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The structure and function of angler mental models about fish population ecology: The influence of specialization and target species

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ABSTRACT

As devotion to a recreational activity increases with specialization, recreationists' ecological understanding (i.e., mental models) of the resource system is also expected to change. To test this hypothesis, we collected cognitive maps of northern pike (*Esox lucius*) ecology from anglers ($N=235$) and assessed their relation to anglers' level of specialization and preferred target species. We also compared angler cognitive maps with cognitive maps collected from fisheries scientists ($N=17$) to examine if increased specialization among anglers led to similar ecological understanding of formally-trained fishery professionals. Our results indicate that, regardless of target species, as anglers become more specialized they tend to refine their structural understanding of pike ecology by simplifying relations among the ecological factors that affect pike populations. Further, although the refined ecological understanding of more specialized anglers' was found to be structurally dissimilar to experts, the mental models of pike ecology of more specialized anglers, particularly those with experience of the target species pike, were found to be functionally similar to how trained fisheries biologists viewed pike ecology. Our results suggest that more specialized anglers develop simple heuristics to deal with complex ecological issues, which may in turn affect the uptake of information and the acceptability of management actions designed by agencies and managers.

MANAGEMENT IMPLICATIONS

We present a quantitative method for measuring how anglers perceive the ecology of an exploited species (northern pike, *E. lucius*) using a combination of semi-quantitative fuzzy cognitive mapping and network metrics. The key finding is that as angler specialization increases, the knowledge of ecological dynamics is refined leading to mental models that are structurally different from academically trained fisheries biologists, but that behave functionally similar to experts.

- Similar perceived functionality of key management interventions suggest limited conflict potential among pike managers and more specialized anglers with regards to acceptance of management policies.
- Specialized anglers can be expected to perceive ecological dynamics similarly to academically trained fisheries scientists and thus may be allies in support of common management tools.
- The simplification of mental models in highly specialized anglers suggest variation in how different anglers learn and uptake new ecological knowledge, which has implications for the design of outreach strategies.

1. Introduction

The recreation specialization framework constitutes a popular conceptual foundation to explain heterogeneity among outdoor recreationists. Originally developed in the context of freshwater trout angling, specialization assumes "a continuum of behavior from the general to the particular, reflected by equipment and skills used in the sport and activity setting preferences" (Bryan, 1977, p. 175). Three decades of empirical research have tested a range of propositions originating from Bryan's (1977) pioneering work. Scott and Shafer (2001) summarized available literature and report that recreationists differ predictably in a range of co-varying behavioral and psychological traits (e.g., Dorow, Beardmore,

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Haider, & Arlinghaus, 2010; Fisher, 1997; Salz, Loomis, & Finn, 2001; Wilde & Ditton, 1994). Hence, it is safe to assume that as specialization and commitment levels change, so do other characteristics of recreationists including: (a) motives for participation (e.g., Ditton, Loomis, & Choi, 1992; McFarlane, 1994; Beardmore, Haider, Hunt, & Arlinghaus, 2011), (b) harvesting desires (e.g., Aas, Haider, & Hunt, 2000; Dorow et al., 2010), (c) setting and environmental preferences (e.g., Bryan, 1977; Oh & Ditton, 2008; Beardmore, Hunt, Haider, & Arlinghaus, 2013), (d) knowledge and ecological understanding (Morgan & Soucy, 2006, 2008), and (e) preferences for management policies and compliance with rules (e.g., Chipman & Helfrich, 1988; Arlinghaus & Mehner, 2005; Dorow et al., 2010; Oh & Ditton, 2006, 2008).

Few studies, however, have examined relationships between specialization and recreationists' understanding of natural resource dynamics, despite the potential influence that ecological knowledge may have on the acceptability of regulations and management preferences (Arlinghaus & Mehner, 2005; Dorow & Arlinghaus, 2012). Although specialization is thought to entail the acquisition of ecological understanding (Bryan, 1977; Morgan & Soucy, 2008; Scott & Shafer, 2001), the exact relationship between specialization and the construction of knowledge about a naturally fluctuating natural resource has so far seen only limited quantitative examination (for qualitative and semi-quantitative studies of variation in anglers' ecological knowledge, see Eden and Bear (2011) and von Lindern (2010)). Understanding these relationships among consumptive resource users such as anglers may shed light on the cognitive assumptions that underlie stakeholders' reactions to proposed management measures and can help explain variation in management preferences (von Lindern, 2010; Biggs et al., 2011). For example, in one of the few studies of anglers' ecological mental models and its relation management preferences, von Lindern (2010) found that anglers who held “additive” mental models (i.e. they considered adding new fish via stocking and natural recruitment to influence harvestable stock sizes independently) tended to think that stocking was more effective than area closures. By contrast, anglers who held “compensatory” mental models (i.e. they perceived compensatory interactions between stocking and natural recruitment) tended to think area closures were more effective than stocking.

We focused our study on angler understanding of the ecology and management of northern pike (*Esox lucius*), which is an important recreational fishery in Germany (Arlinghaus & Mehner, 2004; Arlinghaus, Bork, & Fladung, 2008). Our goal was to examine how variation in the structure and function of angler mental models of pike population dynamics related to angler specialization and experience with an exploited resource (anglers who target pike versus anglers who do not target pike). Further, we sought to compare the ecological understanding of differently specialized anglers with the structural and functional knowledge of fisheries biologists (i.e. representing academically trained experts) to understand the degree that informal and formal expertise align with specialization and species choice.

We use the term “mental model” to refer to personalized, mental constructs that provide interpretation and structure of an external environment (Jones, Ross, Lynam, Perez, & Leitch, 2011), which affect how individuals perceive and interact with the outside world (Craik, 1943; Denzau & North, 1994). Mental models are constructed and modified by individuals over time as they experience the environment around them (Johnson-Laird, 1983; Mohammed & Dumville, 2001). These internal representations of the external world are used alongside other cognitions, such as values and attitudes, and subconscious physiological reactions to mediate between knowledge stored in the long term memory and the short-term requirements of making a context-appropriate decision (Biggs et al., 2011; Nercessian, 2008). Accordingly, mental models within a specific domain are thought to influence human behavior in relation to natural resources (Biggs et al., 2011; von Lindern, 2010) including the perceived impacts of different natural resource policies (Gray, Chan, Clark, & Jordan, 2012; Nayaki, Gray, Lepczyk, & Rentsch, 2014).

In the context of recreational fisheries, mental models involve angler understanding of the factors that influence changes in the qualities and quantities of fish and fish populations (e.g., size of fish and stock, expected catch rates; von Lindern, 2010). Such conceptualization resonates with Bryan's (1977) original proposition that as angler specialization increases, individual understanding of the vulnerabilities of habitats and exploited species also increases. Hence, the changes in ecological understanding that is expected to vary with increasing specialization should be reflected in changes in angler mental models about fish population dynamics. Past research has indeed indicated that as anglers move along a specialization continuum, their perception of the natural resource and the social and ecological role of the angler as agents of ecological change also changes (Oh & Ditton, 2008). As anglers become more specialized, they may pay more attention to the impact of angling pressure on fish populations (Bryan, 1977; Oh & Ditton, 2008; but see Dorow & Arlinghaus, 2012 for an alternative views) and they may more strongly emphasize the role that habitat quality plays in influencing the dynamics of fish resources (Bryan, 1977, but see Arlinghaus and Mehner (2005) for an alternative view). This, in turn, may affect conservation-related behaviors (Oh & Ditton, 2008), stewardship of aquatic resources (Knuth & Siemer, 2004) and preferred management policies (Chipman & Helfrich, 1988; Dorow et al., 2010; Dorow & Arlinghaus, 2012).

In the present study, we examined the relationship between specialization operationalized as commitment to angling, target species selection, and angler mental models of pike ecology using the structural and functional analysis of semi-quantitative cognitive maps created by anglers. We also compared the structure and functions of angler mental models to those of academically trained fisheries biologists assuming that as anglers move along the spectrum of specialization, their ecological understanding becomes increasingly similar to the subjective ecological knowledge held by formally trained fisheries scientists. We tested the following hypotheses:

H1. : More specialized anglers, in particular anglers who targeted pike possess structurally more complex mental models about the factors regulating pike population dynamics compared to less specialized anglers. The angler mental models of specialized anglers are most similar to those of academically trained fisheries biologists.

H2. : More specialized anglers, in particular anglers who targeted pike, identify key ecological factors as more important in influencing pike population dynamics (e.g., high importance of vegetated habitat for pike populations) compared to less specialized anglers. More specialized anglers resemble fisheries biologists more in terms of the importance placed on key ecological concepts affecting pike populations compared to less specialized anglers.

H3. : More specialized anglers, in particular anglers who targeted pike, identify impacts associated with pike conservation measures more similarly to fisheries biologists compared to less specialized anglers.

2. Materials and methods

Study participants were self-selected from a mailed solicitation sent to all angling clubs in the German state of Lower Saxony (N=461). Forty one of the 461 total clubs in the state indicated

Table 1
Items used to construct the specialization index, Cronbach's alpha reliability, and raw mean score and standard deviation estimated from $N=235$ respondents.

Items of the specialization index	*Raw score M (SD)*	Alpha(α) loading
Centrality to lifestyle[a]		**α=.834**
If I stopped fishing, I would probably lose touch with a lot of my friends	2.5(1.2)	
If I could not go fishing, I am not sure what I would do	2.1(1.1)	
Because of fishing, I do not have time to spend participating in other leisure activities	2.6(1.2)	
Most of my friends are in some way connected with fishing	2.5(1.1)	
I would rather go fishing than do most anything else	3.3(1.1)	
Other leisure activities do not interest me as much as fishing	3.3(1.3)	
I find that a lot of my life is organized around fishing	3.3(1.2)	
Psychological commitment index	**19.7**(**6.0**)	

[a] Scale: 1–5 (strongly disagree, disagree, neutral, agree, strongly agree).

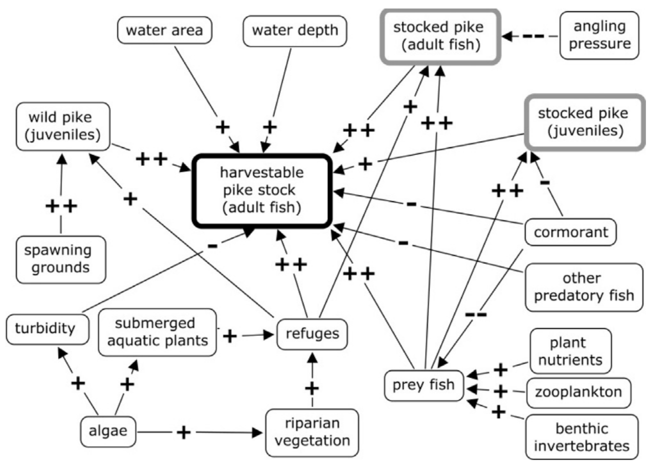

Fig. 1. Example of an individual fuzzy cognitive map of pike ecology considered a mental model representation. Weighted relationships between variables were defined as "++" (strong positive influence), "+" (positive influence), "–" (strong negative influence) or "-" (negative influence) which were translated into quantitative values for structural and functional analyses. "Stocked Pike (adult fish)" and "Stocked Pike (juvenile fish)" are highlighted to demonstrate perceived structural relationships between these variables and their weighted influence on overall "Harvestable Pike Stock (adult fish)" located at the center of the cognitive map in bold.

interest to participate in the project, which was part of a larger project analyzing stocking in German angling clubs (www.besatz-fisch.de). From this sample, 17 clubs were chosen to take part in the study based on several criteria including the club's expressed interest in improving their knowledge of pike fisheries management. Oral presentations detailing the research project were given at each of the 17 clubs during their annual meetings, where attendance ranged from about 30 to 120 anglers and club managers. At each annual meeting, up to 25 anglers were accepted as volunteers for mail-back surveys and later to participate in workshops in which cognitive maps of pike ecology were collected. In total, 268 anglers participated in the study from which 33 anglers were excluded due to incomplete data. Final analyses for both specialization (collected through a mail survey) and mental models about pike ecology (collected from cognitive mapping exercises during workshops) was based on a total of 235 anglers, comprised of 112 anglers who targeted pike (pike anglers) and 123 who did not target pike (non-pike anglers).

To compare how ecological knowledge, target species, and specialization compared structurally and functionally to the understanding of biologically trained academic experts, cognitive maps of pike ecology were also collected from 17 volunteers comprised of researchers, post-docs and PhD students employed by one academic unit within a research institute specializing in fish ecology and biology and an inland fisheries institute. Both organizations were located in the states of Berlin and Brandenburg.

2.1. Measuring specialization

A 12 page self-administered questionnaire was mailed to participating anglers 10 days prior to the workshops. The questionnaire included a list of items operationalizing specialization. Of the three common subdimensions of specialization, including: psychological commitment, skill/knowledge and behavioral commitment (Scott & Shafer, 2001), we focused on psychological commitment given its high explanatory power for predicting angler behavior in Germany (Beardmore et al., 2013). Psychological commitment was measured by seven centrality-to-lifestyle items taken verbatim from Dorow et al. (2010) (adapted from the original scale by Kim, Scott, and Crompton, (1997)). Similar to previous studies, reliability of the psychological commitment in our sample was also large (Cronbach's alpha=.83) (Table 1). We used the scores from these seven items and averaged all items per individual to conserve the total sample while creating an index score of specialization for each of the anglers included in the sample.

2.2. Determining target species

Anglers were also asked to rank their three preferred target species fished for during the previous calendar year. Respondents who chose pike as one of the top three were classified as pike anglers while all other respondents were classified as non-pike anglers. Non-pike anglers primarily targeted zander (*Sander lucioperca*), common carp (*Cyprinus carpio*), European eel (*Anguilla anguilla*) and a range of non-piscivorous coarse fish species like small roach (*Rutilus rutilus*) or bream (*Abramis brama*).

2.3. Mental model representations of pike population ecology

Individual mental model representations of pike population dynamics were derived during a Fuzzy Cognitive Mapping exercise during separate workshops with anglers and fisheries biologists. Fuzzy Cognitive Maps (FCM) are graphical representations of beliefs that are useful proxy measurements for personally-held mental models about a specific domain (Gray et al., 2012; Gray, Gray, & Zanre, 2014; Jones et al., 2011; Özesmi & Özesmi, 2004). To standardize the collection of FCM, all respondents received the same set of 19 cards representing key ecological and managerial factors affecting pike population dynamics (e.g., prey fish, refuges, underwater vegetation, zooplankton, angling pressure, adult pike population, Fig. 1). This list of predetermined concepts was developed during independent focus groups with anglers and fishery experts about the biology and fisheries ecology of pike. Additionally, prior to the workshops, the data collection protocol was piloted during two focus groups with a small number of anglers who were recruited through internet angling forum and notices at local tackle shops in Berlin.

Each workshop where mental model representations were collected lasted about four hours, and was held in the clubhouse or at a local restaurant, and was facilitated by an independent moderator. Collecting FCM during the workshops followed four stages similar to those outlined by Özesmi and Özesmi (2004) to create mental model representations. An example is shown in Fig. 1. First, anglers were given a 15 min presentation on building a cognitive map and were shown an unrelated FCM about the ecological dynamics of a forest. The presentation emphasized that each participant should identify the key ecological concepts they considered relevant to the system with instruction on how they could represent ecological relationships between these concepts using the graphical method of FCM (i.e, using directed arrows and weighting relationships). Second, participants were given: (a) the 19 cards containing the key concepts of pike ecology generated during the earlier focus groups, and (b) a set of unidirectional arrows with plusses (+) or (++) and minuses (−) or (− −) to indicate the amount and weight of directional (linear) influence one concept can have on another. Third, participants were asked to arrange the concepts and arrows graphically so they could represent their personal understanding of pike population dynamics. Participants were also supplied with blank cards so they could add other concepts of perceived relevance to their FCM, and were told that they did not need to use all of the concepts provided; however less than 2% of anglers and only 1 expert elected to include concepts other than those provided. Participants then individually developed mental model representations of pike population ecology by arranging the concepts, and their relationships and weighted influences, on a table. Once participants were satisfied with their result, a photograph was taken so that the mental models could be transcribed and the amount of influence (plusses or minuses) could be converted into "fuzzy" quantitative approximations of influence among concepts. Arrows that included "+" were coded as .25, "++" as .75, "–" as −.25 and "− −" as −.75 were converted in a matrix format of the cognitive map for analyses (see below). The relationships in the FCM were quantified so that differences in models could be compared (Fig. 1). The mental models of fisheries biologists were collected in the same manner during two workshops at their respective academic institutions.

2.3.1. Analysis of structural differences of mental model representations

To measure variation in angler understanding, we used a series of network structural metrics that were applied to each participants, individual FCM. Each individual structural metric applied to the individual FCM indicated a unique aspect of the angler's belief structure of pike ecology, which was treated as dependent variables in a regression analysis used to test our hypotheses. Thus, anglers' individual specialization and species choice were considered independent variables and the nine structural metrics applied to their FCM were treated as dependent variables to analyze how specialization influenced several aspects of angler beliefs. The nine dependent FCM variables (Table 2) included counting the number of each type of variable (transmitter, receiver, ordinary see Ozesmi and Ozesmi, 2004), summing the number of concepts, number of connections and calculating the ratio of connections to concepts. These metrics represented how much information about pike ecology was represented in each model generally. Previous studies have shown that professionally trained fisheries experts tend to have higher values using these metrics compared to other fishery stakeholder groups like commercial fishers and recreational anglers (Gray et al., 2012). Hence, more specialized anglers were also expected to score higher on these measures compared to less specialized anglers.

The density, complexity, and hierarchy of the mental models were also calculated with network metrics to indicate the degree of complex reasoning in a mental model representation and provide more specific measure of anglers' concept maps (Gray et al., 2014; Özesmi & Özesmi, 2004). Density indicates the degree of connectivity or sparseness represented in a model (Hage & Harary, 1983; Özesmi & Özesmi, 2004) with more specialized anglers expected to identify more relationships between core ecological concepts. For example, a more knowledgeable angler may indicate that stocking pike may have multiple relationships to other components of the pike ecology, such as reducing prey fish populations, increasing competition with native pike, and contributing additively to the pike population. To calculate the density of the entire mental model the number of connections was divided by the maximum number of connections possible between all concepts. Also, a complexity score was calculated as the ratio of receiver variables (concepts that have arrows directed to them only) to transmitter variables (concepts that have arrows directed towards them only). Many receiver variables indicate that the cognitive map considers more possible outcomes (Eden, Ackerman, & Cropper, 1992). Conversely, a large number of transmitter variables indicates thinking with more top down influences and represents the degree of "flatness" of a cognitive map where causal arguments are not well elaborated (Eden et al., 1992; Özesmi & Özesmi, 2004). If anglers' models represented many simple linear

Table 2
Structural network metrics and description of their inference for understanding differences in angler beliefs about pike population dynamics.

Mental model structural measurement	Description of measure
N **(Concepts)**	Number of variables included in model; higher number of concepts indicates more components in the mental model (Özesmi & Özesmi, 2004)
C (Connections)	Number of connections included between variables; higher number of connections indicates higher degree of interaction between components in a mental model (Özesmi & Özesmi, 2004)
NT **(Transmitter)**	Components which only have "forcing" functions; indicates number of components that effect other system components but are not effected by others (Eden et al., 1992)
NR **(Receivers)**	Components which have only receiving functions; indicates the number of components that are effected by other system components but have no effect (Eden et al., 1992)
NO **(Ordinary)**	Components with both transmitting and receiving functions; indicates the number of concepts that influence and are influenced by other concepts (Eden et al., 1992)
C/N	Number of connections divided by number of variables (concepts). The higher the C/N score, the higher the degree of connectedness in a system (Özesmi & Özesmi, 2004)
Complexity	Ratio of receiver variables to transmitter variables is a measure of the degree to which outcomes of driving forces are considered. Higher complexity indicates more complex systems thinking (Eden et al., 1992; Özesmi & Özesmi, 2004)
Density	Number of connections compared to number of all possible connections. The higher the density, the more possible structural areas that can be theoretically changed given more connectedness in the model (Özesmi & Özesmi, 2004; Hage & Harary, 1983)
Hierarchy	Index developed to indicate hierarchical to democratic view of the system. On a scale of 0–1, the measure indicates the degree of top-down down (score 1) or fully democratic perception (score 0) of a system (MacDonald, 1983)

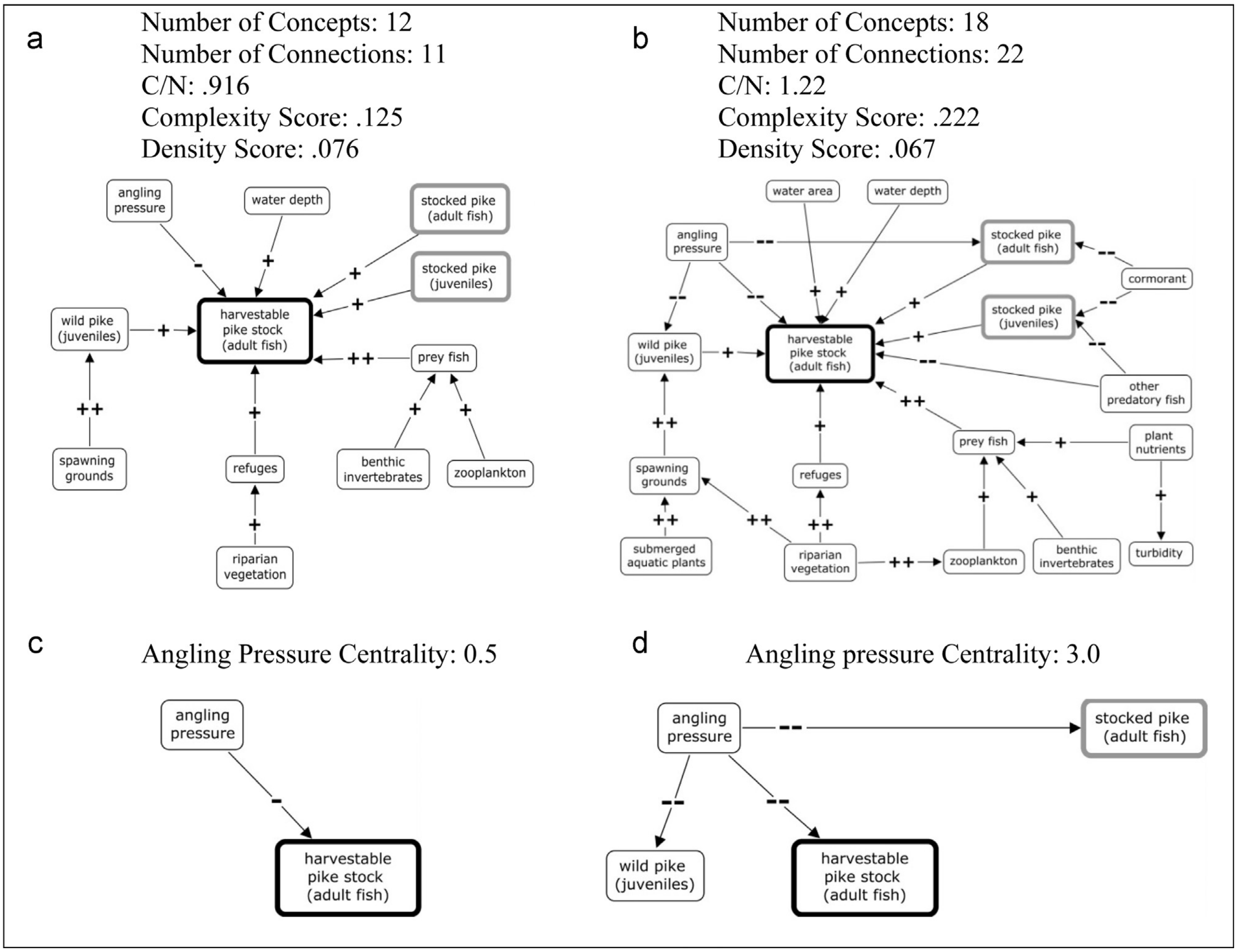

Fig. 2. Example of how the (a) and (b) basic network structure and (c) and (d) concept-specific centrality measures can vary across fuzzy cognitive maps..

connections, such as defining connections largely between several driving factors to few receiving factors (e.g. the eight transmitting variables and one receiving variable of harvestable pike populations yielding a complexity score of .125 in Fig. 2a), then the complexity score would be low. If anglers considered a more complex view with additional relationships and outcomes represented (e.g. seven transmitting variables and two receiving variables of harvestable pike and turbidity yielding a complexity score of .222 in Fig. 2b), they would have a high complexity score. In our study, more specialized anglers were expected to have higher complexity scores. Finally, hierarchy scores were calculated, which indicate the degree of "democratic" thinking (MacDonald, 1983), which represents whether anglers see pike population dynamics structured more by a top-down processes (hierarchy scores closer to 1) or whether influence is distributed evenly (i.e., democratically) across more of the components in the model (hierarchy scores closer to 0). We expected less specialized anglers to have a lower hierarchy score because their representations of dynamics between components might indicate many driving forces, as opposed to more specialized anglers who were expected to focus on fewer ecologically relevant factors that largely drive changes in pike population dynamics. See the example of how network measures can vary based on the general structure of an FCM in Fig. 2a and b.

In addition to these nine structural measures (Table 2), seven concept-specific centrality scores for individual mental model components (a measure of relative importance of specific concepts in the overall mental model of pike ecology) were estimated for key variables hypothesized to be perceived differently by anglers. The variables were considered to be disproportionally important to the pike life cycle (e.g., littoral vegetation) and were selected based on expert ecological knowledge obtained through a literature search (e.g. Craig, 1996) and from focus groups with fisheries biologists. Accordingly, individual centrality scores were calculated for: (a) angling pressure; (b) riparian vegetation; (c) submerged vegetation; (d) refuges; (e) spawning habitat; (f) stocking adults; and (g) stocking juveniles. We expected that more specialized pike anglers would have higher centrality scores for each of these variables, compared to less specialized pike anglers and both types of non-pike anglers given that we assumed that their understanding would more closely align with the subjective knowledge of fisheries scientists. See the example of how the centrality score for a given concept can vary in Fig. 2c and d.

The independent variables selected to predict variation in structural metrics included the psychological commitment index and species choice (pike anglers or non-pike anglers). To test the first two hypotheses, General Linear Models (GLM) were fit to each structural measure independently using the specialization score and species choice as main effects for the entire angler dataset ($N=235$). Models were run with 1) main effects of specialization on each of the nine structural metrics using the variable centrality as an specialization index and 2) the interaction of specialization by species choice to test whether a potential specialization effect depended on angler experience with pike as a target species.

2.3.2. Analysis of functional differences of mental model representations

A particular strength of FCM is its ability to understand system-level behavior under a range of possible scenarios (Kosko, 1986) and then draw inferences about perceived emergent outcomes associated with the dynamics of a complex ecological system. FCM scenario analysis can be undertaken on either individual maps or by averaging a group of maps using mean scores after concept maps are converted into adjacency matrices, where all components in the map are listed on the *a* and *j* axes and the direction and line weights represented are used along with matrix algebra calculations to determine current system states which are compared to scenario state outcomes (Kosko, 1986; Özesmi & Özesmi, 2004; Gray et al., 2015). When fuzzy cognitive maps are considered representations of mental models, these scenario analyses can be considered mental model predictions about the perceived outcomes associated with various changes in the components included in a cognitive map (Gray et al., 2014).

Scenarios can be considered system-state outcomes associated with changes to the system based on the way the dynamics between variables were defined (and weighted) either by an individual respondent or by averaging the line weights between stakeholder group maps, referred to as a "social cognitive map" (see Özesmi and Özesmi (2004) and Gray et al. (2012)). For example, a perceived change in the adult pike stock as a result of a change in spawning habitat would only occur if a participant linked the concept of spawning habitat directly or indirectly to the adult pike stock concept structurally in the FCM. Similarly, developing "social cognitive maps" sometimes referred to as a "community map", by combining several individual maps allows connections represented by several members of a group to become reinforced, while relationships mentioned by only a few individuals with a group are weighted less, allowing the predominant belief structures within a group to become better understood (Gray et al., 2014). For additional explanation of FCM scenario analysis, either individually or by groups for comparison, see Gray et al. (2015).

To test the third hypothesis related to the degree to which knowledge of anglers varied functionally compared to biologists, five averaged models, also referred to as "community maps" (Özesmi & Özesmi, 2004) were developed for subgroups of anglers at each end of the specialization scale (high and low specialization) by target species (pike angler or not) and for fisheries scientists. To that end, we averaged a subset of anglers' individual mental models, using the adjacency matrix format of the concept maps, that represented the extreme ends of specialization by species choice into: (a) highly specialized pike anglers (HSP), (b) lowly specialized pike anglers (LSP), (c) highly specialized non-pike anglers (HSNP), (d) lowly specialized non-pike anglers (LSNP) and (e) for biologists. Group models were built using the mean values from the adjacency matrices from 17 anglers from each group representing 15% of the most highly specialized pike anglers, 15% of the most lowly specialized pike anglers, 14% of the most highly specialized non-pike anglers, and 14% of the most lowly specialized non-pike anglers. Whereas overall mean specialization scale score for the entire angler dataset (N=235) was 19.7 (SD=6), the mean score for HSNP group model was 29.3 (SD=2.7), the mean raw score for LSNP group model was 12.2(1.6) and the mean raw score for highly specialized pike anglers HSP and lowly specialized pike anglers LSP was 29.3 (SD=2.1) and 9.4 (SD=2.2), respectively. Additionally all of the 17 models of fisheries scientists were averaged so that functional knowledge scenario results could be compared across all five groups using an identical number of people (N=17) to develop group models. Using the same number of FCMs (i.e., 17) for grouping and subsequent comparison is preferred when using the arithmetic mean approach to creating community maps because network dynamics are sensitive to changes in the number of maps included in averaging FCMs (Taber, 1991). By using mean aggregation techniques, perceptions about the strength of specific relationships become summarized within group, consensus is reinforced and opposed perceptions are balanced (Bougon, Weick, & Binkhorst, 1977).

We ran seven scenario analyses on each of the five aggregated models for each of the four angler groups and for fisheries scientists to understand the perceived impacts of pike stocking (increasing pike stocking of adults and increasing pike stocking of juveniles), pike-specific habitat quality changes (increasing riparian vegetation, increasing submerged aquatic plants) and general habitat-related changes (increased refuge, increased spawning grounds, decreased angling pressure). The resulting functional comparisons indicated how the different cognitive assumptions held on average by each angler group and by the biologists translated into ecosystem state changes when the pike models were subjected to hypothetical management interventions.

For the seven scenario analyses for each of the five "social cognitive maps" we followed methods developed by Kosko (1986) and informed by Özesmi and Özesmi (2004) that relied on determining steady-state values calculated using matrix algebra derived from the adjacency matrix format of the averaged FCM for each group. After the steady-state was determined, policy scenarios were run by "clamping" (Kosko, 1986) the concepts within the model as continually high (e.g., stocking juveniles, stocking juveniles, riparian vegetation, submerged aquatic plants, refuge, spawning grounds) set to 1 at each time iteration and or continually low (e.g. angling pressure) set to 0 at each time step until the system stabilized and the values repeated. The final vector of the each scenario was then compared to the original steady state vector for all concepts included in each groups' community map. The resulting values for each variable represented the amount of relative change of all 19 system variables under the seven scenarios.

For this analysis, 35 models were run in total, seven for each scenario for each of the five group models. Differences in how anglers anticipated system change under these seven scenarios were qualitatively compared to understand how structural variation in mental models among anglers and biologists (see above) might exhibit themselves functionally in terms of predictions of change in the ecological system under different management options. Specifically, scenario results for each of the four angler group models were evaluated for the positive, negative or absent changes in all of the components included in the FCM and compared to scientist-based predictions of changes to pike ecosystems to determine the similarity between fisheries biologists and the four angler groups. Simple percentage-based similarity scores were calculated for the overall scenario results using experts as a baseline to identify the degree to which angler scenarios were consistent with the functional knowledge of fisheries biological experts. Additionally, percent agreement was determined by grouping variables within the model into four sub-categories under each of the seven scenarios for (1) pike population variables (e.g. pike population size), (2) biotic habitat variables (e.g. prey, algae), (3) abiotic habitat variables (e.g. water area) and (4) functional/general habitat variables (e.g. refuge) to determine categorically where angler and fishery biologists predictions were consistent in general. See Table 3 for an example and the mental model components included in each of the four categories.

3. Results

3.1. Angler specialization, target species and the structure of mental models about pike population ecology

Overall, the structural analysis indicated that the number of connections per concept (C/N), the number of ordinary variables,

Table 3
Example results of functional knowledge predictions for increased riparian vegetation scenario for four averaged angler groups' models compared to expert functional knowledge predictions. Shading indicates area of agreement between experts and angler groups. HSP=highly specialized pike angers; HSNP=highly specialized non-pike anglers; LSP=lowly specialized pike anglers; LSNP=lowly specialized non-pike anglers.

Variable type	Concept	Expert	HSP	HSNP	LSP	LSNP
Population variables	Pike population	+	+	+	+	+
	Juvenile wild pike	+	+	No change	+	No change
Biotic variables	Prey fish	No change	+	+	No change	+
	Predatory fish	No change	No change	No change	No change	No change
	Algae	No change	No change	No change	No change	No change
	Benthic invertebrates	+	+	No change	No change	+
	Zooplankton	No change	No change	No change	No change	+
	Submerged plants	No change	No change	No change	No change	No change
	Cormorant	No change	No change	No change	No change	No change
Abiotic variables	Plant nutrients	No change	No change	No change	No change	No change
	Water turbidity	No change	No change	No change	No change	No change
	Water surface area	No change	No change	No change	No change	No change
	Water depth	No change	No change	No change	No change	No change
Habitat variables	Spawning grounds	+	+	No change	+	+
	Refuge	+	+	+	+	+
	Angling pressure	No change	No change	No change	No change	No change

Table 4
GLM results for main effects and interactions of pike angler and specialization on mental model structural measures (see Table 2) related to pike population ecology. Significant models are in bold and [ŧ] indicates full model.

Mental model structural measure	β	SS	df	MS[a]	F	R^2	p
***N* Concepts**[ŧ]		21.93	3	7.31	1.28	.015	.281
Pike anglers	.097	1.51	1	1.51	.266		.606
Specialization	−.363	2.53	1	2.53	.445		.505
Pike × specialization	.900	18.13	1	18.13	3.18		.076
***C* Connections**[ŧ]		258.57	3	86.19	1.83	.021	.141
Pike anglers	−.408	37.18	1	37.18	.792		.374
Specialization	−2.39	233.20	1	233.20	4.97		.027
Pike × specialization	2.31	87.40	1	87.40	1.83		.174
***N* Transmitter**[ŧ]		84.19	3	28.06	2.41	.028	.067*
Pike anglers	.278	29.78	1	29.78	2.56		.111
Specialization	.532	46.88	1	46.88	4.03		.046*
Pike × specialization	.360	2.33	1	2.33	.201		.654
***N* Receiver**[ŧ]		1.14	3	.382	.442	.005	.723
Pike anglers	.136	.357	1	.357	.413		.521
Specialization	.082	.012	1	.012	.014		.905
Pike × specialization	−.074	.557	1	.557	.644		.423
***N* Ordinary**[ŧ]		87.43	3	29.14	2.43	.028	.066*
Pike anglers	−.317	23.26	1	23.26	1.94		.165
Specialization	−.977	69.36	1	69.36	5.80		.017*
Pike × specialization	.614	25.40	1	25.40	2.1		.147
C/N[ŧ]		**.80**	**3**	**.26**	**2.73**	**.031**	**.045****
Pike anglers	−.031	.173	1	.173	1.76		.185
Specialization	**−.117**	**.604**	**1**	**.604**	**6.17**		**.014****
Pike × specialization	.082	.080	**1**	.080	.813		.368
Complexity[ŧ]		.08	3	.03	1.21	.014	.307
Pike anglers	.024	.01	1	.01	.453		.502
Specialization	.002	.039	1	.039	1.83		.176
Pike × specialization	−.013	.061	1	.061	2.83		.094
Density[ŧ]		.003	3	.001	2.41	.028	.067*
Pike anglers	−.003	.001	1	.001	2.67		.103
Specialization	−.004	.001	1	.001	2.79		.096*
Pike × specialization	−.001	.000	1	.000	.010		.922
Hierarchy index[ŧ]		.000	3	.000	.359		.783
Pike anglers	−.002	.000	1	.000	.565		.453
Specialization	.004	.000	1	.000	.069		.793
Pike × specialization	−.006	.000	1	.000	.129		.720

Asterisks indicate significance (*=$p < .10$, **=$p < .05$)

[a] Mean square.

and the overall density of the pike mental model were all negatively related to angler specialization, although only C/N was significant at the $p < .05$ level while all other p values were not significant and only trends were indicated ($p < .1$) (Table 4, Fig. 3).

The number of transmitter variables, by contrast, was positively correlated with specialization and also approached significance. The number of concepts, number of connections, number of receiver variables, and the complexity and hierarchy scores were all insignificant in terms of both main effects and the interaction effect of angler specialization and target species (Table 4). These results suggested a pattern that as anglers specialized they represented their understanding of pike ecology in less dense networks with fewer connections per node. However, at the same time, they increased the perceived number of "driving" ecological forces that influence pike population dynamics (Fig. 3).

All of the concept-specific centrality variables (which measured how important specific variables were to the networked structure of pike ecology) were not found to vary significantly across anglers by target species or specialization (Table 5). These included the centrality of riparian vegetation, submerged aquatic vegetation, refuge, and spawning habitat as well as stocking-related concepts (stocking adults and stocking juveniles). However "angling pressure" did suggest evidence of a directionality in terms of an interaction effect between specialization and target species choice at a small overall p value ($p < .1$) (Table 5). As shown in Fig. 4, this interaction indicated that the importance of angling pressure decreased in non-pike anglers as they specialized, while the importance of angling pressure increased slightly as pike anglers specialized.

3.2. Structural comparison of group models

Average structural metrics of the mental models significantly varied ($p < .05$) among the four angler groups (which were clustered into low and high specialization pike and non-pike anglers, respectively) when compared to fisheries biological experts (Table 6). Hence, while the mental model structures of the four extreme angler groups, regardless of specialization and species choice were largely similar, the fisheries biologists group's mental models were structurally distinct to the four angler groups. In terms of general structural measurements, fisheries scientists on average tended to represent almost half as many transmitting variables (concepts with only arrows outward), represented far more ordinary variables (concepts with arrows outward and inward) and included more connections, more connections per node, and had overall more dense model representations of pike population dynamics compared to all angler groups (Table 6). Similar results were found in terms of concept-specific centrality scores, with biologists representing each variable measured as more central to the overall dynamics compared to angling groups

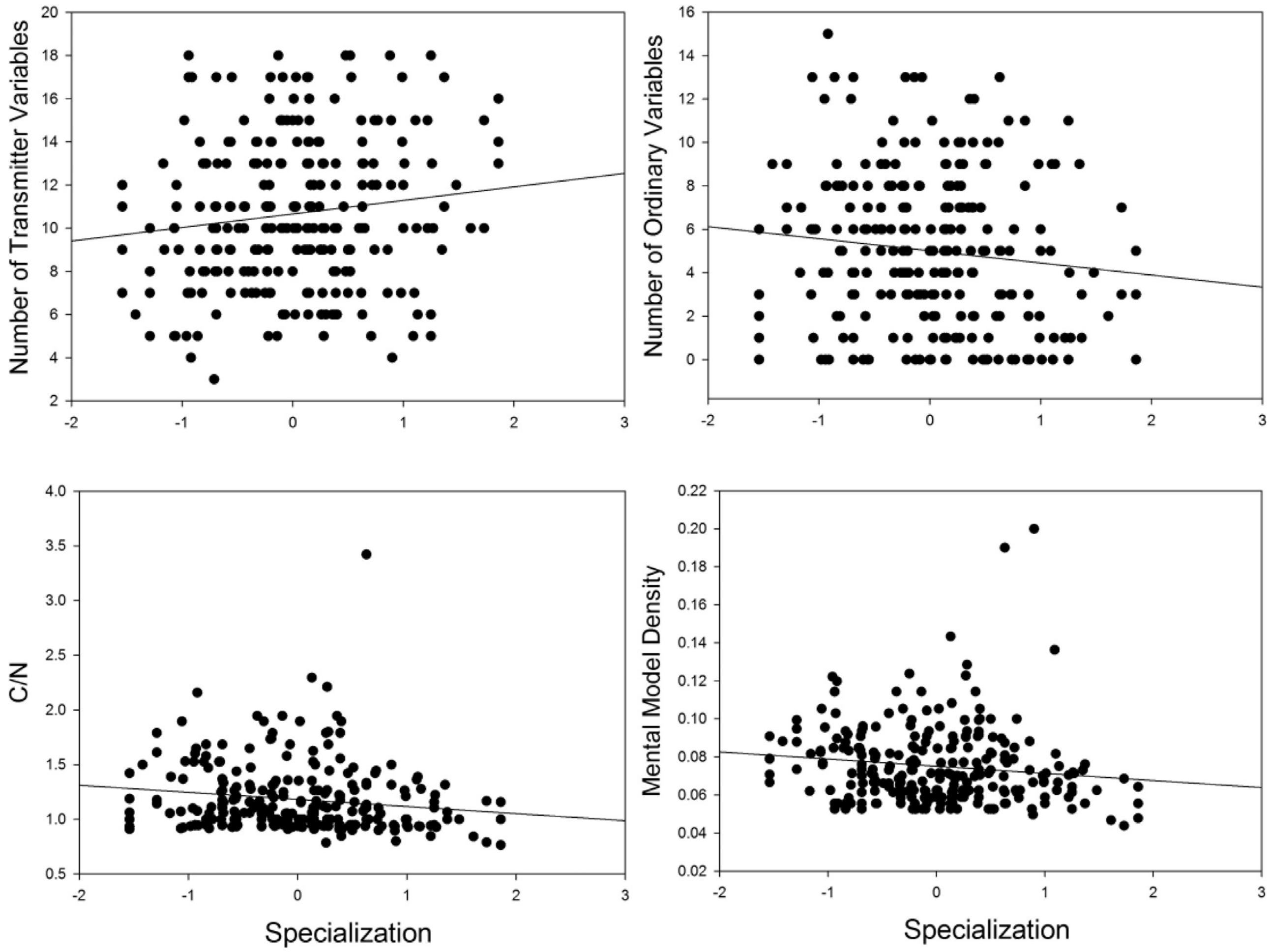

Fig. 3. Relationships between specialization and significant general network measures of mental models about pike populations.

including stocked adult pike, stocked juvenile pike, spawning places, riparian vegetation, aquatic plants, refuge and angling pressure. Some of the structural metrics were not statistically significant for some groups, including lowly specialized non-pike anglers (LSNP) who showed similarities to the biologist group in terms of the centrality of spawning places and refuge. Additionally, LSP anglers also showed similarities to biologists in terms of the centrality of refuge.

3.3. Functional comparison of group models

Among the three types of management scenarios that were investigated (increasing stocking, managing pike habitat, managing general habitat), the predicted ecological responses of highly specialized pike anglers (HSP) most closely matched scientist-based predictions in terms of impacts of stocking (97% overall agreement) (Table 7), pike-specific habitat impacts (91% overall agreement) (Table 8) and for general habitat impacts (77% overall agreement) (Table 9). These results indicated that HSP tended to define dynamics between variables in their pike mental model representation in a similar fashion to fisheries biologists compared to the other three angler groups. Two of the other angler group models also showed similar agreement with biologists, however unlike HSP, these results were not consistent across all three types of management scenarios. For example, analysis of the averaged lowly specialized non-pike angler group model (LSNP) indicated the same agreement as HSP for the stocking scenarios (Table 7), but showed less agreement with the biologists' views for the pike-specific habitat changes (74% overall agreement, see Table 8) and general habitat scenarios (66% overall agreement, see Table 9). Similarly, highly-specialized non-pike anglers (HSNP) showed similar agreement to scientists as did HSP for general habitat impacts (97% overall agreement) but considerably less for pike specific-habitat impacts (72%) and for stocking impacts (89%). Finally, lowly specialized pike anglers (LSP) showed the least similarity to the biologists' functional knowledge across the three types of management scenarios with 88% agreement for stocking scenarios, 89% agreement with scientists for pike-specific habitat scenarios and 72% agreement for general habitat scenarios (Table 9).

4. Discussion

Overall, our research confirmed the findings of Bryan (1977) and of many subsequent studies that highly specialized recreationists exhibit cognitive differences influenced by their level of specialization (Kuentzel & McDonald, 1992) including subjective perceptions of the environment (Schreyer, Lime, & Williams, 1984), which differentiate them from less specialized recreationists. However, contrary to our first two hypotheses, that more specialized pike anglers possess structurally more complex mental models about pike ecology (as evidenced by as their maps including more concepts, more connections, or higher density) and they place a greater relative importance on specific ecological variables relevant to pike ecology (e.g. higher centrality of angling pressure and riparian vegetation), our results suggested that angler mental models are refined to key relationships and components (i.e. more specialized represent less), as opposed to simply

Table 5
GLM results for main effects and interactions of pike angler and specialization on concept-specific centrality. Significant models are in bold and ŧ indicates corrected model.

Variable centrality	*β*	SS	*df*	MS[a]	*F*	R^2	*p*
Angling pressureŧ		1.09	3	.366	2.21	.026	.087*
Pike anglers	−.039	.093	1	.093	.562		.454
Specialization	−.134	.356	1	.356	2.15		.144
Pike × specialization	.163	.833	1	.833	5.04		.026
Riparian vegetationŧ		1.13	3	.377	1.17	.014	.331
Pike anglers	.062	.240	1	.240	.731		.394
Specialization	−.121	.392	1	.392	1.19		.276
Pike × specialization	.130	.532	1	.532	1.61		.205
Submerged vegetationŧ		.370	3	.123	.249	.003	.862
Pike anglers	.075	.346	1	.346	.700		.403
Specialization	.026	.016	1	.016	.033		.855
Pike × specialization	−.030	.028	1	.028	.057		.811
Refugeŧ		1.06	3	.335	.982	.012	.402
Pike anglers	−.051	.164	1	.164	.454		.501
Specialization	−.110	.958	1	.958	2.64		.105
Pike × specialization	.047	.068	1	.068	.189		.664
Spawning habitatŧ		.474	3	.158	.415	.005	.742
Pike anglers	−.034	.072	1	.072	.189		.664
Specialization	−.088	.189	1	.189	.498		.481
Pike × specialization	.098	.302	1	.302	.793		.374
Stocking adultsŧ		.970	3	.323	.868	.010	.458
Pike anglers	.012	.008	1	.008	.022		.881
Specialization	−.124	.806	1	.806	2.16		.143
Pike × specialization	.087	.240	1	.240	.645		.423
Stocking juvenilesŧ		1.102	3	.367	.925	.011	.430
Pike anglers	−.018	.019	1	.019	.049		.825
Specialization	−.087	1.06	1	1.06	2.66		.104
Pike × specialization	−.009	.002	1	.002	.006		.938

Asterisks indicate significance (*= $p<.10$)

[a] Mean square.

accumulating knowledge of more relationships and components. However, the functional analysis revealed that the "simpler" mental models of more specialized anglers were functionally similar in terms of predicted outcomes to hypothetical management interventions (stocking, habitat management, angling pressure reduction) to those of ecologically trained fisheries biologists. Although these results run counter to our hypotheses, they are consistent with previous psychological studies that indicate that rather than building ever-increasing complexity, individuals often refine knowledge into heuristics that simplify behavior in complex environments, focusing on specific functional relationships (Kruglanski & Gigerenzer, 2011). Such refined understanding supports context-appropriate decision-making by exploiting known and predictable structures of information found within a given environment (referred to as "ecological rationality") and is based on the evolved psychological capacities of individuals, such as their memory and their perceptual system (Goldstein & Gigerenzer, 2002). Thus, specialization and increasing interaction with a target species may facilitate the development of heuristics and rules that are reinforced over time. However, although these models are simplified working preceptons of resource systems, they represent sophisticated reasoning when relied upon functionally.

Related to the issue of cognitive simplification, we cannot refute the alternative view that our result of structurally dissimilar and functionally similar mental models of more specialized anglers compared to biologists was simply a function of the specific management interventions that we modeled from group level social cognitive maps. In fact, descriptively it was obvious that a major structural difference between the mental models of fisheries biologist and of anglers was that the fisheries scientists perceived greater complexity at the "edges" of the ecological relationships by also considering the larger food web effects (e.g., from nutrients to fish production), while the anglers focused on the more direct pathways to their target species (e.g., from prey fish to pike) leaving aside the wider food webs. Hence, if we had modeled changes to nutrients, for example, the functional similarity of the angler and biologist mental models might have been less similar compared to the management actions that are presented in our paper. It is also important to note that functional similarity does not mean that the biologist's mental model were closer to reality than any angler mental model. Rather, our quantitative comparison of how the construction of knowledge varies across different groups of stakeholder involved in the management and harvesting of a natural resource was meant to indicate variation in knowledge and not necessarily a measure of knowledge correctness.

Our third hypothesis that more specialized anglers, and in particular pike anglers would possess functional knowledge most similar to fisheries scientists was supported. The support for this hypothesis emerged from the functional analyses that showed that HSP model predictions were most similar to the averaged scientists' mental model predictions across all types of management scenarios. Moreover, we found a positive effect of specialization in pike anglers on the centrality of angling pressure, while the

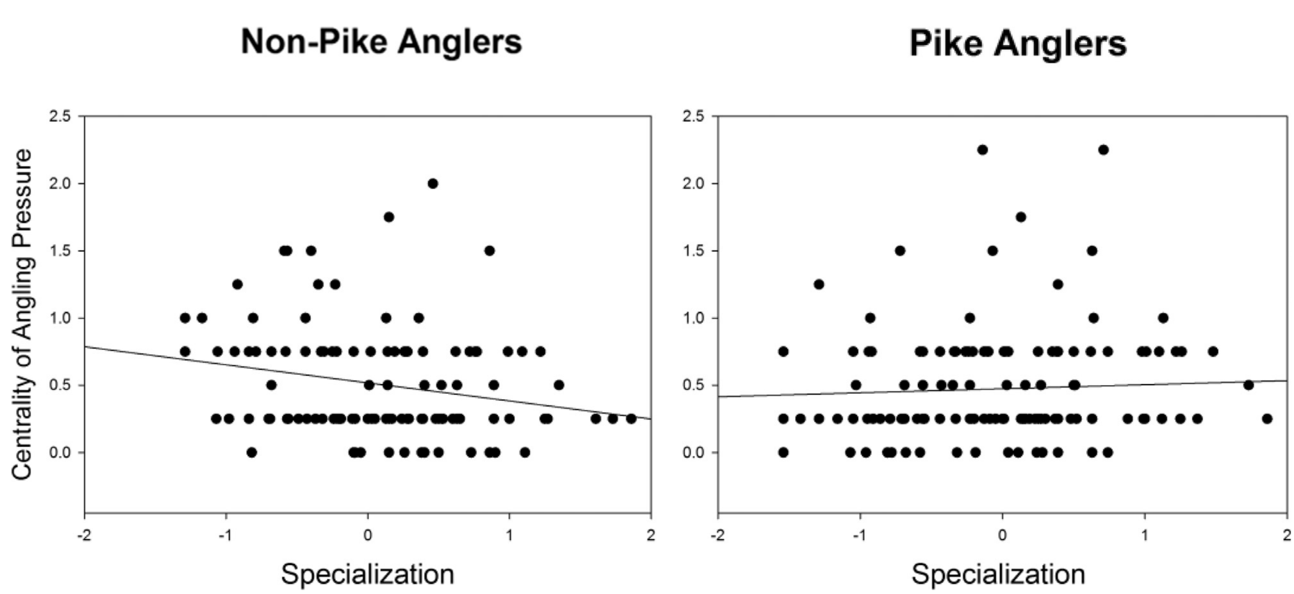

Fig. 4. Relationships between specialization and centrality of "angling pressure" for pike and non-pike anglers across specialization.

Table 6
ANOVA comparison of the 17 anglers in each extreme specialization and target species group compared to expert group in terms of general structural metrics of pike mental model and for centrality of key variables in the model. Post-hoc differences are indicated by dissimilar letters. HSP=highly specialized pike angers; HSNP=highly specialized non-pike anglers; LSP=lowly specialized pike anglers; LSNP=lowly specialized non-pike anglers.

Structural measurement	HSNP (*N*=17) Mean ± SD	LSNP (*N*=17) Mean ± SD	HSP (*N*=17) Mean ± SD	LSP (*N*=17) Mean ± SD	Experts (*N*=17) Mean ± SD	*F*	df	*p*
Number of transmitter variables	10.4(3.6)a	9.4(3.2)a	11.3(4.4)a	10.0(3.5)a	5.4(1.9)b	7.5	4	<.001
Number of receiver variables	1.6(1.5)	1.4(1.0)	1.7(1.1)	1.5(.7)	.94(.97)	1.2	4	.286
Number of ordinary variables	4.4(3.7)a	6.9(3.4)a	4.4(4.0)a	4.2(3.2)a	12.3(1.8)b	18.8	4	<.001
Number of concepts	16.7(3.8)a	17.4(2.0)a	17.4(2.3)a	15.6(2.9)ab	18.7(.50)a	3.4	4	.013
Number of connections	17.9(5.8)a	23(7.6)a	18.6(4.5)a	19(7.2)a	35.7(7.3)b	21.7	4	<.001
C/N	1.0(.20)a	1.3(.37)a	1.1(.18)a	1.2(.29)a	1.9(.40)b	22.7	4	<.001
Complexity	.17(.16)	.16(13)	.21(.20)	.18(.13)	.20(.19)	.25	4	.907
Density	.07(.03)a	.08(.02)a	.06(.01)a	.08(.02)a	.10(.02)b	6.9	4	<.001
Hierarchy	.004(.001)	.007(.004)	.004(.002)	.004(.003)	.006(.002)	2.9	4	.063
Centrality of variables								
Stocked adult pike	.30(.22)a	.62(.70)a	.24(.42)a	.47(.60)a	1.8(.52)b	9.8	4	<.001
Stocked young pike	.56(.54)a	.82(.69)a	.41(.50)a	.70(.69)a	1.5(.75)b	7.9	4	<.001
Spawning places	.76(.56)a	1.16(.67)ab	.78(.46)a	.90(.55)a	1.6(1.0)b	5.1	4	.001
Riparian vegetation	.66(.49)a	.92(.64)a	.89(49)a	.73(.63)a	1.4(1.0)b	3.5	4	.012
Aquatic plants	.67(42)a	.70(.41)a	.86(67)a	.79(.52)a	2.3(1.1)b	17.0	4	<.001
Refuge	.82(.56)a	.96(.67)ab	.66(.40)a	.92(.68)ab	1.4(84)b	2.8	4	.034
Angling pressure	.42(.38)a	.67(.32)a	.56(.51)a	.50(.38) a	1.4(.86)b	10.5	4	<.001

Table 7
Percent agreement of impacts to two pike variables (Pike), eight biotic variables (B), four abiotic variables (Ab) and three functional habitat variables (Fh) included in the fuzzy cognitive map representations of mental models under two stocking scenarios, increased stocking adult pike and increased stocking juvenile pike. Shaded areas indicate highest level of agreement with expert predictions per variable category by group. HS=highly specialized and LS=lowly specialized.

Angler Group (*N*=17 per group)	**Stocking scenarios**								
	Increased stocking adult pike				Increased stocking juvenile pike				Overall mean agreement
	Pike	*B*	*Ab*	*Fh*	*Pike*	*B*	*Ab*	*Fh*	
HS Pike	1.0	.75	1.0	1.0	1.0	1.0	1.0	1.0	.97
HS non-Pike	1.0	.75	1.0	1.0	.5	.88	1.0	1.0	.89
LS Pike	.5	.63	1.0	1.0	1.0	.88	1.0	1.0	.88
LS non-Pike	1.0	.88	1.0	1.0	1.0	.88	1.0	1.0	.97

Table 8
Percent agreement of impacts to two pike variables (Pike), seven biotic variables (B), four abiotic variables (Ab) and three functional habitat variables (Fh) included in the fuzzy cognitive map representations of mental models under two pike-specific habitat-related scenarios including increased riparian vegetation and increased submerged aquatic vegetation. Shaded areas indicate highest level of agreement with expert predictions per variable category by group. HS=highly specialized and LS=lowly specialized.

Angler group (*N*=17 per group)	**Pike-specific habitat scenarios**								
	Increased riparian vegetation				*Increased submerged aquatic plants*				Overall mean agreement
	Pike	*B*	*Ab*	*Fh*	*Pike*	*B*	*Ab*	*Fh*	
HS Pike	1.0	.88	1.0	1.0	1.0	.63	.75	1.0	.91
HS non-Pike	.5	.75	1.0	.5	1.0	.5	.5	1.0	.72
LS Pike	1.0	.88	1.0	1.0	1.0	.75	.5	1.0	.89
LS non-Pike	.5	.75	1.0	1.0	1.0	.63	25	1.0	.74

relationship was negative in the non-pike anglers. Many studies have shown that pike populations are very vulnerable to angling pressure (Arlinghaus, Dieckmann, & Matsumura, 2010 and references therein), and hence the increasing importance placed on angling pressure as pike anglers become more specialized is consistent with the literature. Overall, our results suggested that as anglers move along a continuum of specialization, knowledge of resource dynamics is simplified structurally, but the knowledge domain retains the most important relationships between key variables that affect the state of a resource. The final outcome of this refinement represents an informal expertize that is functionally (but not structurally) similar to the specific relationships defined by formal experts. It is important to note, however, that this learning progression along the lines of specialization in terms of functional knowledge is not uniform across anglers but instead is moderated by the experience with a given species that anglers are devoted to and interact with. For example, analysis of functional knowledge indicated that both types of pike anglers' knowledge were more similar to fisheries scientists based on the pike-specific habitat management scenarios, while both types of highly specialized anglers' knowledge, independent of target species, were most similar to scientists under the general habitat

Table 9
Percent agreement of impacts to two pike variables (Pike), eight biotic variables (B), four abiotic variables (Ab) and two functional habitat variables (Fh) included in the FCM representations of mental models under three general habitat scenarios including increased spawning grounds, increased refuge, and decreased angling pressure. Shaded areas indicate highest level of agreement with expert predictions per variable category by group. HS = highly specialized and LS = lowly specialized.

Angler Group (N=17 per group)	**General habitat scenarios**												
	Increased spawning grounds				*Increased refuge*				*Decreased angling pressure*				Overall mean agreement
	Pike	*B*	*Ab*	*Fh*	*Pike*	*B*	*Ab*	*Fh*	*Pike*	*B*	*Ab*	*Fh*	
HS Pike	1.0	.63	1.0	.5	1.0	.63	.75	1.0	.5	.75	1.0	.5	.77
HS non-Pike	1.0	.75	1.0	.5	1.0	.50	.75	1.0	.5	.75	1.0	.5	.77
LS Pike	1.0	1.0	1.0	.5	1.0	.75	.5	1.0	.5	.88	.5	0	.72
LS non-Pike	1.0	.63	.25	1.0	.5	.63	.25	1.0	.5	.63	1.0	.5	.66

management scenarios. These findings indicate that in terms of the cognitive construction of general ecosystem understanding, specialization may influence mental model refinement of general ecosystem properties; however, in terms of the construction of species-specific ecosystem understanding, repeated interaction with a particular species may influence knowledge-building in specific ways. These findings indicate a certain "simplification" of pike population ecology as anglers specialize on alternative species, but they still retain a functional mental model that reflect knowledge of general ecological and fishing-related impacts on fish stocks independent of the target species.

We found a disconnect among mental model structure and function and fewer significant relationships in terms of the mental model structural metrics and specialization than we had anticipated. These results could be attributable to the nature of our mental modeling exercise, as we bounded people to the same set of ecological concepts. However, given the fundamental differences in the mental model structure among extreme ends of the angler specialization groups and the fisheries experts, this explanation is unlikely. It is more probable that the anglers are more homogenous in their mental model structure than we initially believed. Indeed, past studies have indicated that it is difficult to measure significant variation in mental models, and existing methods may lead to understanding differences in only a few important dimensions of mental model structure, such as degree of complexity or dynamic complexity (Doyle and Ford, 1998). Additionally, research specifically designed with interventions intended to change mental models in recreational anglers has indicated that individual mental models of fish ecology may be relatively stable over time and may not be easily changed. For example, von Lindern (2010) engaged six angling clubs with a designed intervention and intended to measure changes in angler mental models of trout stocking, which could serve as a method to change anglers' understanding away from an additive and more linear perception of trout stocking toward a more complex and compensatory understanding. By engaging angling clubs in workshops and providing anglers with detailed information about the stocking success in their waters, the intervention was not successful in significantly changing ecological understanding.

Our study is among the first (see also von Lindern (2010)) to use mental model assessments with a graphical method in recreational fisheries. However, more work is needed, specifically with regard to measurement methodologies. Barriers to popularizing our mental model assessment method include the time needed to conduct the exercise (about 45 min in workshop settings), the limited ability to represent non-linear relationships and the lack of test-retest reliability assessments. There are many more issues which need be accounted for when researchers seek to accurately measure or represent mental models. As Jones et al. (2011) point out "mental models exist within the mind and are therefore not available for direct inspection or measurement". Although this statement applies to any latent psychological construct, assessing complex ecological understanding graphically constitutes a particularly challenging task of operationalization, which needs more methodological work in natural resource management contexts.

There is significant variation in how mental models are elicited and measured across the social sciences. Each measure of mental models published so far emerges from different research traditions, and likely gives insight into a discrete, yet incomplete dimension of human understanding (Jones et al., 2011). Given the large-scale scope of our study, anglers started the modeling task with predetermined concept cards intended to decrease the cognitive load placed on our study participants, but this might have directed anglers into a specific thought process and might have affected the structural properties of the graphical networks. We deliberately took this approach to increase the comparability of the cognitive maps among the hundreds of participants, but inevitably this may have constrained the thinking of our subjects (for trade-off considerations in FCM data collection techniques, see Gray et al. (2014)). Although we found functional similarities as hypothesized, these qualitative scenario analyses were generalized for analytical ease and therefore the complexity and specific details of both individual responses, and averaged responses, may have been lost. Future studies would benefit from a refinement of mental model assessment methods, specifically with regard to functional analysis, alongside the measurement of simpler indicators of specialization to better understand how specialization affects subjective theory building about natural resource systems.

Lastly, given the issues related to understanding to measuring mental models, there are questions about the degree to which this mental model approach differs from more standard measurements of human cognitions (values, beliefs, attitudes) within human dimensions research. While traditional social science approaches in natural resource management routinely attempt to uncover trends in how segmented resource user groups (e.g. by dimensions like specialization) vary in terms of beliefs about environmental change, attitudes toward management policies or behavioral intentions (e.g., Arlinghaus, Bork, & Fladung., 2008), we contend that mental model approaches represent a complementary means by which to understand the ecological understanding of resource stakeholders. Mental models, by definition, differ conceptually from values (i.e., desirable end states or modes of conduct), beliefs (i.e., a firm opinion or acceptance of a fact) and attitudes (i.e., evaluation, favorable or unfavorable, of an object). A mental model is informed by beliefs and attitudes and together with these cognitions filter information and influence decision-making (Biggs et al., 2011). Von Lindern (2010) conceptualized mental models as a separate antecedent to behavior that exerts independent or possibly interactive effects on behavior similar to attitudes, beliefs or norms. We acknowledge that certain components of cognitive understanding of pike ecology in our mental model exercise, e.g., the centrality of specific ecologically concepts, may be perceived as conceptually similar to a belief assessment of how relevant certain ecological issues are for influencing pike stocks. However, it is important to acknowledge a very important conceptual difference here: while mental model structure can be considered emergent properties that are the result of a network of interactions and hence somewhat unconscious to the study subjects, he or she will provide a conscious answer to any item or set of items designed to measure beliefs or attitudes. Therefore, we would not necessarily predict that an attitude assessment towards a management tool (e.g., constraining angling effort) assessed via a Likert-scale-based traditional survey format would provide the same result as with a functional mental model analysis. For example, when a particular participant represents a mental model they may perceive the effect of reducing angling pressure as very effective for increasing pike stocks, however the same individual might also express a negative evaluation of reducing angling pressure as a management tool when measured on an item-based survey. The difference is that the effect of changing angling pressure, when represented through a network of interactions in a mental model, may not allow the consequences of these actions to be immediately obvious to the subject. Conversely, the same individual might automatically perceive the personal consequences of changing angling pressure when confronted with the task of expressing an attitude to effort controls. Future studies are needed to assess the correlation of mental models with beliefs, attitudes and behavioral intentions to better understand how mental models align with other cognitions within the cognitive hierarchy to uncover their relationship to human behavior.

5. Conclusions and implications

Our study contributes to a limited number of fairly recent studies (Eden & Bear, 2011; von Lindern, 2010) that explore the relationship between anglers and their ecological knowledge about the dynamics of fish populations. As previous work has already pointed out, considering the ecological knowledge of consumptive users such as anglers as homogeneous leads to inadequate and misleading results (Robbins, 2006; Johnston, Arlinghaus, & Diekmann, 2010). Instead, acknowledging heterogeneity provides insight into the how social factors influence the construction of knowledge in different communities, how this variation in knowledge leads to different mental predictions associated with competing natural resource management policy options and how these predictions may influence human interactions with the environments they are managing (Eden and Bear, 2011; Halbrendt, Gray, Radovich, Crow, & Kimura, 2014). From a managerial perspective, our study provides insight that, for a given target species, anglers varying by specialization will think differently about the components affecting fish populations and thus will likely react very distinctively to new policies (see, e.g., Dorow et al. (2010)). Indeed, our research has shown that fisheries scientists and highly specialized anglers may have a very similar functional perception of the system and hence academic messages maybe particularly conducive to more specialized anglers. Further research is needed to fully understand the role of mental models in explaining the management preferences of diverse recreational anglers, which span a spectrum of specialization, and more information is needed about how anglers differ from academic experts. Applying our technique to a more random sample of anglers would be a much needed step forward and will likely contribute more variance explained by specialization and species choice than was present in our data from rather homogenous group of self-selecting angling clubs members. Given that anglers often either lobby (e.g. in the U.S.A., Gray et al., 2012) or directly manage (e.g., in central Europe, Daedlow, Beard, & Arlinghaus, 2011) fishery resources across the world, a better understanding of how to align anglers', managers' and scientists' knowledge about ecosystem functioning would likely aid in better communication and consensus building for management plans across different groups (Biggs et al., 2011).

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