-ecological systems framework to assess sustainability. Proceedings of the National Academy of Sciences, 112(19), 5979–5984.

[47] J. Liu, T. Dietz, S.R. Carpenter, M. Alberti, C. Folke, E. Moran, A.N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S.H. Schneider, W.W. Taylor, Complexity of coupled human and natural systems, Science 317 (2007) 1513–1516.

[48] M. Lubell, G. Robins, P. Wang, Network structure and institutional complexity in an ecology of water management games, Ecol. Soc. 19 (4) (2014) 23.

[49] C. McCarty, J.L. Molina, Social network analysis, in: H.R. Bernard, C.C. Gravlee (Eds.), Handbook of Methods in Cultural Anthropology, second ed., Rowman & Littlefield., London, 2015.

[50] J.L. Moreno, H.H. Jennings, Statistics of social configurations, Sociometry (1938) 342–374.

[51] M.E.J. Newman, M. Girvan, Finding and evaluating community structure in networks, Phys. Rev. E 69 (2) (2004), 026113.

[52] L. Newman, A. Dale, Homophily and agency: creating effective sustainable development networks, Environ. Dev. Sustain. 9 (2007) 79–90.

[53] M. Newman, Networks: An Introduction, Oxford University Press, Oxford, 2010.

[54] K.L. Ovitz, T.R. Johnson, Seeking sustainability: employing Ostrom's SESF to explore spatial fit in Maine's sea urchin fishery, Int. J. Commons 13 (1) (2019) 276, https://doi.org/10.18352/ijc.866.

[55] E. Ostrom, Governing the Commons: The Evolution of Institutions for Collective Action, Cambridge University Press, New York, NY, 1990.

[56] E. Ostrom, Understanding Institutional Diversity, Princeton University Press, Princeton, NJ, 2005.

[57] E. Ostrom, A general framework for analyzing sustainability of social-ecological systems, Science 325 (2009) 419–422.

[58] Ostrom, E., & Basurto, X. (2009). Beyond the Tragedy of the Common. Beyond the Tragedy of the Common, 1000–1026.

[59] C.T. Perry, L. Alvarez-Filip, N.A.J. Graham, P.J. Mumby, S.K. Wilson, P.S. Kench, D.P. Manzello, K.M. Morgan, A.B.A. Slangen, D.P. Thomson, F. Januchowski-Hartley, S.G. Smithers, R.S. Steneck, R. Carlton, E.N. Edinger, I.C. Enochs, N. Estrada-Saldívar, M.D.E. Haywood, G. Kolodziej, C. Macdonald, Loss of coral reef growth capacity to track future increases in sea level, Nature 558 (7710) (2018) 396–400, https://doi.org/10.1038/s41586-018-0194-z.

[60] C. Prell, K. Hubacek, M. Reed, Stakeholder analysis and social network analysis in natural resource management, Soc. Nat. Resour. 22 (2009) 501–518.

[61] Ramirez-Sanchez, S. (2011). Who and How: Engaging Well-Connected Fishers in Social Networks to Improve Fisheries Management and Conservation. Pp. 119–46 in Social Networks and Natural Resource Management: Uncovering the Social Fabric of Environmental Governance, edited by Ö. Bodin and C. Prell: Cambridge University Press.

[62] S. Ramirez-Sanchez, E. Pinkerton, The impact of resource scarcity on bonding and bridging social capital: the case of fishers' information-sharing networks in Loreto, BCS, Mexico, Ecol. Soc. 14 (1) (2009).

[63] T.M. Schusler, D.J. Decker, Social learning for collaborative natural resource management, Soc. Nat. Resour. 15 (2003) 309–326.

[64] D. Salgueiro-Otero, M.L. Barnes, E. Ojea, Climate adaptation pathways and the role of social-ecological networks in small-scale fisheries, Sci. Rep. 12 (1) (2022) 1–13.

[65] H. Smith, X. Basurto, Defining small-scale fisheries and examining the role of science in shaping perceptions of who and what counts: a systematic review, Front. Mar. Sci. 6 (2019) 236.

[66] Smith, S.L., Cook, S., Golden, A., Iwane, M.A., Kleiber, D., Leong, K.M.,. & Wise, S. (2022). Review of adaptations of US Commercial Fisheries in response to the COVID-19 pandemic using the Resist-Accept-Direct (RAD) framework. Fisheries Management and Ecology.

[67] Stoffle, B., Stoltz, A., Crosson, S., & TOOKES, J.S. (2020). In the Wake of Two Storms: An Impact Assessment of Hurricanes Irma and Maria on the St. Croix and

St. Thomas Fisheries, USVI. 2020 Officers And Directors High Plains Society For Applied Anthropology.
[68] Valdés-Pizzini, Manuel, Juan J.Agar, Kathi Kitner, Carlos Garcia- Quijano, Michael Tust, and Francesca Forrestal (2010) Cruzan Fisheries: A Rapid Assessment of the Historical, Social, Cultural and Economic Processes that Shaped Coastal Communities' Dependence and Engagement in Fishing in the Island of St. Croix, U. S. Virgin Islands. NOAA Series on U.S. Caribbean Fishing Communities. NOAA Technical Memorandum NMFS-SEFSC-597. Miami, FL: NOAA Fisheries, Southeast Fisheries Science Center.
[69] S. Wasserman, K. Faust, Social Network Analysis- Methods and Applications, Cambridge University Press, Cambridge, 1994.
[70] Wilkinson, C., Souter, D. (2008). Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville.
[71] T. Yandle, J. Sweeney Tookes, C.A. Grace-McCaskey, US virgin islands fishing community resilience: informing a research agenda, Coast. Manag. 48 (5) (2020) 481–504.