



## Full length article

# Network analysis of a regional fishery: Implications for management of natural resources, and recruitment and retention of anglers



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## ARTICLE INFO

Handled by A.E. Punt

## Keywords:

Angler recruitment and retention

Angler survey

Natural resource management

Resilience

Social-ecological system

## ABSTRACT

Angler groups and water-body types interact to create a complex social-ecological system. Network analysis could inform detailed mechanistic models on, and provide managers better information about, basic patterns of fishing activity. Differences in behavior and reservoir selection among angler groups in a regional fishery, the Salt Valley fishery in southeastern Nebraska, USA, were assessed using a combination of cluster and network analyses. The four angler groups assessed ranged from less active, unskilled anglers (group One) to highly active, very skilled anglers (group Four). Reservoir use patterns and the resulting network communities of these four angler groups differed; the number of reservoir communities for these groups ranged from two to three and appeared to be driven by reservoir location (group One), reservoir size and its associated attributes (groups Two and Four), or an interaction between reservoir size and location (group Three). Network analysis is a useful tool to describe differences in participation among angler groups within a regional fishery, and provides new insights about possible recruitment of anglers. For example, group One anglers fished reservoirs closer to home and had a greater probability of dropping out if local reservoir access were restricted.

## 1. Introduction

Models to describe angler choice of fishing location and movement among water bodies have developed from simple, gravity models (Freund and Wilson, 1973) to complex, multinomial-logit choice, or generalized nested-logit models (Hunt et al., 2004; Hunt, 2005). These more complex models used random utility theory (McFadden, 1974; Train, 2009) to describe the process by which anglers chose fishing sites to maximize their greatest utility or benefit (Cascetta, 2009). Site-selection models were further refined with the use of recreational-specialization theory (Bryan, 1977) to evaluate angler types and create angler groups for use in site-selection models (e.g., Oh and Ditton, 2006; Beardmore et al., 2013).

One limitation of previous modeling techniques is the inability to determine the social and ecological linkages (Berkes et al., 2000). Within any geographic area, there are likely multiple groups of anglers and multiple groups of water bodies. For example, angler groups may be defined by angler preference and behavior (Connelly et al., 2001; Oh and Ditton, 2005, 2006; Morey et al., 2006; Beardmore et al., 2013; Chizinski et al., In press), whereas water-body types may be defined by fish assemblage (e.g., largemouth bass *Micropterus salmoides* and blue-

gill *Lepomis macrochirus* fishery versus hybrid striped bass *Morone chrysops* × *M. saxatilis*, walleye *Sander vitreus*, and largemouth bass fishery) – this is just one of many ways to group anglers and water bodies. Angler groups and water-body types likely interact to create a complex social-ecological system (Hunt et al., 2013; Arlinghaus et al., 2017). It is difficult to predict potential changes to and resilience of a social-ecological system without a thorough understanding of the structure of the complete system (Johnston et al., 2013, 2015; Pope et al., 2014). A requisite of this understanding is knowledge about similarities and differences among defined groups of anglers and defined groups of water bodies. Splitting and lumping to delineate groups (Zerubavel, 1996) of recreational anglers has potential consequences on design of programs to recruit and retain anglers on a regional scale.

A modeling technique that combines the desirable attributes of the previously described techniques and allows for a unique understanding of the underlying structure of a social-ecological system is network analysis. Network analysis, derived from graph theory (West, 2001; Diestel, 2010), has been used to describe friendships derived from mobile-phone records (Eagle et al., 2009), corporate knowledge transfer via interlocking directorates (Mizruchi, 1996; O'Hagan and

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Green, 2004), disease-transmission patterns (Christley et al., 2005), brain synapses (Rubinov and Sporns, 2010), ecological food-webs (Krause et al., 2003), plant-pollinator communities (Bosch et al., 2009), and relationships between recreational anglers and fish caught (Chizinski et al., In press). Network analysis allows for the explicit linking of nodes (i.e., objects of interest) by weighted edges (i.e., strength of association) to gain an understanding of the importance of linkages among nodes within a social-ecological system.

Changes in the regional fishery (Martin and Pope, 2011), or available water bodies for anglers to choose, result in changes in network structure directing the social-ecological system. Resilience of social-ecological systems has been proposed as one particular metric that may be particularly suited for study with network analysis (Janssen et al., 2006). The resilience of a regional fishery depends on the set of water-body options from which anglers can choose (Pope et al., 2014). A resilient regional fishery would be one that 1) has a set of diverse water-body options that satisfies needs and desires of multiple angler groups, and 2) maintains redundancy within those options in case of failure of fish populations, changes in water-body accessibility, or changes in composition of angler groups.

The angler-water body interaction is a social-ecological network of interest for fisheries management, especially for control of invasive species (Johnson et al., 2001) and prevention of overharvest (Carpenter and Brock, 2004). Establishing direct linkages between anglers and water bodies provides managers with a tool for understanding potential pathways for invasive species spread through boat movement (Haak et al., 2017) and understanding secondary effects of overharvest of key sportfish species. For example, if one water body is overharvested or endures a fish kill, managers may be able to proactively manage for increased effort or harvest at nearby water bodies (or substitute sites) and reduce bag limits before overharvest becomes a concern (see Allen et al. (2013) for recruitment overfishing example). Thus, a clear understanding of complex network structure of a regional fishery will further our knowledge of angler dynamics; this increased understanding would benefit individuals developing mechanistic models and provide managers better information on basic patterns of fishing activity.

## 2. Methods

### 2.1. Approach

Our goals were to explore (a) how distinct or diverse are angler patterns of participation in a regional fishery, (b) how water bodies are connected through angler use (i.e., define communities of similar reservoirs within the regional fishery), and (c) how resilient a regional fishery is to removals of reservoirs. Answering these questions required five steps:

- Categorize reservoirs based on fish communities and reservoir size. These categories were used to determine the sampling approach.
- Group anglers based on fishing experience and recreational specialization.
- Quantify the reservoirs in the regional fishery visited by each angler, along with the relative frequency of visits.
- Quantify the connections among reservoirs in the regional fishery based on (a) anglers within each group determined in step 2 and (b) all anglers (global) in the regional fishery.
- Quantify changes in network metrics when reservoirs were removed from the global regional fishery.
- Steps 1–2 required use of cluster analyses, whereas steps 3–5 required the use of network theory and network analyses.

### 2.2. Study system

Groupings of 19 reservoirs in the Salt Creek watershed (Fig. 1),

hereafter Salt Valley, of southeastern Nebraska, USA by surface area and fish species resulted in four categories (Table 1): 1) extra small (< 25 ha) reservoirs with a simple littoral fish community (n = 8), 2) small (40–80 ha) reservoirs with additions of some larger pelagic fish (n = 4), 3) medium (80–300 ha) reservoirs with large pelagic, predatory fish present (n = 6), and 4) large (> 700 ha) reservoirs with all fish species present (n = 1).

### 2.3. Data collection

Respondents were recruited from in-person contacts at the 19 reservoirs within the Salt Valley during 2010–2012. Respondents at seven reservoirs were contacted per year, two (when possible) from each of four categories from a pre-defined classification scheme based on reservoir size and fish community (Table 1). In-person contacts were conducted year-round, except for times when ice was unsafe. Contact days (n = 12/month) and times were chosen following a stratified multistage probability-sampling regime (Malvestuto, 1996). Contact days each month were stratified by two categories with equal probability: weekend (including holidays) and weekday. Contact times were stratified by three categories with equal probability: early (0000–0800 h), mid (0800–1600 h) and late (1600–2400 h). To collect in-depth information on angler use patterns within the Salt Valley, all individual anglers contacted were asked to participate in a return-mail survey. Return, postage-paid envelopes were provided to anglers to increase survey return rates (Armstrong and Lusk, 1987). Questions included on the return-mail survey addressed visitation to the 19 reservoirs in the Salt Valley during the last 12 months, self-reported skill, demographics, recreational specialization, and motivations for selecting a reservoir.

### 2.4. Angler groups

Data from questions aimed at determining components of recreational specialization (Bryan, 1977; Chipman and Helfrich, 1988; Fisher, 1997; Beardmore et al., 2013) were used for k-means cluster analysis using the PAM function in the *cluster* package in R (Maechler et al., 2013). The three variables used to group anglers were 1) total number of days fished during the last 12 months, 2) self-reported angler skill level, ranging from unskilled to very skilled measured by a 5-point scale, and 3) consistency that the angler buys an annual license. This last measure, an indicator to long-term commitment to angling or importance to one's life, was calculated as a self-reported number of years holding a fishing license divided by the adjusted-angler's age (adjusted by subtracting 16 years because no license is needed until age 16 in Nebraska). A dissimilarity matrix based on Gower's distance (Gower, 1971) was used for cluster analysis because angler skill was measured on an ordinal scale and treated as a factor variable. The number of groups was determined from the iteration with the greatest average silhouette width after running iterations ranging from two to 20 groups (Rousseeuw, 1987). A larger silhouette width indicates a better fit of the clustering algorithm, and is used as a measure of fit.

### 2.5. Network analyses

Network analyses were conducted using the *igraph* package in R (Csardi and Nepusz, 2006; R Core Team, 2012). All plots used a force-directed layout (Fruchterman and Reingold, 1991) unless otherwise noted as a spatial layout. Force-directed layouts use algorithms inspired by physical forces (e.g., springs and gravity) such that the resulting graphs place nodes that are connected to each other closer together.

The data on visitation to Salt Valley reservoirs were summarized into a matrix with anglers listed in rows, reservoirs listed in columns, and the number of days that a reservoir was visited during the last 12 months by an angler listed in the corresponding cell value. If an angler did not visit a reservoir, the corresponding cell received a zero. There

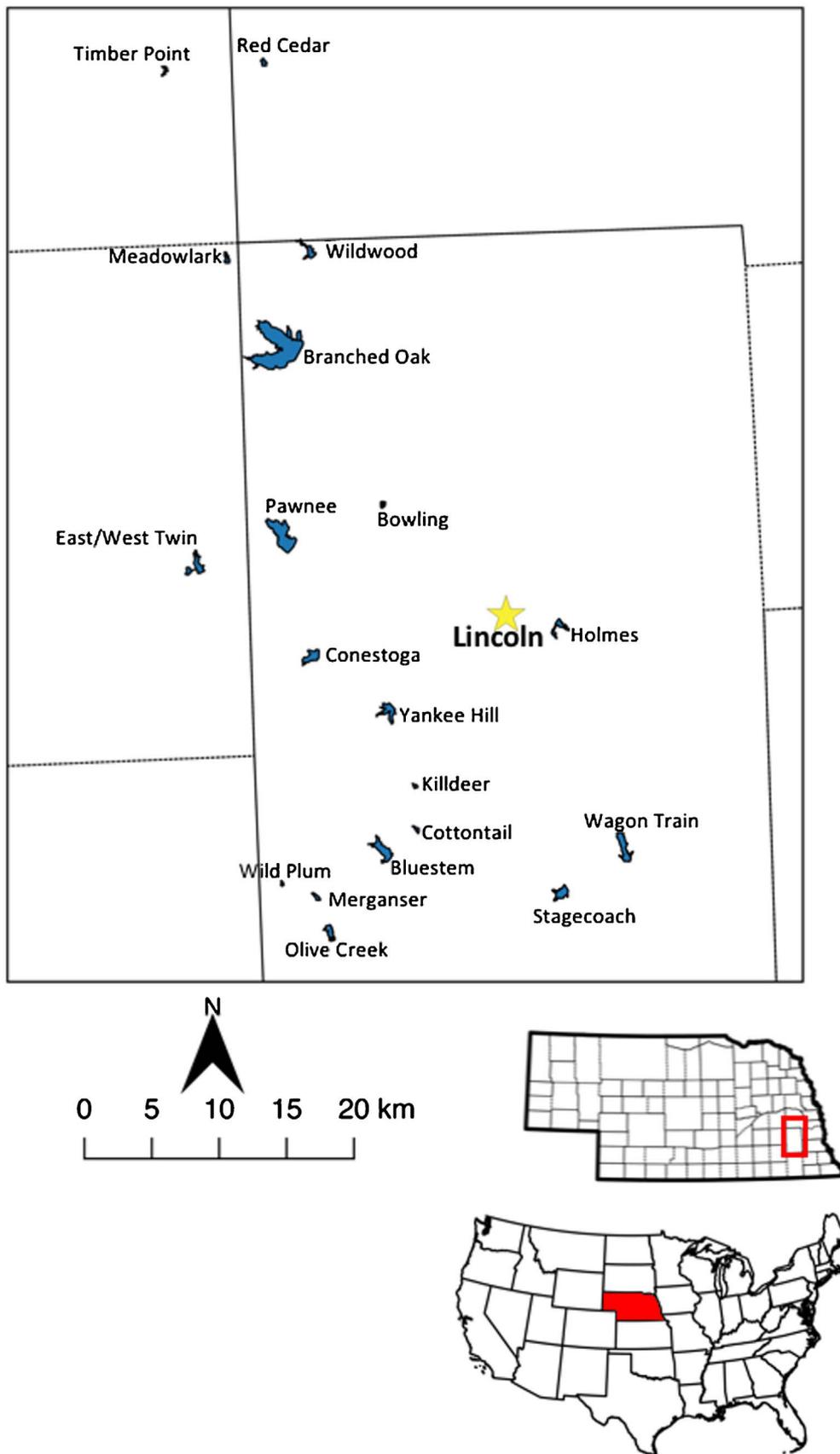


Fig. 1. Map of 19 study reservoirs in the Salt Valley watershed of southeastern Nebraska, USA.

**Table 1**

Delineation of reservoir categories by surface area (hectares) and fish community. An “X” indicates fish species present in that reservoir. Fishes are bluegill (BLG) *Lepomis macrochirus*, largemouth bass (LMB) *Micropterus salmoides*, walleye (WAE) *Sander vitreus*, crappie (CRP) *Pomoxis* spp., flathead catfish (FHC) *Pylodictis olivaris*, channel catfish (CCF) *Ictalurus punctatus*, hybrid striped bass (HSB) *Morone chrysops* × *M. saxatilis*.

Category	Reservoir	Surface area	BLG	LMB	WAE	CRP	FHC	CCF	HSB
1	Bowling	4.9	X	X				X	
	Wild Plum	6.5	X	X				X	
	Killdeer	8.1	X	X		X		X	
	Timber Point	11.3	X	X		X		X	
	Cottontail	11.7	X	X				X	
	Merganser	16.6	X	X				X	
	Red Cedar	20.2	X	X		X	X	X	
	Meadowlark	22.3	X	X		X		X	
2	Holmes	40.5	X	X	X			X	
	Wildwood	41.7	X	X	X			X	
	Olive Creek	70.8	X	X				X	
	Stagecoach	78.9	X	X	X	X		X	X
3	Yankee Hill	84.2	X	X	X			X	
	Conestoga	93.1	X	X	X	X	X	X	X
	East/West Twin	109.3	X	X	X	X		X	
	Wagon Train	127.5	X	X	X			X	
	Bluestem	131.9	X	X	X	X	X	X	
	Pawnee	299.5	X	X	X	X	X	X	
	Branched Oak	728.4	X	X	X	X	X	X	X

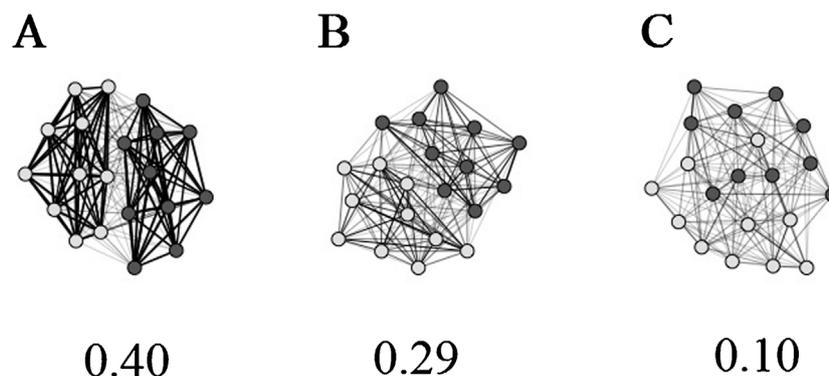
were separate matrices created for each angler group (as determined from the cluster analysis), as well as one global matrix for all anglers. Thus, the number of rows ( $N$ ) varied across matrices, but there were always 19 columns corresponding to the number of reservoirs considered. Surveys were combined across years because survey respondents were only recruited from seven of the 19 reservoirs each year.

Graph representation of the connections between reservoirs by angler groups was created using a bipartite projection of each angler-reservoir matrix. In the resulting network, each reservoir was represented by a *node*, reservoirs visited by the same angler were connected by an *edge*, and edges were weighted by the number of anglers that connected those reservoirs. We then used a modularity-based community detection algorithm (Clauset et al., 2004) to determine whether discrete communities of nodes, or groups of tightly connected reservoirs, existed within each reservoir co-visitation network. This class of community detection methods seeks to search for network partitions that maximize *modularity*, which is defined as the fraction of edges that fall within groups minus the expected fraction of edges within communities if edges were distributed at random among nodes (Newman, 2006). Theoretically, modularity ranges from 0 to 1, though functionally this range depends on degree distribution (Fig. 2).

We applied a bootstrapping method to account for sampling error and help reveal patterns that could be obscured in the raw datasets

(Lusseau et al., 2008). For example, bootstrapping can help distinguish between rare connections (e.g., if one angler visits a distinct pair of reservoirs many times) from frequent connections (many anglers visiting the same pairs of reservoirs). The original angler-reservoir matrices were resampled with replacement by row to create a new matrix with the same dimensions ( $N \times 19$ ) as the original matrix. This resampling was repeated 1000 times to create bootstrapped matrices. Each bootstrapped matrix was then run through a bipartite projection in *igraph* to obtain the network of reservoirs, and the same community-detection algorithm was used on each bootstrapped iteration (Clauset et al., 2004). Membership of each reservoir to a community subgroup was recorded for each iteration and combined to create a  $1000 \times 19$  matrix of community membership. This new matrix was then used to create a  $19 \times 19$  square adjacency matrix by calculating a probability of each pair of reservoirs being connected. This probability was calculated as the proportion of 1000 iterations in which the pair of reservoirs was in the same community.

The resulting matrix of community membership for each angler group (including the global matrix) was used for all further reservoir analyses. Degree, or the number of other nodes to which each node is connected, was calculated for all reservoirs (Wasserman and Faust, 1994). Additional network-level metrics such as degree distribution, density, number of communities, and modularity (Table 2) were



**Fig. 2.** Examples of networks (identical number of nodes [20], density [0.81], and number of communities [2]) displaying a range in modularity identified by numbers under each network. A is a network with high modularity, B is a network with moderate modularity, and C is a network with low modularity (community designation of nodes in network C is meaningless because there is weak community structure). The connections between the nodes (edges) within a community are black and between the nodes among communities are in light gray.

**Table 2**  
Overview and definitions of network analysis.

Term	Definition
node	Discrete elements of the network. Here, each reservoir is a node.
edge	Connections between nodes. Here, edges connect reservoirs when visited by the same angler, and edges are weighted by the number of anglers that visit the pair of reservoirs.
degree	The number of edges connected to a given node.
degree distribution	The probability distribution of degree for all nodes in a network.
dyad	A pair of nodes. Here, two reservoirs visited by the same angler.
density	The proportion of all dyads in the network that are connected by an edge.
communities	Sets of highly interconnected nodes, as assigned by the community detection search algorithm. Here, defined by Clauset et al. (2004).
modularity	A measure of deviation between observed and expected sum of edge weights that occur only within communities.

calculated for each angler group (Csardi and Nepusz, 2006). The spatial structure of the regional fishery was examined by plotting reservoirs in their correct geographic location. Reservoir latitude and longitude were added as vertex attributes of the nodes and a new geographic layout was created. Other attributes of the regional fishery such as reservoir size were included as an attribute matrix.

### 2.6. Reservoir removal

Resilience of the regional fishery to disturbance was tested by topological removal of reservoirs from the global network and analyzing network measures such as modularity. Every possible combination of reservoirs was selected and removed from the network from one reservoir per iteration to 18 reservoirs per iteration (i.e., only one reservoir remaining in the network). Modularity of each resulting network was calculated using the same community detection method described above. Further analysis examined the number of communities and mean community size at each level of removal to assess the effects of reservoir removal.

## 3. Results

Eight hundred ninety seven usable return-mail surveys were received from January 2010 through December 2012. Fifty-nine surveys were removed from the dataset because anglers did not answer all questions related to recreational specialization. Anglers reported  $35.9 \pm 44.1$  (mean  $\pm$  SE) days fishing the 19 reservoirs of the Salt Valley during the last 12 months with a total of 32,249 days reported. Anglers visited  $4.6 \pm 0.9$  reservoirs during the last 12 months with a range from one to 15 reservoirs. Visitation by individual anglers at individual reservoirs ranged from zero to 250 days fishing during the last 12 months, with the mean  $\pm$  SE ranging from  $0.07 \pm 0.02$  at Red Cedar Lake to  $5.3 \pm 0.6$  days at Holmes Lake.

### 3.1. Angler groups

Four groups described the most variation in the angler-community dataset based on recreational specialization. The four-group solution (Fig. 3) described 16% of the variation in the angler dataset with two components. The four groups differed in the total number of days fished during the last 12 months (Kruskal-Wallis,  $X^2 = 167.7$ ,  $df = 3$ ,  $P < 0.001$ ), self-reported skill level (Kruskal-Wallis,  $X^2 = 823.0$ ,  $df = 3$ ,  $P < 0.001$ ) and proportion of years with license (Kruskal-Wallis,  $X^2 = 122$ ,  $df = 3$ ,  $P < 0.001$ ). In general, as the number of days spent fishing increased, so did angler self-reported skill and the proportion of years holding a license (Fig. 4). Angler group One represents anglers ( $N = 70$ ) that fish few days per year ( $18.4 \pm 1.6$ ), have low angling skill, and buy a fishing license once every two years. Angler group Two represents anglers ( $N = 317$ ) that fish more often than group One ( $38.6 \pm 2.3$  days), have average angling skill, and buy a fishing license three out of every four years. Angler group Three represents anglers ( $N = 312$ ) that fish more often ( $56.7 \pm 2.7$  days),

are skilled anglers, and buy a fishing license nine out of every 10 years. Angler group Four represents anglers ( $N = 139$ ) that fish the most ( $87.6 \pm 5.5$  days), are very skilled anglers, and buy a license every year.

### 3.2. Angler-group networks

Reservoir networks of angler groups differed in structure and function. Density of reservoir networks ranged from 0.71 for angler group One to 1.00 for angler group Three (Table 3). The number of reservoir communities identified with the fast-and-greedy community-detection algorithm ranged from two to three, with modularity ranging from 0.01 to 0.09 (Table 3). Reservoir communities varied among angler groups with angler groups Two and Four being the most similar to each other and to the overall network structure of the regional fishery, using data from all anglers combined (Fig. 5). The resulting networks from these two angler groups (i.e., Two and Four) had two reservoir communities, which corresponded with small ( $< 50$  ha) and large ( $\geq 50$  ha) reservoirs, although modularity was low indicating a weak division into communities. The network of angler group One had three reservoir communities and appears to be driven by spatial location within the regional fishery (Fig. 5), with communities of southern reservoirs, communities of northern reservoirs, and communities of mid-latitude reservoirs. The large number of connections between reservoir communities indicates low modularity and relative weak strength of this community detection. The network of angler group Three had three reservoir communities, and appears to have an interaction effect between reservoir size and spatial location, with communities of southern, northern, and mid-latitude reservoirs.

### 3.3. Global network

The observed network of reservoirs had 19 nodes with 171 edges. The density of the observed network was 1.0, indicating an edge occurred between every pair of nodes; i.e., at least one angler visited every combination of reservoirs. Therefore, the degree of each node was 18, indicating a complete network, with little variation between nodes. No distinct communities were found among the reservoirs using community detection algorithms.

After bootstrapping the observed network, the resulting network based on probability of group membership had 19 nodes with 135 edges (Fig. 6). The reservoirs most centrally located on the graph, Bluestem, Bowling, Meadowlark, Olive Creek, Red Cedar, and Timber Point, were the most important in connecting all Salt-Valley reservoirs together. The density, or proportion of possible edges that actually exist, of the bootstrapped network was 0.77 (Table 3) and degree ranged from nine to 18. Community detection of the bootstrapped network revealed two separate communities within the regional fishery (Fig. 6), indicating that anglers of the Salt Valley regional fishery use these two groups of reservoirs differently. There was no spatial component to the delineation of these two communities, with each community stretching across the entire Salt Valley regional fishery (Fig. 6, bottom). The two

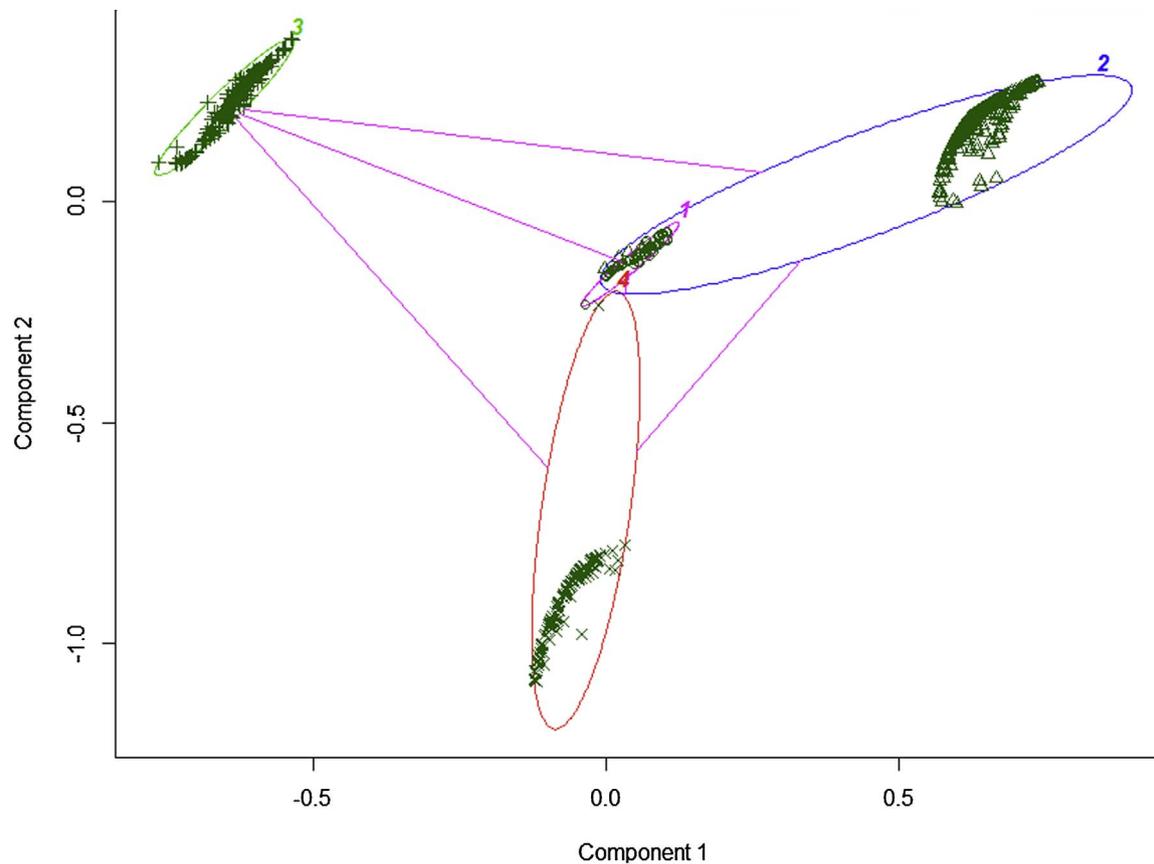


Fig. 3. Cluster analysis of anglers in the Salt Valley regional fishery based on recreational specialization. Four-cluster solution explains 15.9% of variability in data.

communities of the regional fishery did differ by reservoir surface area, with a community of small (< 50 ha) and a community of large (> 50 ha) reservoirs. Furthermore, those six centrally located reservoirs remained centrally located and belonged to two water-body types. Bluestem and Olive Creek were located within the community of large reservoirs, but were located closer to the community of small reservoirs, indicating that these two reservoirs were connectors between the two communities. Modularity of the bootstrapped network was 0.33 using the fast-and-greedy algorithm, signifying a greater number of edges within communities than would be expected at random. The community of small reservoirs matched our a priori group of small water bodies.

### 3.4. Reservoir removal

Topological removal of reservoirs from the global regional fishery had an unexpected result on modularity (strength of division of network into communities). We predicted that as reservoirs were removed from the system, the behavior of the system would be altered because the network would be broken up into more discrete communities of reservoirs—that is, modularity was expected to increase. Instead, modularity decreased as more reservoirs were removed from the regional fishery (Fig. 7). Further, the number of reservoir communities from community detection in the regional fishery did not decrease until 10 reservoirs were removed (Fig. 7).

## 4. Discussion

A network analysis approach is useful for describing differences in fishing participation across angler groups within a regional fishery. Anglers make choices among fishing locations on a daily basis and these decisions have an effect on that angler's future decisions with regard to fishing locations. Fishery managers may not believe that changes at one

reservoir will affect anglers at another reservoir, though there are often subtle changes, perhaps due to crowding or overfishing, that can have large, cumulative effects (Post et al., 2002; Carpenter and Brock, 2004; Allen et al., 2013). The explicit connections shown in network analysis between fishing locations within an angler group allow researchers and managers to examine potential consequences of any action (e.g., invasive species) on that angler group with a given region (Johnson et al., 2001).

We took an exploratory approach to help researchers and managers understand angler's substitution patterns among water bodies for recreational fishing. The angling population of the Salt Valley regional fishery is comprised of at least four distinct groups, ranging from less active, unskilled anglers to highly active, very skilled anglers. It is possible that we missed one or more groups of anglers because of survey response bias (e.g., Messonnier et al., 2000); we cannot assess such bias because data describing non-respondents to our survey are not available. Thus, inference of our results is somewhat limited—that is, we were unable to accurately describe the composition of angler groups within the Salt Valley. Importantly, we were able to describe differences in fishing patterns among the angler groups we assessed—that is, we were able to gain understanding of angler heterogeneity (Ditton and Fedler, 1989; Johnston et al., 2010). Reservoir-use patterns and the resulting network communities of the four angler groups differed. Specifically, angler groups One and Three differ from the global pattern of two reservoir communities defined by reservoir size and associated attributes. These two groups have different reservoir network communities that appear to have a strong spatial component on decisions of where to fish, whereas the global network community did not show any spatial influence. A thorough understanding of the behavior of angler group One, the less skilled anglers, is important to understand for angler recruitment and retention. This group, in particular, has a strong spatial factor to the network community that drives their decisions to fish reservoirs that are closer to their home, potentially driven by social

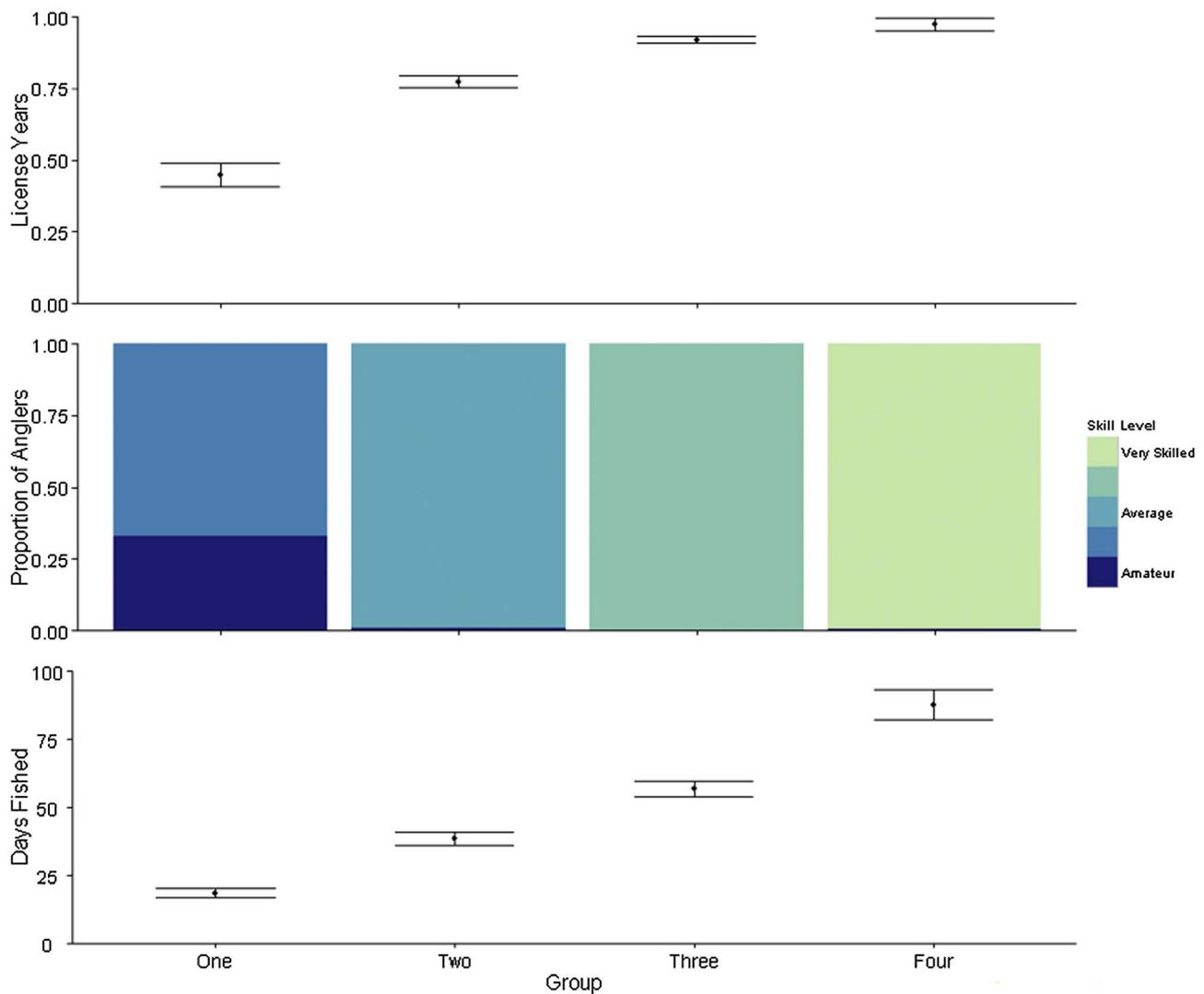


Fig. 4. Groups of the anglers of the Salt Valley regional fishery, defined by mean  $\pm$  SE proportion of years holding a fishing license, proportion of anglers reporting angler skill level from amateur to very skilled, and mean  $\pm$  SE number of days fished during the last 12 months.

Table 3  
Network characteristics of global (all anglers) and angler-group networks.

	Global	Group 1	Group 2	Group 3	Group 4
Density	0.77	0.71	0.98	1.00	0.99
Modularity	0.327	0.086	0.013	0.016	0.016
Number of Communities	2	3	2	3	2

factors rather than ecological factors (Hunt and Ditton, 1997). Differences in angler behavior across these four angler groups, which represent a gradient of recreational specialization, are important to understand for angler recruitment and retention. Anglers that are less active and unskilled are more likely to stop angling if access at their favorite reservoir is prevented, whereas anglers that are highly active and very skilled are likely to keep angling at another substitute reservoir.

The global network of respondents consisted of two distinct reservoir communities that were not defined by spatial proximity. Rather, these two communities were defined by reservoir size and associated attributes, indicating that respondents to our survey see separate, qualitatively different fishing experiences on small and large reservoirs. This is likely driven by a combination of access, permit fees (i.e., no Nebraska Game and Parks Commission park permit needed to

access seven out of eight reservoirs in the small-reservoir community whereas a park permit is required to access nine out of 11 reservoirs in the large-reservoir community), and fish assemblages. However, these factors are all highly correlated and the current study cannot determine which factors are the most important. It is important to note the reservoirs that are centrally located within the force-directed graphs (Fig. 6, top). Reservoirs such as Bluestem, Olive Creek, Red Cedar, and Timber Point play an important role in connecting the two reservoir communities. From a management viewpoint, these reservoirs are traffic gateways between the two communities and likely are of greater risk for invasive species.

The social classification based on angler use patterns differs from our a priori ecological classification based on fish assemblage and reservoir size. The social classification contains two reservoir communities, whereas the ecological classification contains four reservoir communities. This dissimilarity indicates that respondents do not see differences among reservoirs in the same manner that biologists and researchers typically do. However, the small-reservoir type (reservoirs < 30 ha containing largemouth bass *Micropterus salmoides*, bluegill *Lepomis macrochirus*, and channel catfish *Ictalurus punctatus*) from the ecological classification and the small-reservoir community from the social classification are identical. Biologists and researchers are splitters of water-body types, whereas anglers that we assessed are lumpers of water-body types. From a social-ecological system perspec-

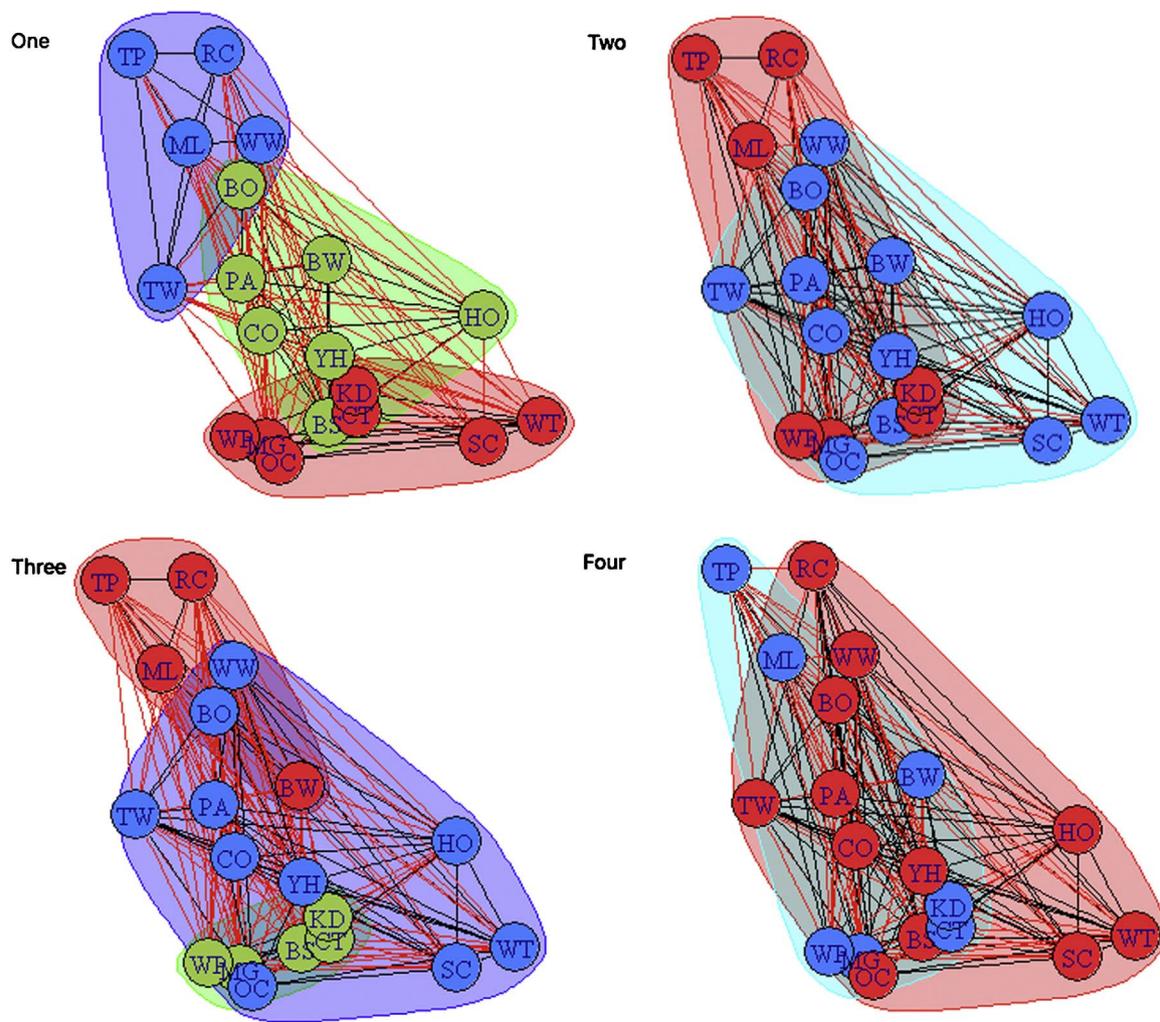


Fig. 5. Spatial layout of the reservoir networks for angler groups One, Two, Three, and Four. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red, blue, and green nodes indicate three distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group; red edges are those connecting two reservoirs in different groups.

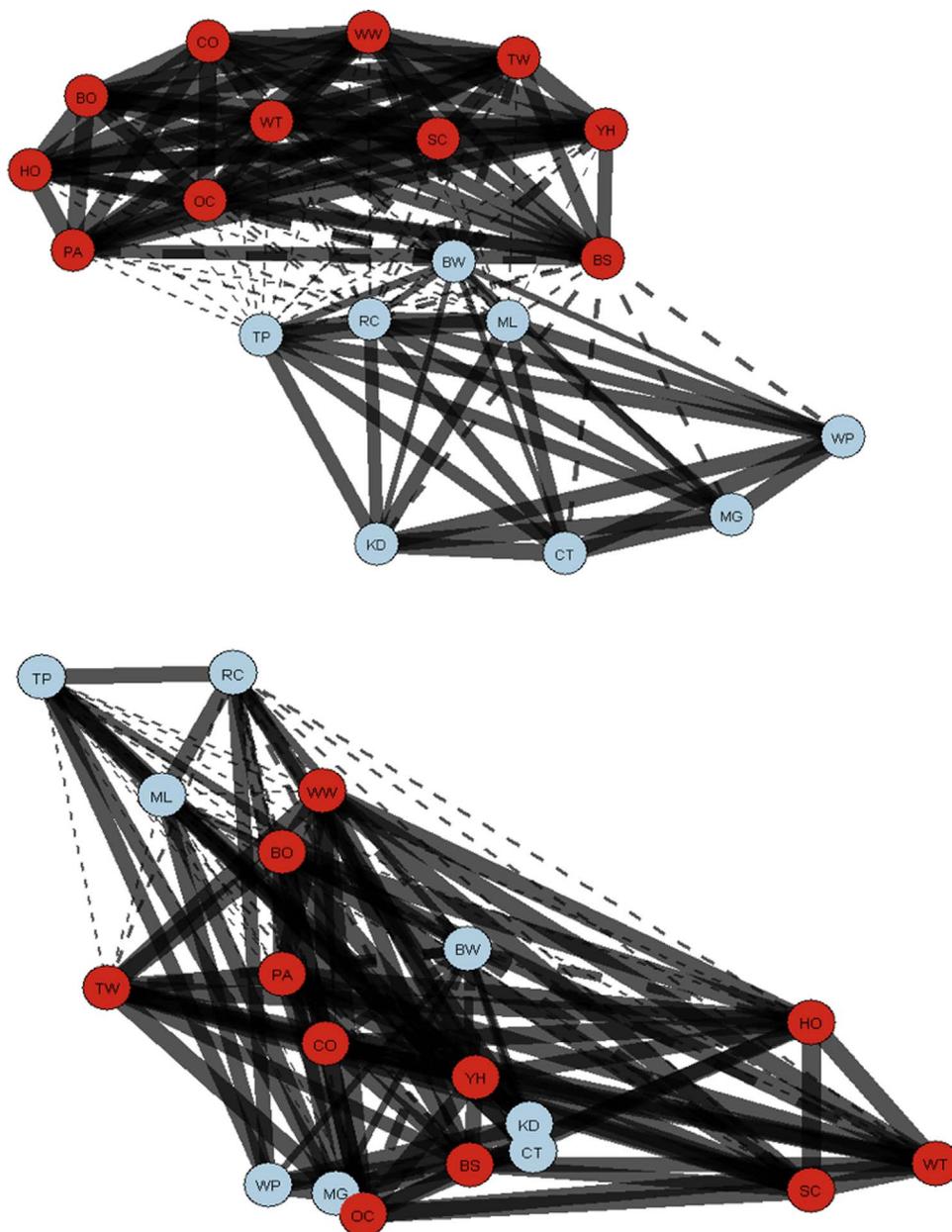
tive, the social classification encompasses variability in angler choice and is likely a better reservoir classification system to base regional management objectives. Our study explicitly linked recreational specialization to site choice within a region to identify distinct water-body types as potential units for fisheries management.

The Salt Valley regional fishery appears to be highly resilient to disturbances that would remove reservoirs from the system, at least for the respondents of our survey. Reservoir removals have little effect on existing network structure unless more than five reservoirs were removed at one time. The change in structure as reservoirs are removed depends on which reservoirs are removed, but reservoirs removed that affect resilience are counter to what we initially expected. We expected that the reservoirs that would be most important to maintaining resilience would be those larger reservoirs with greater fishing effort, as those reservoirs are likely visited by more anglers. However, reservoirs that reduce modularity (i.e., reduce resilience) faster than other reservoirs are some of the smaller reservoirs with the least fishing pressure in the region. This is likely because these reservoirs are used as an exploratory trip for most anglers, and are therefore used by many anglers in the regional fishery, but for few days. Although not tested, the resiliency of the angler group One network is likely less than the global network because of the greater dependency on spatial location and smaller reservoir community size.

An understanding of the network structure of a regional fishery is needed for knowing what anglers will do in response to manmade

disturbances, such as reservoir renovations or regulation changes. However, it is also important for understanding the potential implications of spread of invasive species and overharvest of sportfish. Invasive species such as Zebra or Quagga mussels (*Dreissena polymorpha* and *D. bugensis*, respectively) are likely to spread from an infected reservoir to other reservoirs that have strong angler-use connections with the infected reservoir (Haak et al., 2017). Similarly, knowing angler movement patterns and preferences can help predict what anglers will do when a population of popular fish species declines, or harvest regulations become limiting (Beard et al., 2003). Anglers are likely to move to the next reservoir with the strongest connection that also has a good population of the species of interest to continue harvest. Proactive management of regional fisheries, after gaining an understanding of angler behavior, can lead to changes in regulations that prevent spread of invasive species or prevent overharvest of sportfish. Furthermore, studying both angler typology and angler movement or behavior is necessary to create new management strategies to prevent conflict among user groups (Aas et al., 2000).

One assumption that needs to be addressed for the topological removal of reservoirs to measure resilience is that angler behavior remains the same given that the choice of reservoirs has changed. In our assessment, we removed data of angler behavior from the dataset without any measure of the direct effects certain reservoir removals would have on this regional fishery. For a more complete understanding of regional fishery resilience, additional surveys of anglers are needed



**Fig. 6.** Community membership in the Salt Valley regional fishery bootstrapped network (top), and the spatial layout of that regional network (bottom). Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red and blue nodes indicate two distinct groups of reservoirs. Solid edges are those connecting two reservoirs within the same community; dashed edges are those connecting two reservoirs in different communities. Reservoir two-letter codes represent: BO = Branched Oak Lake, BS = Bluestem Lake, BW = Bowling Lake, CO = Conestoga Lake, CT = Cottontail Lake, HO = Holmes Lake, KD = Killdeer Lake, MG = Merganser Lake, ML = Meadowlark Lake, OC = Olive Creek Lake, PA = Pawnee Lake, RC = Red Cedar Lake, SC = Stagecoach Lake, TP = Timber Point Lake, TW = Twin Lakes, WP = Wild Plum Lake, WT = Wagon Train Lake, WW = Wildwood Lake, and YH = Yankee Hill Lake.

to determine the substitutability of reservoirs under different removal scenarios; these surveys need to be carefully crafted to prevent perceived restrictions to fishing access (Salz and Loomis, 2005). A weakness of our approach, which should be addressed in additional surveys, was an incomplete approach to recreational specialization, including behavioral, affective and cognitive dimensions as well as centrality to lifestyle (Tsaour and Liang 2008; and references therein). The three variables used to group anglers provided measures of commitment to fishing and expertise, but do not provide measures of setting preferences. That is, we may have had some highly specialized anglers that we contacted who behaved like casual anglers in our regional fishery (and associated network assessment) because they fish mostly on rivers or other reservoirs in a different regional fishery.

The application of network theory to user participation has wide-

spread implications for natural resources management. Natural resource agencies are interested in increasing recruitment and retention of hunters and anglers to secure funding and a user base for the future. However, this is a difficult task without an understanding of behavior of current hunters and anglers along with future expectations of new hunters and anglers. Network analysis allows natural resource agencies to gain a better understanding of current user behavior. The techniques of network theory can be used to determine where and what is the best placement of new properties for participation, as well as assess whether current locations generate use in excess of their maintenance costs (i.e., is the return-on-investment enough to maintain properties?). A thorough understanding of our user base in natural resources will allow natural resource management agencies to better manage for and serve our constituents.

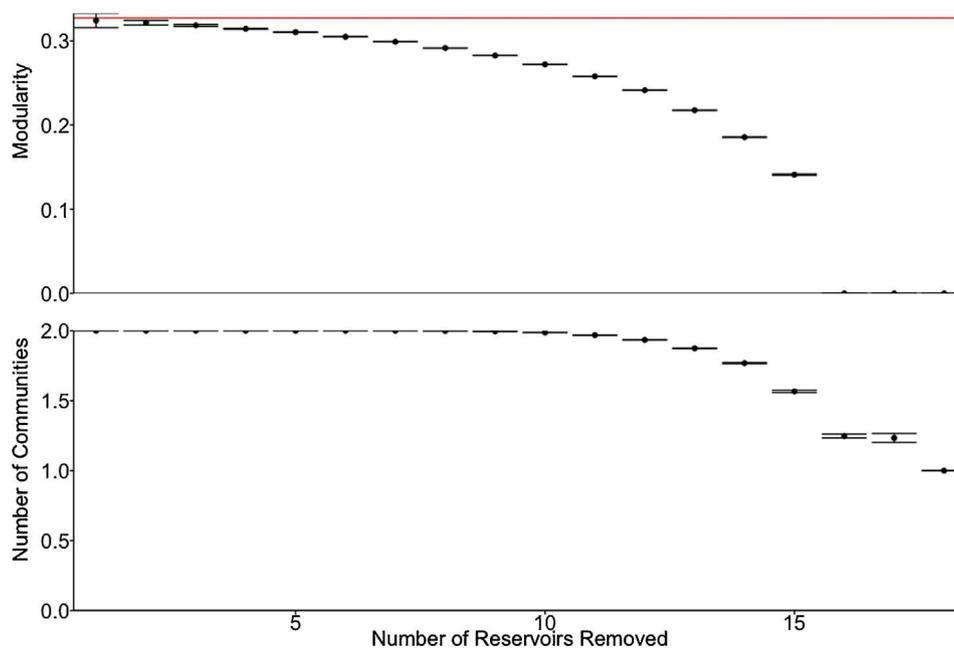


Fig. 7. Modularity (mean  $\pm$  SE; top) and number of communities (mean  $\pm$  SE; bottom) for each level of the node removal experiment in the network of the Salt Valley regional fishery. Red line indicates modularity of full observed network.

## Acknowledgements

We thank T.D. Beard, Jr., K. Eskridge, R. Holland, and M. Pegg for helpful comments on earlier drafts of this manuscript. We also thank T. Barada, C. Wiley, P. Sprik, C. Dietrich, M. Dedinsky, C. Depue, D. Dobesh, H. Evans, A. Fandrich, H. Hummel, C. Knight, L. Kowalewski, N. Luben, A. Maple, J.P. Montes, A. Pella, P. Stolberg, and J. Walrath for assistance in the field, and T. Barada, A. Blank, J. Jackson, J. Katt, D. Gabelhouse, Jr., R. Holland, and M. Porath for insightful discussions on this project. This project was funded by Federal Aid in Sport Fish Restoration project F-182-R, which was administered by the Nebraska Game and Parks Commission. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The Nebraska Cooperative Fish and Wildlife Research Unit is jointly supported by a cooperative agreement among the U.S. Geological Survey, the Nebraska Game and Parks Commission, the University of Nebraska, the U.S. Fish and Wildlife Service, and the Wildlife Management Institute.

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