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Research

Understanding the bushmeat hunting crisis in African savannas using fuzzy cognitive mapping and stakeholder knowledge

Julia L. van Velden [1], Boyson H. Moyo [2], Helen Ross [3] and Duan Biggs [1,4,5]

ABSTRACT. Critical conservation issues such as bushmeat hunting, which exist in complex social, political, and policy landscapes, require the incorporation of diverse sources of knowledge as a key aspect of decision making. We demonstrate the utilization of both individual and collective stakeholder knowledge to contribute toward decision making. We used fuzzy cognitive mapping in a two-stage process to investigate bushmeat hunting and consumption in Malawi as a case study, and arrived at models of the bushmeat hunting and consumption systems in the form of cognitive maps. We also explored the effect of three different intervention scenarios, namely wildlife farming, microenterprise initiatives, and ecotourism. We found that the concept of hunting was perceived as more complex than consumption, and that poverty, human population, and political will were shared as important drivers of both issues. The two-stage process we used indicated that individual and group phases were equally important. Key concepts were drawn out during the individual elicitation stage, while the participatory group phase allowed nuanced understanding of many of these concepts. We found that wildlife farming was predicted to be the most effective scenario for meeting many of the key state outcomes for both hunting and consumption. These results provide an example of using fuzzy cognitive mapping in a multistage process and illustrate its utility for arriving at decisions regarding interventions in complex social-ecological systems.

Key Words: *cognitive models; expert systems; mental models; participatory models; poaching; social learning; wild meat*

INTRODUCTION

Most of the world's most pressing conservation problems such as overexploitation (via logging, hunting, or fishing), agricultural activity, or urban development (Maxwell et al. 2016) require a deep understanding of the social-ecological systems in which they are embedded (Collins et al. 2011). Harvesting of animals for human consumption is the largest danger to threatened megafauna (Ripple et al. 2019) and is responsible for species declines worldwide (Benítez-López et al. 2017). Bushmeat hunting or wild meat harvesting is defined here as any nondomesticated terrestrial mammal, bird, reptile, or amphibian harvested for food (Nasi et al. 2008). This term includes all steps in the supply chain including the acquisition, trade, and consumption of wild meat and features complex social-ecological systems. For example, factors such as poverty, culture, land-use rights, development and infrastructure, governance and corruption, food security, and human population growth may all influence bushmeat hunting in some way (Bennett et al. 2007, Lindsey et al. 2013). Despite this complexity, simplistic narratives around why people hunt and consume bushmeat often prevail, which obscures the multidimensional nature of this issue (Travers et al. 2019*a*). Although generating income and providing meat for households are primary motivators for hunting, bushmeat may serve many purposes, including maintaining cultural traditions and managing damage from wildlife or because hunting is perceived as a right (van Velden et al. 2020*a*, Lindsey et al. 2013). Managers and decision makers therefore often struggle to fully visualize the bushmeat hunting and consumption systems, leading to the implementation of interventions based on limited evidence (Coad and Wicander 2014). Specifically, there is a need to use predictive approaches to understand how conservation interventions impact social-ecological systems, especially to explore the consequences of different management interventions in advance of implementation (Milner-Gulland 2012, Travers et al. 2019*b*).

Although studies about bushmeat hunting have traditionally focused on forest systems (van Velden et al. 2018), this issue is increasingly recognized as one of the most pressing threats to wildlife conservation in savannas (Lindsey et al. 2017). This is illustrated in the southern African country of Malawi, one of the world's poorest nations (World Bank Group 2020). Although Malawi has recently began investing into conservation initiatives, via partnerships with international nongovernmental organizations (Baghai et al. 2018) and changes to laws and sentencing for wildlife crimes (Jere 2017), the high rate of illegal bushmeat hunting from protected areas remains one of the key challenges (Munthali and Mkanda 2002, van Velden et al. 2020*a*), due in part to underfunding (Lindsey et al. 2018). Further, strict antihunting wildlife laws may negatively impact the legitimacy and perception of conservation more generally (Strong and Silva 2020). This makes strategies that go beyond enforcement a top priority. Previous quantitative research has shown the complexity of the social-ecological factors affecting bushmeat hunting and consumption in Malawi (van Velden et al. 2020*a*) and elsewhere (Travers et al. 2019*a*). These kinds of complex social-ecological systems are defined by positive feedback dynamics characterized by uncertainty, where it is not possible to specify in advance all possible outcomes and deliberative processes may be needed to temporarily define the problem (Marshall 2013). Although data-driven approaches are informative, such research can be expensive to conduct and may not fully capture the wider political, sociological, and policy landscape within which conservation

[1]Environmental Futures Research Institute, Griffith University, Nathan, Australia, [2]Lilongwe University of Agriculture and Natural Resources (LUANAR), Lilongwe, Malawi, [3]School of Agriculture and Food Sciences, The University of Queensland, Brisbane, Australia, [4]Centre for Complex Systems in Transition, School of Public Leadership, Stellenbosch University, Stellenbosch, South Africa, [5]Department of Conservation Ecology and Entomology, Stellenbosch University, Matieland, South Africa

takes place. Therefore, it is vital to utilize multiple sources of data, such as bringing in local expert stakeholders to provide context and perspective to the data derived from quantitative approaches.

The concept of "mental models," which are internal representations of external realities (Jones et al. 2011), are used to reveal stakeholder's understanding of natural and social processes, to improve natural resource management. Stakeholders can share complex knowledge structures and reveal underlying assumptions about issues (Moon et al. 2019). Mental models can be expanded from an individual to a shared mental model, which represents a collective cognition among groups of individuals, and is used to support collective decision making (Langan-Fox et al. 2001). This process can be achieved via participatory modeling, which is defined as "a purposeful learning process for action that engages the implicit and explicit knowledge of stakeholders to create formalized and shared representations of reality" (Voinov et al. 2018:233). Participatory modeling enables sharing of knowledge in such a way that solutions can be found, aiding in both conflict resolution and decision making. This is especially vital in conservation where conflicting views by stakeholder groups can cause policy deadlocks (Biggs et al. 2017), and where issues like sustainable use of bushmeat have become increasingly polarized (Hutton and Leader-Williams 2003, Strong and Silva 2020). Resolving such conflicts requires recognizing problems as shared by the parties involved and engaging with mutual goals, key aspects of participatory processes (Redpath et al. 2013). Participatory modeling can be achieved in a variety of different ways, including qualitative (e.g., causal loop diagrams, decision-tree analysis), semiquantitative (e.g., fuzzy cognitive mapping, scenario building), or fully quantitative (e.g., agent-based modeling, Bayesian models) approaches (Voinov et al. 2018). Participatory modeling therefore offers a flexible approach to eliciting information from experts or other stakeholders to better understand conservation problems and make decisions.

We focus on using cognitive mapping as a way of eliciting participants' mental models. This technique results in models of how a given system operates, where important variables are defined, and the causal relationships are described, using expert stakeholder knowledge (Özesmi and Özesmi 2004). Cognitive maps have been conceived in two different ways. First, in the environmental psychology field, this term has been used to refer to exploring how participants would spatially organize important concepts in a system (Kearney and Kaplan 1997). Second, cognitive maps can be understood as graphical representations of causal relationships, which are defined by the participants rather than the researcher (first used by Axelrod 1976). We use the second conceptualization here. Cognitive maps allow decision makers, stakeholders, and local communities to become involved in describing a specific system (Gray et al. 2015). Fuzzy cognitive maps (FCMs) are a modification of Axelrod's "digraphs," where fuzzy causal functions are applied using real numbers and mathematical pairwise associations, to indicate how strong connections between different variables (or nodes) are (Kosko 1986), making this application semiquantitative in nature. The "fuzzy" aspect of the causal functions indicates that the edge values (or weighting of relationships between variables) are not restricted to integers +1 or -1, but can fall anywhere between this scale (Kafetzis et al. 2010).

FCMs can also be used to understand how a system may change in response to a conservation intervention using a rapid participatory process, which is vital given that many systems do not have enough information, time, money, or expertise to develop an appropriate mathematical model (Game et al. 2018). This is especially important in contexts where conservation problems are urgent and there are high social and ecological stakes, but data are not resolved. FCMs are quick and easy to construct using readily available software and detailed information from expert sources, can incorporate as many knowledge sources as needed, and are easily modified, allowing pattern prediction and changes in behaviors of the model to become clear (Özesmi and Özesmi 2004). Importantly, this approach allows diverse stakeholders to have a say in decision making and clarify what social values and preferences they hold, which is vital for conservation efforts to acquire the support they need (Lynam et al. 2007). Further, because these cognitive maps can be elicited from multiple individuals or groups and then combined, they are also useful for exploring differences in worldviews and thinking between a range of stakeholder groups (Gray et al. 2017). Because of these benefits, FCMs can be an important contribution to the decision-making process, as conservation decisions often have to meet multiple (and sometimes opposing) objectives and can include large uncertainty because of the nature of the complex social-ecological systems from which they arise (Fuller et al. 2020).

Here we use the concept of fuzzy cognitive mapping to explore hunting and consumption of bushmeat in Malawi, using this process to aid in decision making by allowing experts to collaboratively explore this complex issue. Studies have previously used this methodology to understand bushmeat hunting in Tanzania using community-based models (Nyaki et al. 2014, Gray et al. 2015). However, bushmeat consumption has to date not been modeled using such participatory methods, despite the importance of understanding both sides of the supply chain. We expand earlier work and address knowledge gaps by (a) presenting models generated from conservation experts in Malawi, exploring both bushmeat hunting and consumption; (b) exploring the utility and importance of eliciting knowledge from individuals versus in a participatory group setting; (c) presenting the potential effects of three different programs to reduce bushmeat hunting and/or consumption; and (d) discussing how this knowledge can be used in future conservation planning.

METHODS

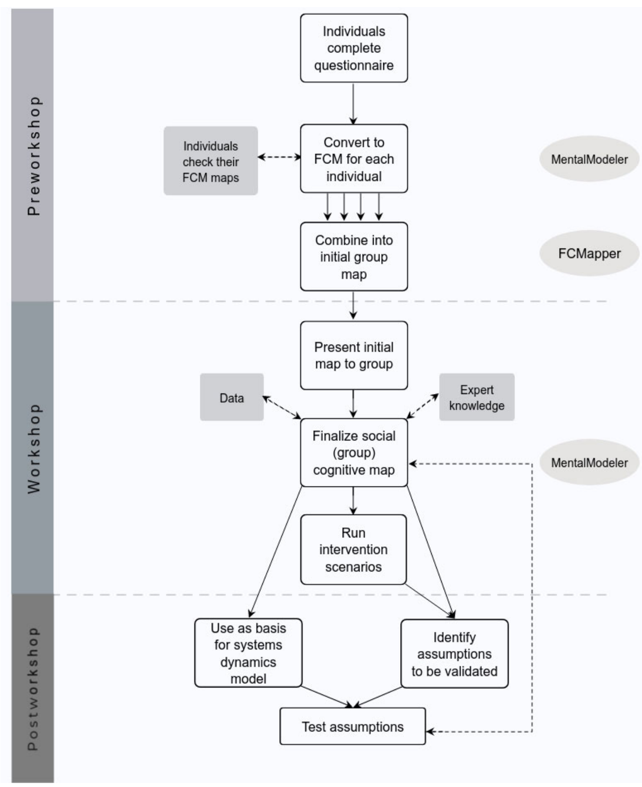
Study site

Malawi has a relatively high amount (22.9%) of its land surface dedicated to protected areas (World Bank Group 2018), however many of these areas struggle to deliver on conservation goals. Issues include lack of fencing, inconsistent or under-resourced enforcement, and lack of appropriate community benefits, all of which may impact bushmeat hunting and consumption. Malawi has a mild tropical climate with an austral summer rainy season and dry winters (Jury and Mwafulirwa 2002), with the natural habitat primarily consisting of Miombo woodland (Olson et al. 2001). However, much of the land outside of protected areas has been converted to agriculture. This means that animals available for bushmeat hunting outside of protected areas primarily consist of bird, rodents, or small-bodied antelope (Maseko et al. 2017). As such, larger bodied animals within protected areas represent a potentially valuable protein resource to local communities. However, any hunting inside a protected area is illegal in Malawi (Jere 2017).

Individual cognitive maps and creation of initial group cognitive map

We used the fuzzy cognitive mapping (FCM) approach to aid in the process of exploring conservation expert's understanding of the illegal bushmeat hunting and consumption systems in Malawi. We conducted the FCM process in four main steps. First, FC maps were elicited from individual expert stakeholders and then combined into initial group maps. Next, the initial group cognitive maps were presented and modified in a workshop setting. The group cognitive maps were then used to investigate the effect of three interventions on the system via group examination of scenarios. Finally, we identified key areas of uncertainty and ideas for future research, and evaluated the FCM process (Fig. 1).

Fig. 1. Process for participatory fuzzy cognitive mapping (FCM), illustrating three stages: preworkshop, where individual cognitive maps are elicited and combined; workshop, where the initial map is presented to a group, modified, and interventions incorporated; postworkshop where cognitive maps are used to validate assumptions. Dashed lines indicate feedbacks, and round components indicate the software used at each stage.



First, we elicited individual FCMs from eight Malawian conservation experts via a questionnaire delivered over email (Appendix 1), which experts could download and work on in their own time. The elicitation involved asking participants to respond to four questions: (1) Which variables are important to consider when thinking about illegal bushmeat hunting?; (2) Is the relationship between these variables and hunting positive or negative?; (3) Are the relationships between important variables and hunting strongly, moderately, or weakly related?; (4) What are the relationships among the important variables, apart from their relationship to hunting? These questions were then repeated for bushmeat consumption later in the questionnaire. From the responses to these questions we drew up two individual fuzzy cognitive maps for each participant (one for hunting and one for consumption), using the mental modeler software (see http://www.mentalmodeler.org; Gray et al. 2013). We converted the relationships provided by participants to numbers on a scale of -1 to +1, where a number > 0 indicated a positive relationship and a number < 0 indicated a negative relationship (Özesmi and Özesmi 2004). A strong relationship was indicated by ± 1, a medium relationship by ± 0.5, and a weak relationship by ± 0.25 (Nyaki et al. 2014, Henly-Shepard et al. 2015). The individual participants then checked the cognitive maps via email correspondence. This methodology allowed us to contact experts in remote areas who did not have reliable internet access, however virtual meetings or in-person interviews could also be used to draw or check the maps.

We next combined the individual cognitive maps into two initial group maps, one for hunting and one for consumption. Appendix 1, Figure A1.1 illustrates the accumulation curves for new variables, which indicated sufficient sampling of individuals to discover the majority of important concepts (Özesmi and Özesmi 2004). The concepts shared between individual maps are available in Appendix Table A1.1. We used the combine.maps function in the FCMapper package in R (Turney and Bachhofer 2016) to aggregate the matrices of the individual cognitive maps, where relationships that are shared between two or more maps are averaged. We weighted all cognitive maps equally on the assumption that all individual maps are similarly valid.

Modification and finalization of the group cognitive map

We next presented the initial group cognitive maps at a workshop held in Lilongwe, Malawi in November 2019, which involved eight participants, representing five different organizations working in conservation in Malawi. These groups included two universities, the international NGO African Parks, the Department of National Parks and Wildlife (both staff from individual protected areas and executives), and the Lilongwe Wildlife Trust, a local conservation NGO. This represents all of the major organizations in the conservation space in Malawi, apart from Peace Parks Foundation, whose members were unable to attend. Not all participants at the workshop had answered the initial FCM questionnaire (four had completed the questionnaire and four had not). Also, four people who answered the initial questionnaire were not present at the workshop. The workshop presented the concept of FCM in detail and then presented the initial group cognitive maps for hunting and consumption. We also presented detailed findings of previous research into bushmeat hunting (van Velden et al. 2020*a, b*). The initial group cognitive maps were discussed by going through each component, relationship, and strength in detail with the group using Mental Modeler software, via a projection of these maps. Changes to the map were recorded as the discussion progressed and finalized after arriving at a group consensus. Whiteboards, flipcharts, and cards were also made available to participants for the discussion and to illustrate relationships.

Table 1. Description of intervention scenarios and their perceived relationships to other components in the fuzzy cognitive maps.

Intervention scenario	Description	Map of interest	Components in map to which intervention was linked, with sign of relationship (+ or -)
Wildlife farming	Program to create the enabling conditions for wildlife to be owned and farmed by local communities, including training in management and health, setup of regulatory systems, certifications, and start-up donations of wildlife	Consumption	Availability of alternative proteins (+) Sustainability of alternative livelihoods (+) Food security (+) Household income (+)
		Hunting	Poverty (-) Local demand for bushmeat from protected areas (-) Sustainability of alternative livelihoods (+)
Microenterprise initiative	Program where participants receive training and a seed-grant to start a business of their choice. Businesses administrated in groups, where loans and profits could be pooled for further expansion	Hunting	Poverty (-) Dependence on wildlife resources (-) Food security (+) Sustainability of alternative livelihoods (+) Community development status (+) Political will (+)
Ecotourism	Program to create tourist visitation experiences in local communities near protected areas e.g., "cultural villages," where money received by visits is put into a trust to be used by the community as they see fit	Hunting	Sustainability of alternative livelihoods (+) Community development status (+) Poverty (-) Community participation in protected areas (+) Proximity to protected area (+)

Effect of interventions on group FC maps using scenarios

We next conducted a scenario analysis, where we investigated the predicted effect of three different hypothetical interventions on the group cognitive maps. These interventions were drawn from ones previously investigated in Malawi and from suggestions from the group. Workshop participants chose to investigate wildlife farming, microenterprise initiatives, and ecotourism programs (Table 1). These were added separately as components to the group maps for both hunting and consumption, and linkages made to other components. The predicted effect of the scenario was analyzed by exploring how the system might change from its stable (or steady) state, to an alternative state under the scenario (Gray et al. 2015). The stable or steady state indicates what will happen to the system if things continue as they are, i.e., the system with current levels of bushmeat hunting (Özesmi and Özesmi 2004). The changes to the stable state when an intervention is introduced to the map can then be investigated by "clamping" this component to a high or low level (+1 or -1; Kosko 1986). We clamped each of the three intervention components to a high level. Further, the desired states of all components in the maps were recorded, with participants indicating a preference for the component to decrease, increase, or remain the same (no preference). We then recorded whether the state of that component under the intervention scenario met that preference or not. In this way, interventions can be compared to see which may most be able to create a future state for the whole system that is desired by participants.

Identification of uncertainties and assessment

We asked participants to explain key assumptions made when the group generated the map and identify areas that required further research, areas that the group was relatively certain about, and finally actions that could be implemented in the future. We also asked respondents to answer questions about the FCM process and how effective they found the approach to help to further knowledge and create new shared understanding via a qualitative postworkshop questionnaire.

Analysis

The information extracted from the group cognitive maps for both hunting and consumption of bushmeat that were generated from individual questionnaires and those finalized at the workshop (Table 2) included the number of connections, the degree of complexity of each map, the indegree, outdegree, and centrality of each variable in the map, as well as whether the variable was a driver, ordinary, or receiver variable (Özesmi and Özesmi 2004). We ran scenarios for each of the three interventions investigated, using a sigmoid activation function to analyze their effect on the components' steady state (Bueno and Salmeron 2009). We also compared the preworkshop group map generated from the initial individual questionnaires with the group map finalized after the workshop, using the FCMapper package function comp.maps, which calculates the S2 (the proportion of shared concepts between maps) and Jaccard (a ratio of shared vs unshared components) similarity indices, to show how similar the components of two cognitive maps are.

RESULTS

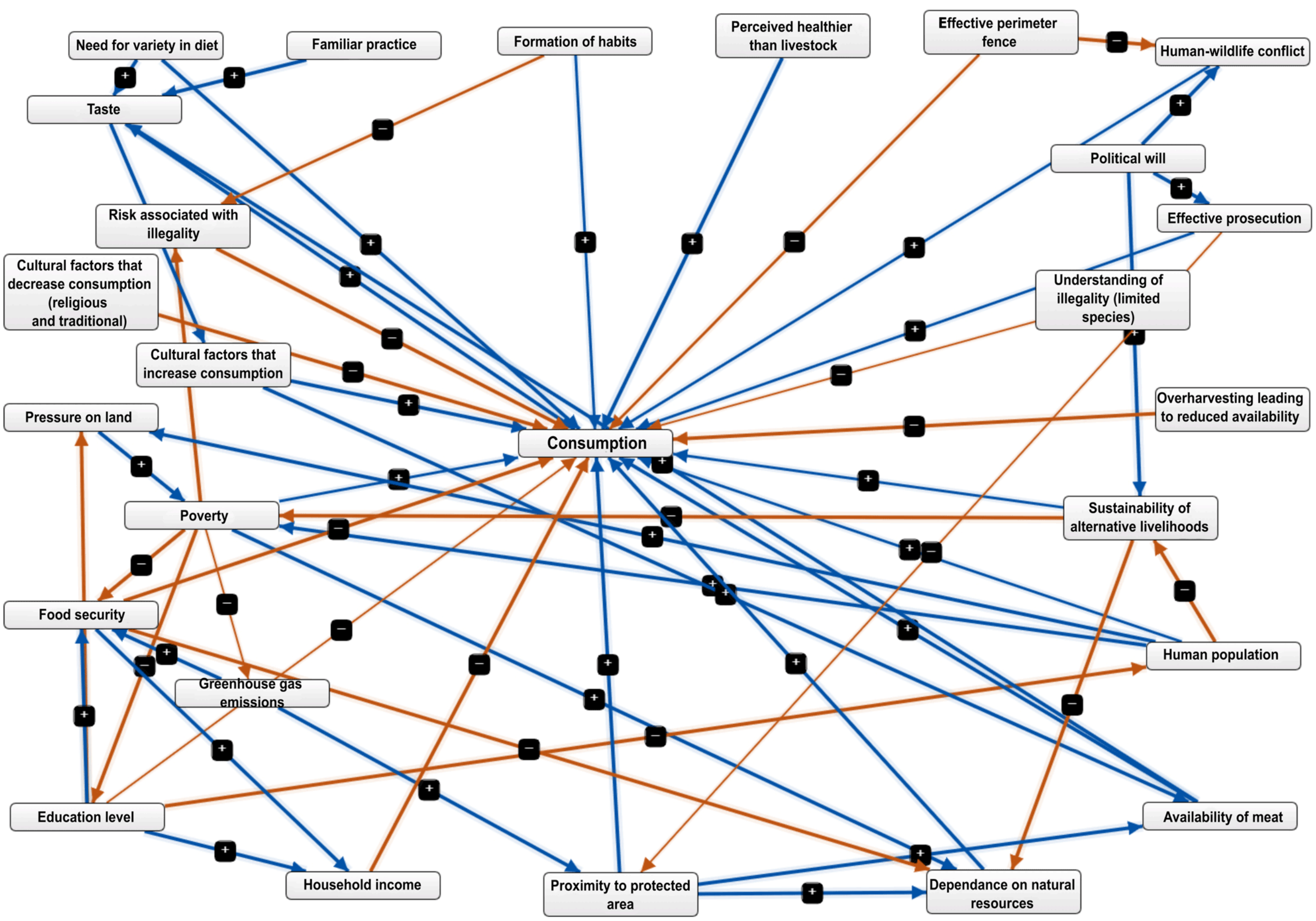
Comparison between hunting and consumption FC maps

The cognitive map for hunting, generated during the workshop, had approximately twice as many components (n = 55) and connections (n = 100) as the consumption map (n = 26 and 53, respectively), although consumption had higher density of components (Table 3). Hunting had substantially more driver variables than consumption, and greater map complexity. Hunting and consumption of bushmeat were the most central variables and had the highest level of indegree for each respective map. Apart from this, the most central variables in the consumption map (Fig. 2) were poverty, food security, education level, dependence on natural resources, and taste of meat (centrality scores > 5). Centrality indicates a component's overall contribution to the map. Apart from education level, these components also had the highest levels of indegree (≥ 3), indicating they had the most connections flowing into them and

Table 2. Definitions of terms used relating to fuzzy cognitive mapping.

Term	Definition
Driver/transmitter variable	All connections flow out of the variable, and no connections flow into the variable
Ordinary variable	Has a mixture of connections flowing in and out of the variable, can be more or less of a receiver or transmitter variable
Receiver variable	All connections flow into the variable, and no connections flow out of the variable
Map complexity	Ratio of number of receiver to transmitter variables
Indegree	Cumulative strength of variables entering a specific variable
Outdegree	Cumulative strength of connections exiting a specific variable
Centrality	How connected a specific variable is to other variables, i.e., summation of its indegree and outdegree

Fig. 2. Finalized fuzzy cognitive map for bushmeat consumption in Malawi, where blocks represent important components and arrows represent relationships between components. The color of the arrow indicates whether the relationship is positive (blue) or negative (orange). The width of the arrow indicates the strength of the relationship (where strong relationships are wider than weak relationships). Generated using MentalModeler software.

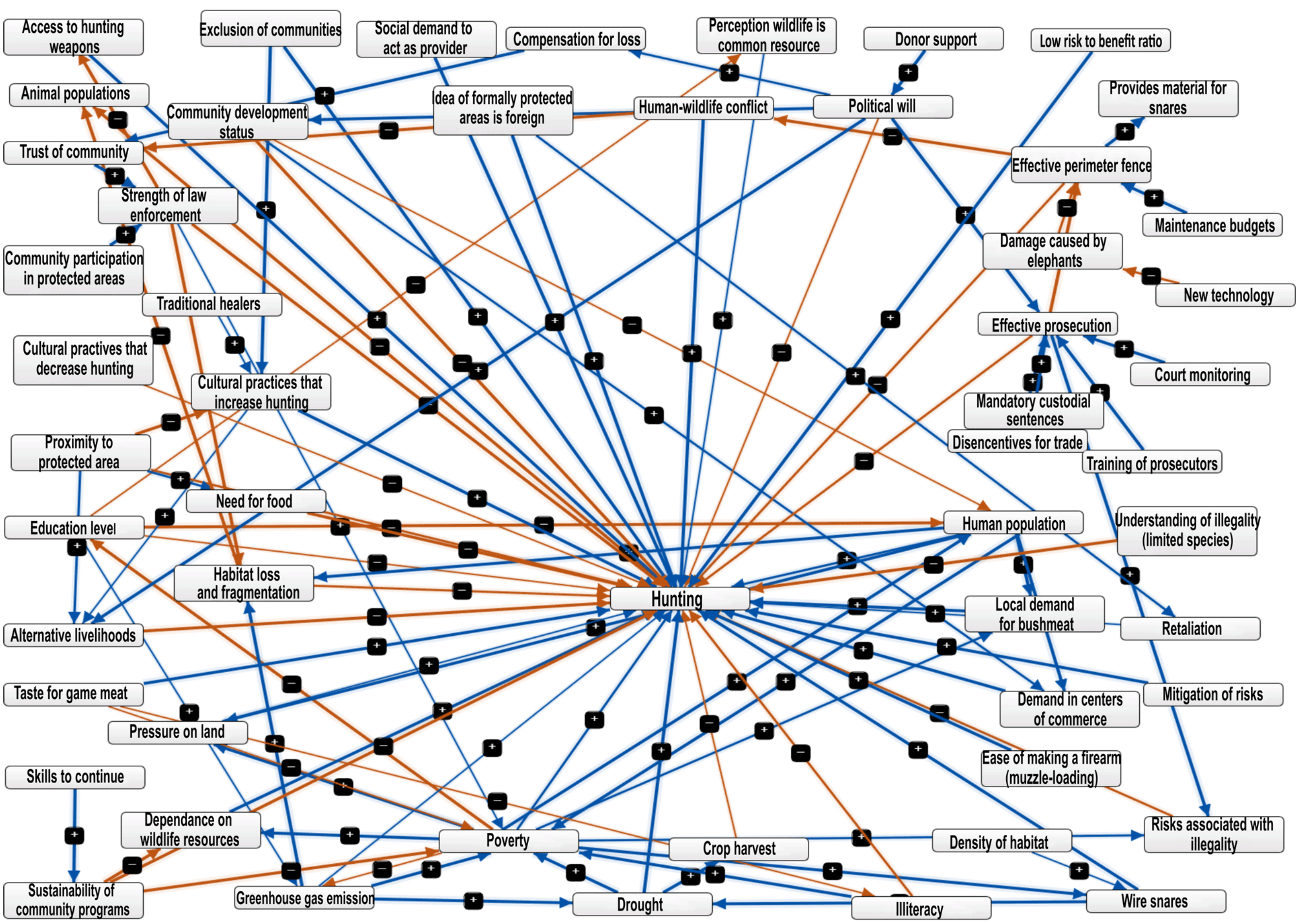


were more likely to be influenced by other components than influence the system themselves. Poverty, education level, human population, food security, proximity to protected area, and political will had the highest level of outdegree (≥ 3), indicating these variables had the most connections going out of them and therefore can act as driver variables. For the hunting map (Fig. 3) the most central variables (score ≥ 5) were poverty, human population, effective prosecution, strength of law enforcement, drought, and effective perimeter fencing. Poverty, effective prosecution, and habitat loss/fragmentation had high levels of indegree (> 3). Poverty, human population, political will, effective prosecution, greenhouse gas emissions, strength of law enforcement, sustainability of community programs, and drought all had high levels of outdegree (≥ 3). The similarity between the final postworkshop hunting and consumption cognitive maps was relatively low (S2 = 0.148, Jaccard = 0.159), indicating that not many concepts were shared between them, and therefore that hunting and consumption require separate consideration.

Table 3. Comparison of metrics for group fuzzy cognitive maps generated from individual questionnaires (preworkshop) and following a participatory workshop, for bushmeat consumption and hunting in Malawi.

Metric	Consumption		Hunting	
	Preworkshop	Postworkshop	Preworkshop	Postworkshop
Total components	28	26	38	55
Total connections	50	53	75	100
Connections divided by components	1.78	2.04	1.97	1.81
Density	0.066	0.082	0.053	0.034
Average connections per component	1.786	2.04	1.974	1.83
Number of driver variables	12	9	17	20
Number of receiver variables	1	1	1	3
Number of ordinary variables	15	16	20	31
Complexity score	0.083	0.11	0.059	0.15

Table 3. Comparison of metrics for group fuzzy cognitive maps generated from individual questionnaires (preworkshop) and following a participatory workshop, for bushmeat consumption and hunting in Malawi.



Comparison between pre- and postworkshop group cognitive maps

The number of components in the consumption cognitive map decreased slightly between pre- and postworkshop, while the number of connections increased slightly, leading to an increase in map complexity (Table 3). For the hunting cognitive maps, both the number of components and the number of connections increased substantially after the workshop discussion, increasing the complexity of the map. However, the components included in the FC map for hunting between the preworkshop group map and postworkshop map showed a relatively high degree of similarity (S2 = 0.323, Jaccard = 0.460). Four concepts were not marked as

Table 4. Comparison of whether the outcome of the scenario analysis achieved the preferred state of the component (yes = 1, no = 0), for three hypothetical interventions. The identity of the cognitive map to which the intervention was added (either hunting or consumption) is indicated by italics. Blanks in the table indicate that variable was not affected under the intervention.

Component	Preferred state	Intervention scenario (*relevant cognitive map*)			
		Wildlife farming (*hunting*)	Wildlife farming (*consumption*)	Ecotourism (*hunting*)	Microenterprise (*hunting*)
Hunting	Decrease	1		1	1
Consumption	Decrease		1		
Poverty	Decrease	1	1	1	1
Education level	Increase	1	1	1	1
Human population	Decrease	1		1	1
Greenhouse gas emissions	Decrease	0		0	0
Pressure on land	Decrease	1		1	1
Food security	Increase		1		1
Community development status	Increase			1	1
Local demand for bushmeat	Decrease	1		1	1
Demand in centers of commerce	Decrease	1			
Alternative livelihoods	Increase	1	1	1	1
Wire snares	Decrease	1		1	1
Dependence on wildlife resources	Decrease	1	1	1	1
Risk associated with illegality	Increase	0	1	0	0
Habitat loss/fragmentation	Decrease	1		1	1
Animal populations	Increase	1			1
Strength of law enforcement	Increase			1	
Community participation in protected areas	Increase			1	
Household income	Increase		1		

similar because of a slight but important change in the wording of the concept during the workshop, e.g., “cultural factors” was split into those that decrease hunting and those that increase hunting. Similarity between the consumption preworkshop and postworkshop cognitive map was slightly higher (S2 =0.333, Jaccard = 0.5) than hunting, indicating not as much change occurred during the workshop as for hunting.

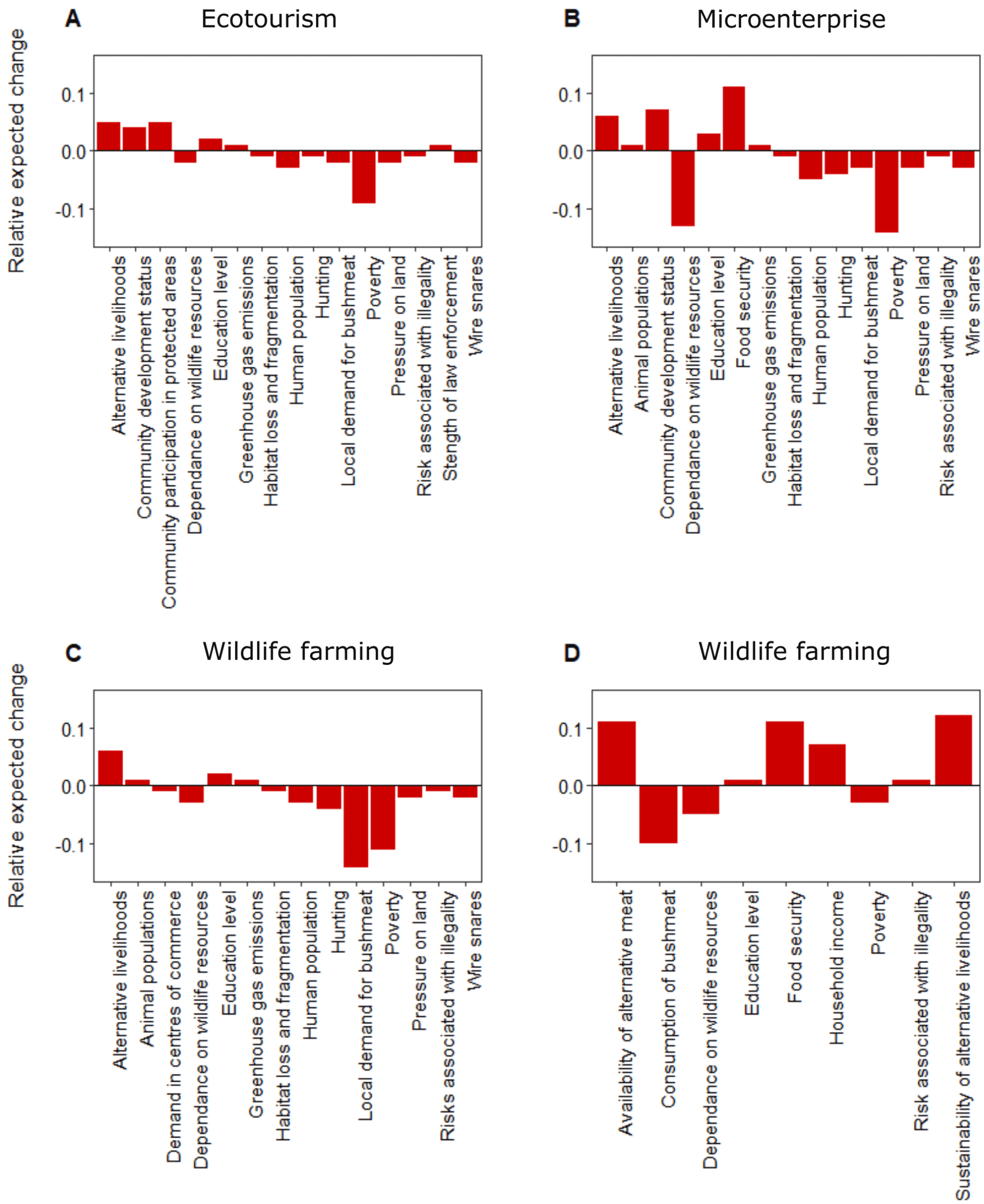
Analysis of interventions to reduce bushmeat hunting and consumption

Of the three interventions investigated by workshop participants (wildlife farming, microenterprises, and ecotourism), only wildlife farming was expected by participants to directly impact both hunting and consumption of bushmeat (Fig. 4). The other two interventions were expected to impact hunting only. Wildlife farming was expected to have the largest hypothetical reduction in bushmeat hunting, compared to the other two intervention scenarios. All interventions were expected to decrease poverty in communities. Animal populations in protected areas were expected to increase under the wildlife farming program and the microenterprise program. Ecotourism, however, was expected to result in more community participation in protected areas than the other two programs. Food security was expected to increase the most under the microenterprise program in the hunting model, and for wildlife farming in the consumption model. Microenterprise was expected to have the largest effect on decreasing dependence on natural resources. Local demand for bushmeat was expected to decrease the most under the wildlife farming intervention. Greenhouse gas emissions were expected to increase slightly under all scenarios, and habitat loss was expected to decrease. Financial or social risks that rule-breakers face from illegally hunting or consuming bushmeat, e.g., ability to pay fines or livelihood consequences of incarceration, was expected to decrease in all hunting scenarios.

Preferred state for each intervention scenario

The preferred state for all variables in both the hunting and consumption final cognitive maps was decided based on group discussions, by asking whether the component should ideally increase, decrease, or stay the same. In the hunting model, 45 components had a preferred state. The state of 15 of these components was expected to be affected under the ecotourism and microenterprise interventions, and 14 components for the wildlife farming intervention. This preferred state was met under the three program scenarios for most of these variables, the exceptions being greenhouse gas emissions and the risk to individuals associated with the illegality of hunting or consuming bushmeat, i.e., 86% of the components moved toward their preferred state under these interventions (Table 4). It was preferred that financial/social risks associated with the illegality of the action would increase, as higher risk was expected to deter people from committing these illegal activities. However, because these programs all were predicted to have positive effects on poverty and/or household incomes, people may be more able to deal with the risks of being caught, such as having increased ability to pay fines for committing an illegal activity. Emissions were preferred to decrease, but increasing wealth under these programs may result in increasing emissions. In the consumption model, 20 components had a preferred state, of which nine were expected to be affected by the wildlife farming intervention, and all of them moved toward their preferred state.

Fig. 4. Relative expected change to components in the bushmeat hunting fuzzy cognitive map, as a result of (a) an ecotourism program, (b) a microenterprise program, (c) a wildlife farming program, and the relative expected change to components in the bushmeat consumption fuzzy cognitive map as a result of (d) a wildlife farming program.



Assessment of the FCM process and key areas for research

Responses to a postworkshop questionnaire indicated that participants found the FCM process to be easy to understand and fair. All participants said it either "helped very much" or "mostly helped" to understand bushmeat hunting and consumption in Malawi. Regarding the strengths of FCM, participants said that it allowed "major causes of bushmeat hunting and consumption to be visualized," that it "highlights links that lead to poaching ... and gives more areas to consider while conducting [their] duties as a law enforcer," and that "it was easy to relate factors." The main problems were that it was sometimes difficult for experts to link factors to bushmeat hunting or consumption because "some links are not directly connected with either hunting or consumption."

Key areas identified as needing more research were: (a) the contribution of local vs nonlocals to hunting, i.e., are interventions based in local communities going to be effective if hunters are coming from long distances?; (b) urban markets in Malawi are known to exist, as is cross-border trade, but they are not well understood; and (c) the nexus between wealth and ability to hunt, as wealthier hunters can pay fines or bribes, access superior weaponry, and transport meat more easily. The relationships expressed in the assumptions that group members made when generating the map need to be further validated by research. For the purposes of the map, the group firstly assumed that hunters were coming from near protected areas; that there was demand for bushmeat from urban areas and that this factor had a medium-strength positive relationship with hunting, and there was a positive relationship between poverty and risks experienced by hunters, i.e., fines would have a larger impact on poorer individuals.

DISCUSSION

Participatory modeling is a practical, rapid, and inclusive way of modeling social-ecological systems. Here we unpack the complex nature of the bushmeat hunting and consumption systems in Malawi, and illustrate the need for separate consideration of these processes, as many drivers were not shared between maps. We also show the potential effects of three intervention scenarios used to reduce bushmeat hunting; these provide a pathway for future research to validate programs on the ground. Further, we provide an example of an extension of the classic FCM group process, by allowing individual views to be adequately and anonymously presented to the group, and then using this as a basis for a participatory group discussion.

Three concepts were shared as important across hunting and consumption: poverty, human population, and political will. Human population is a key driver of resource extraction across the world (Mackenzie and Hartter 2013, Ziegler et al. 2016). However, poverty has been found to have varied effects on hunting and consumption (Travers et al. 2019*a*), for example, Brashares et al. (2011) found that wealthier households consume more bushmeat in urban areas, while the opposite holds true for rural areas. Further, wealthier community members may be more able to afford superior weaponry or take on the financial risks of hunting than poorer members (Damania et al. 2005, Knapp 2012). Political will can affect support for enforcement, as well as support for initiatives like community-based natural resource management or alternative livelihood projects. Governments may be unwilling to enforce antipoaching laws aggressively in areas where communities are heavily reliant on natural resources, and protected areas themselves may often be seen as politically complex, given their history of displacement and changes to land use rights (West et al. 2006). Income initiatives and community-based natural resource management are often seen as politically desirable because they explicitly allow community rights to benefit from wildlife, and the enabling frameworks are well established in southern Africa, including in Malawi (Mauambeta and Kafakoma 2010). However, enforcement and community-based initiatives must work hand-in-hand and the value that wildlife holds must be adequately recognized at all levels. The opinions of the experts elicited for this study are similar to those elicited by Nyaki et al. (2014) and Gray et al. (2015), who found that low income (poverty) and human population growth were among the central variables in bushmeat hunting systems, and our cognitive maps shared many concepts with theirs including sufficient rainfall, law enforcement, bushmeat demand in markets, cultural preferences, and proximity to protected area. This indicates that our cognitive maps may be applicable to other locations and could be used by others as a starting point to begin other participatory processes on this issue.

The need for nuanced programs is also illustrated in that, of the three interventions that were chosen for investigation, only one (wildlife farming) is expected to tackle both hunting and consumption. The other interventions (microenterprise programs and community-based ecotourism) are expected mainly to affect hunting (e.g., Kaaya and Chapman 2017, Eshoo et al. 2018). However, it is likely that given the nature of supply and demand, reduced hunting may lead to reduced consumption or vice versa. Wildlife farming is a supply-side intervention, which aims to supply cheap substitutes of wildlife products under the assumption that, as farmed products enter the market, profit from poaching will decrease and therefore there will be less economic motivation to hunt (Bulte and Damania 2005). Wildlife farming may also act as a microenterprise scheme, allowing alternative incomes to hunters. Wildlife farming has been found to be financially sustainable on marginal land elsewhere in Africa, given clearly defined user rights and appropriate incentive policies (Taylor et al. 2020). Therefore, wildlife farming may influence the bushmeat issue in three ways: it can meet consumer demand legally and therefore decrease demand for illegal bushmeat, it can reduce the economic incentive for hunting, and it can provide alternative livelihood options for hunters.

There are however a number of criteria to be met before wildlife farming can influence illegal markets. First, consumers should show no preference for wild-caught versus farmed products. Second, the farmed product should be widely enough available for demand to be met. Third, demand should not increase because of the legal market. Fourth, farmed products should be cheaper than illegally hunted meat. Fifth, wild populations of animals should not be used to restock farms. And finally, illegal products should not be laundered into the legal market (Tensen 2016). There are indications that these criteria may not be met in the Malawian context. One of the components affecting consumption of bushmeat according to our stakeholder elicitation was that bushmeat is perceived to be healthier than livestock or farmed products, because of the perception that the communal free-ranging grazing system used in Malawi allows livestock to eat refuse. Therefore, consumers may prefer wild-caught meat to wildlife that is farmed under a similar system to livestock. Further, given the very large number of consumers in the system currently (van Velden et al. 2020*a*) it is unlikely that farmed meat can meet this demand. Positively however, the participants indicated that there are currently adequate frameworks within the Malawian government for wildlife farming to be implemented. Also, a pass-on system (where young animals are passed on to others in the program) could be implemented easily, because this system has been used for livestock donation programs. Finally, certifying the meat as legally farmed could utilize currently used technologies such as a text message system and live sales of small wild-farmed animals could circumvent problems with lack of refrigeration and packaging standards.

Wildlife farming may however struggle to compete with illegal hunting because hunting has few barriers to entry, while wildlife farming would require capital and legislative and institutional support (Coad et al. 2019). Although research has indicated that decreasing the price of protein alternatives does decrease illegal bushmeat consumption, there are indications that any increase in wealth would increase meat consumption overall, including increasing illegal bushmeat consumption (Rentsch and Damon 2013). Further, countries where wildlife farming is prevalent, e.g., South Africa or Namibia, do not necessarily have less bushmeat hunting, primarily because of a failure to devolve user-rights or ownership to local communities (Van Vliet et al. 2016). However, given wildlife farming's strong positive effects on key components such as poverty, food security, and animal populations in the cognitive maps for both hunting and consumption, this option does merit further exploration in the Malawian context and validation of the structural connections and predictions of these models.

Our methods give an example of a way in which an individual's knowledge can be incorporated into participatory modeling, in the form of cognitive maps (Kosko 1992). By eliciting individual cognitive maps prior to a workshop setting, and then combining them in a way that ensures all views are at least presented to the group at the start of the workshop, we allow individuals who may not feel completely comfortable sharing their views with a large group to be adequately represented in the process. By providing this anonymity to individuals, we can help overcome some of the known biases in group settings (Bang and Frith 2017), including the false consensus effect, groupthink, group polarization, and escalation of commitment (Jones and Roelofsma 2000). Many of these group biases can be overcome by increasing the diversity of the group because diverse people use different experiences and gather information in different ways, but also by allowing anonymous interaction, or by using explicit rule-based processes such as the Delphi technique where individual opinions are summarized and presented for group discussion over multiple rounds, allowing for revision (Bang and Frith 2017). Other examples of using a multistage elicitation process exist. In Chan et al. (2010), subgroups of participants separately drew up conceptual diagrams about water that were then combined and refined during a workshop with all groups present to create a Bayesian network. Henly-Shepard et al. (2015) used FCM for disaster planning over multiple stages of group discussions, with the cognitive maps being merged between stages. Gray et al. (2017) provides a demonstration of a multistage process using Mental Modeler software to investigate a range of land management practices using both individual and group stages. Our findings are similar to those of Henly-Shepard et al. (2015) and Gray et al. (2017), who found a change between stages in the density, complexity, and the ratio between the number of components to the number of connections for the maps, indicating that collaboration and knowledge-sharing occurred over the multistage process and potentially resulting in social learning (Reed et al. 2010). In our findings, hunting maps acquired many more connections and components during the workshop than consumption maps. This may be as a result of a number of hunting components being split during the workshop, indicating that this concept potentially requires discussion to bring out the nuances of the concept, which may not be the case for consumption. Density of components in this map decreased, potentially indicating refinement of understanding (Gray et al. 2017).

The benefits of group discussion are seen in the increase in complexity of the cognitive maps generated during the workshop, compared to the group map generated using individual ideas. Both maps showed an increase in the number of ordinary variables between stages, which indicates a more interconnected network, with most components having an influence on many other concepts in the system (Christen et al. 2015). This may represent greater systems thinking during the group stage process. However, there was still relatively high similarity in components between the pre- and postworkshop maps, indicating that individuals were able to come up with many of the important components, but the group was better able to link and refine those components following discussion. Group decision-making processes are well known to have multiple benefits. Pooling information can cause uncorrelated errors to cancel out and fairness and acceptance can be ensured via majority decisions (Bang and Frith 2017). The accuracy of systems maps can also be improved in this way and individual biases overcome (Özesmi and Özesmi 2004). Despite these benefits, care must be taken to recognize that even the most expert of knowledge may lead to wrong decisions. An expert may hold accurate judgements but they may not express them accurately, or conversely an expert may express judgments accurately, but they may be far from the truth. By using a structured procedure, encoding information to fit into a type of modeling framework, encouraging independent or anonymous assessments, and including uncertainty into these assessments, the benefits of experts and groups can be maximized (Martin et al. 2012). Here we used a number of these aspects, including anonymous assessments, the use of a structured elicitation process, and incorporating these assessments into a semiquantitative modeling framework. This work therefore combines the benefits of individual expert stakeholders and group settings, and aims to reduce the biases of each.

Limitations

Weaknesses of the FCM approach include the fact that they only represent one point in time and are unable to evolve as the community of experts changes, either in terms of new individuals or individuals changing their views (Özesmi and Özesmi 2004). This may become relevant as the conservation sector in Malawi grows, and as more alternative livelihood and enforcement campaigns become active. Further evaluation of the system may be required as the sector evolves. Second, we did not formally evaluate the questions used to elicit the FCM models from individuals, which would be useful to investigate how this question format holds up against others, e.g., physically arranging cards with components written on them. Third, there are a number of methodological advances to the FCM method that may make results more robust, for example, using Likert-type linguistic scales that are converted to triangular fuzzy numbers to average the weights on shared edges (Pérez-Teruel et al. 2015), or using advances in network theory such as network motifs to identify and describe differences between mental models of individuals (Levy et al. 2018).

Finally, there are inherent limitations to the knowledge of conservation experts. For such processes to arrive at meaningful change there is a need to include community and user-group perspectives. Although such perspectives were summarized during the workshop by presenting results of other studies (van Velden et al. 2020*a, b*) that had worked with relevant communities, community representatives themselves were not included in this FCM process. Therefore this process represents a first stage in a decision-making process, and further rounds of FCMs should directly include participants who either consume or hunt bushmeat in Malawi. This will ensure that their perspectives are adequately reflected, and also check the opinions of the experts presented here.

CONCLUSIONS

Our FCM approach of combining both individual assessments and group-based discussions allowed expert stakeholder knowledge to be elicited in a structured, equitable, and dynamic way. This approach also allowed detailed discussion and facilitated shared understanding of the complex systems of bushmeat hunting and consumption. This study represents the first step in a decision-making process, with the aim to improve the management of bushmeat hunting and consumption in Malawi. Further, these cognitive maps can be used as a way to highlight key uncertainties that can then guide future research, and therefore facilitates the linkages between quantitative data collection and semiqualitative participatory processes.

Specifically we recommend that some key outcomes be empirically tested, e.g., the effect of wildlife farming on socio-demographic and ecological variables such as poverty, animal populations, and food security. Small-scale pilot projects can be designed specifically to measure such outcomes and can then be compared to expected outcomes based on the FC maps generated. This will also allow an updating process, as more data and knowledge becomes available, ensuring that these cognitive maps are used as long-term planning tools in complex systems. Further, we recommend that the possibility of extending these semiquantitative maps to post hoc quantitative system dynamics models be explored (Elsawah et al. 2017) because this will allow stakeholders to increase the overall practical utility of cognitive maps and link them to quantitative measures such as animal population counts. Using this approach in monitoring frameworks may also be possible as a tool for adaptive management. In this paper we provide the first use of fuzzy cognitive mapping to explore both hunting and consumption of bushmeat, as well as the first use of this method to study bushmeat hunting outside of Tanzania. We illustrate how individual and group-based participatory process can be combined quickly and easily, and the utility of these processes by comparing the effects that three different bushmeat interventions may have on this complex system.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/11873

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Data Availability Statement:

The data that support the findings of this study are available on request from the corresponding author, JVV. The data are not publicly available because of the research's ethics permissions stating that the identity of participants would not be made publicly available, apart from their work organizations. This research received ethical clearance from Griffith University (GU Ref No: 2019/742), following the guidelines from the Australian National Statement on Ethical Conduct in Human Research.

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Appendix #1

The following is the questionnaire used to elicit information from individual experts, to then use to draw the FCM diagrams:

Questionnaire 1: Using expert information to understand Malawian bushmeat hunting

Explanation

We are aiming to use a technique called **"Fuzzy cognitive mapping"** to generate semi-quantitative maps of the bushmeat hunting and consumption systems. This method is a great way to visualise a complex system by understanding its key components, the relationships between those components and finally the strength of those relationships. We will then be able to use the system map to find out which management interventions work best to reduce hunting and consumption of bushmeat, and so this process will be able to provide participants with guidance for the future.

To do this we need your expertise. The way to generate such a map requires you to answer four simple questions about hunting and then about consumption. Based on you answers we will generate an individual system map which we can send back to you to look over. We will also combine everyone's maps and present this group cognitive map at the workshop for discussion.

The four questions are:

- What variables/components are important to consider when thinking about illegal bushmeat hunting? This can be anything from habitat, budgets, enforcement levels, characteristics of communities or anything else you can think of.
- What is the relationship of these variables to hunting? I.e. is it positive or negatively related?
- What is the strength of these relationships to hunting? Is it strong, medium or weakly related?
- What are the relationships between all the different variables you think affect illegal hunting (positive or negative) , and what is the strength of this relationship(strong, medium, weak)?

Example

We have drawn up a simple example using just two components to show you the process.

1. **Think about what the key variables are that determine how much bushmeat is hunted.**
   LIST THEM ALL

- Poverty score of households surrounding park
- Availability of snare wire

2. Think about what relationship these variables have to how much bushmeat is illegally hunted.
   Is it positive (where as one increases so does the other) or negative (where as one increases the other decreases)?

- As households get wealthier they may hunt less (answer= negative relationship)
- As availability of snare wire increases hunting will increase (answer= positive relationship)

3. Think about how strong the relationship is between the component and how much bushmeat is hunted.
   IS IT STRONG, MEDIUM OR WEAK?

- I suspect a strong relationship between poverty and hunting (answer=strong)
- I think there will be a medium relationship between snare wire and hunting as there are other factors which are more important probably (answer=medium)

4. **PUT THIS INFORMATION INTO A TABLE LIKE BELOW**

VARIABLE/COMPONENT AFFECTING HUNTING	Relationship to hunting + =positive (as one increases so does the other) -- =negative (as one increases the other decreases)	How strong is this relationship to hunting (Strong, medium, weak)
Poverty score	-	strong
Availability of snare wire	+	medium

5. Think about the relationship between the different components (before, we were thinking about the component and hunting, now we are thinking about each component relative to another).
   Is it positive (where as one increases so does the other) or negative (where as one decreases the other increases)?

   I think that as households get wealthier they will be able to buy more snaring wire (a positive relationship)

6. Think about how strong is the relationship between the components.
   IS IT STRONG, MEDIUM OR WEAK?

I think that the relationship between poverty score and availability of snare wire is strong because households would be able to purchase it if they have more money.

7. PUT THIS INFORMATION INTO A SECOND TABLE LIKE BELOW:

VARIABLE 1	VARIABLE 2	Relationship to each other (+ or -)	Strength of relationship (Strong, medium, weak)
Poverty score	Availability of snaring wire	+	strong

This information will be put together by the research team to generate a model like the one below based on your individual answers. This is an example model of an agricultural system, considering how factors such as climate change might impact the crop harvest.

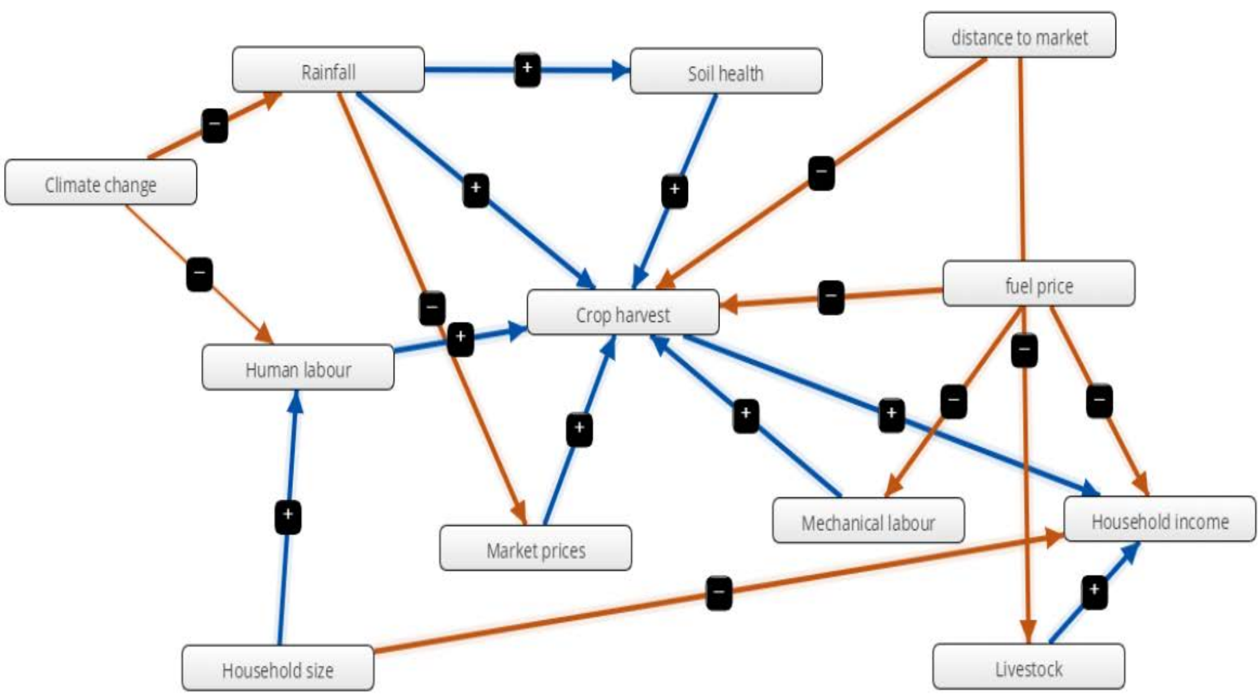

Figure 1: Example of a fuzzy cognitive map. The blocks indicate the important components of the model, the colour and sign of the arrows indicate whether the relationship between components is positive (+) or negative (-) and the thickness of the lines indicates the strength of the relationship.

<u>Now it's your turn</u>

1) Follow these steps, thinking about illegal **<u>HUNTING</u>** of bushmeat from protected areas in Malawi:

a) List all the components that might be important to hunting in column 1. Add as many components as you would like. These can be any factor which might influence illegal bushmeat hunting from a Malawian protected area.

b) Put down what each component's relationship might be to hunting (+ or -) in column 2. Is it positive (where as one increases so does the other) or negative (where as one decreases the other increases)?

c) Put down how strong you think that relationship is (strong, medium or weak) in column 3.

<u>Boundaries of thinking</u>

By ***hunting of bushmeat*** we mean any animal which is hunted specifically for the purpose of obtaining meat (either to sell for income or consume within the hunter's household), from a protected area in Malawi. We **do not** include hunting for body parts with the primary purpose of commercial export (e.g. ivory, rhino horn, pangolin scales), hunting for the pet trade or legal trophy hunting. We also ask you to think specifically about the factors influencing how much hunting occurs and **not** factors affecting how much consumption of bushmeat occurs. Consumption requires its own model (page 6)

The ***context*** we ask you to think about can be either at a national scale or specific to your experience at your protected area. If you think at a national scale be sure to keep in mind how this applies on the ground to Malawian protected areas.

The ***time scale*** we ask you to think about is the current state of affairs relating to bushmeat hunting. For example, even if legislative changes are planned or future programs are proposed, these do not currently affect the system so should not be included in your responses.

Column 1	*Column 2*	*Column 3*
Variable/component affecting hunting	**Relationship to hunting (+ or -)**	**Strength of the relationship (Strong, medium, weak)**

2) Now think about the relationship <u>BETWEEN</u> components:

a) Put one component in the "variable 1" column, and put a second component in the "variable 2" column.

b) Put down what each components relationship might be to each other (+ or -) in column 3

c) Put down how strong you think that relationship is (strong, medium or weak) to each other in column 4

d) Repeat for all the components which you think are connected. If you don't think there's a relationship between the components then don't put them in the table.

Column 1	*Column 2*	*Column 3*	*Column 4*
VARIABLE 1	**VARIABLE 2**	**Relationship to each other (+ or -)**	**Strength of the relationship (Strong, medium, weak)**

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3) Repeat these steps but now think just about illegal **CONSUMPTION** of bushmeat from Malawian protected areas. Note you can repeat components that you mentioned above but consider how they might specifically relate to consumption.

a) List all the components that might be important to consumption in column 1. Add as many components as you would like. These can be any factor which might influence illegal bushmeat consumption from a Malawian protected area.

b) Put down what each components relationship might be to consumption (+ or -) in column 2. Is it positive (where as one increases so does the other) or negative (where as one decreases the other increases)?

c) Put down how strong you think that relationship is (strong, medium or weak) in column 3.

Boundaries of thinking

By ***consumption of bushmeat*** we mean the practice of buying and consuming meat harvested from a wild animal, and in this case an animal caught inside a protected area in Malawi. We **do not** include meat from wild animals caught outside of protected areas.

The ***context*** we ask you to think about can be either at a national scale or specific to your experience at your protected area. If you think at a national scale be sure to keep in mind how this applies on the ground to Malawian protected areas.

The ***time scale*** we ask you to think about is the current state of affairs relating to bushmeat consumption. For example, even if legislative changes are planned or future programs are proposed, these do not currently affect the system so should not be included in your responses.

Column 1	*Column 2*	*Column 3*
Variable/component affecting consumption	**Relationship to consumption (+ or -)**	**Strength of the relationship (strong, medium or weak)**

4) Now think about the relationship <u>BETWEEN</u> components:

a) Put one component in the variable 1 column, and put the second component in the variable 2 column.

b) Put down what each components relationship might be to each other (+ or -) in column 3. Is it positive (where as one increases so does the other) or negative (where as one decreases the other increases)?

c) Put down how strong you think that relationship is (strong, medium or weak) to each other in column 4

d) Repeat for all the components which you think are connected. If you don't think there's a relationship between the components then don't put them in the table.

Column 1	*Column 2*	*Column 3*	*Column 4*
Variable/component 1	**Variable/component 2**	**Relationship to each other (+ or -)**	**Strength of relationship (Strong, medium, weak)**

5) Do you have any comments about anything in the survey which you think needs to be considered?

THANK YOU FOR YOUR PARTICIPATION!

We look forward to your attendance at the workshop

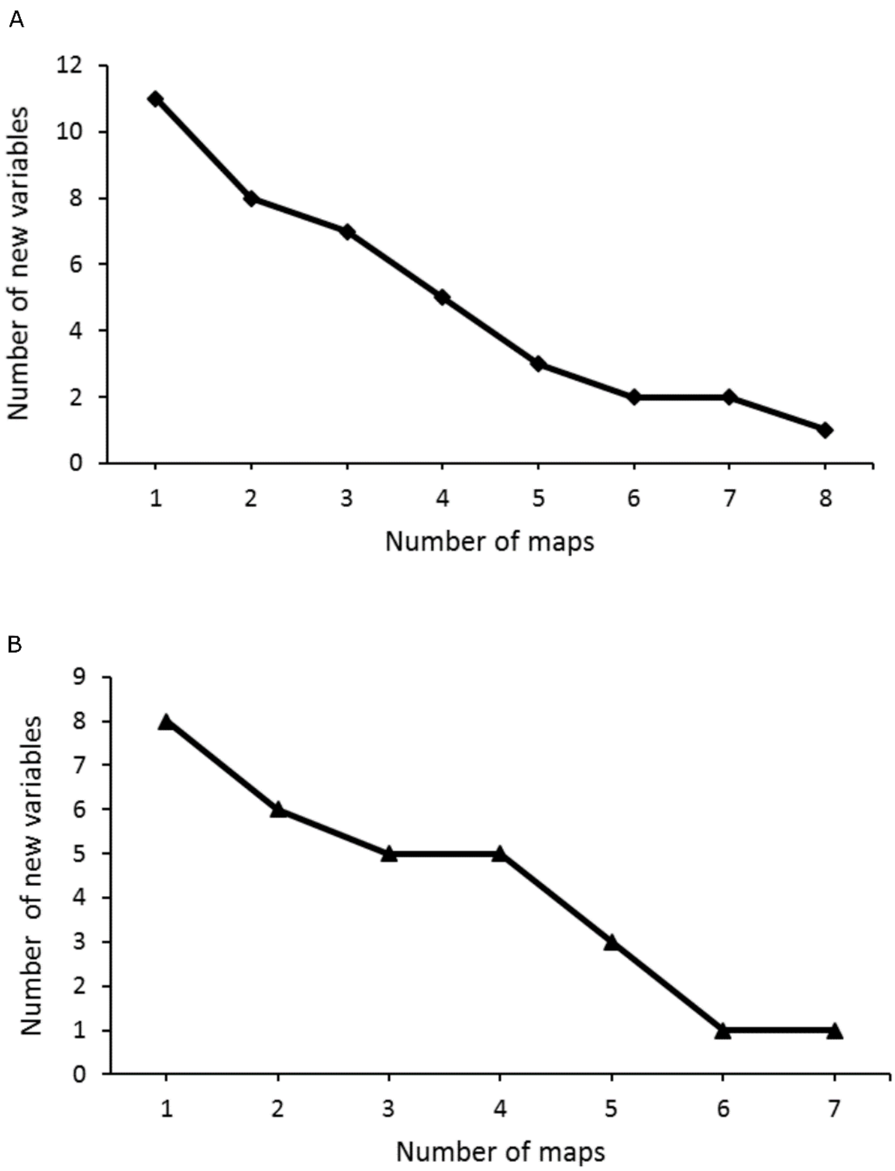

Figure A1.1: Accumulation of new variables for a) the bushmeat hunting and b) the bushmeat consumption Fuzzy cognitive maps, per individual map added.

Table A 1.1: The number of times that a component was listed by different individuals for hunting and consumption maps at the pre-workshop stage

Component	Hunting	Consumption
Poverty	6	6
Human population	3	2
Climate change	3	3
Cultural practices	3	3
Strength of law enforcement	2	N/A
Effective prosecution	2	3
Alternative livelihoods	2	2
Unemployment	N/A	2
Proximity to protected area	N/A	2
Availability of meat	N/A	2