Fisheries Research 194 (2017) 31–41

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

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 bluegill *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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http://dx.doi.org/10.1016/j.fishres.2017.05.007
Received 16 December 2016; Received in revised form 12 May 2017; Accepted 13 May 2017
Available online 23 May 2017
0165-7836/ Published by Elsevier B.V.

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