Current Research in Ecological and Social Psychology 2 (2021) 100018

Contents lists available at ScienceDirect

Current Research in Ecological and Social Psychology

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

How knowledge acquisition shapes system understanding in small-scale fisheries

Sina A. Klein[a,*], Karlijn L van den Broek[a,b], Joseph Luomba[c], Horace O. Onyango[d], Bwambale Mbilingi[e], Joyce Akumu[e]

[a] Research Center for Environmental Economics, Heidelberg University, Bergheimer Straße 20, 69115 Heidelberg, Germany
[b] Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands
[c] Tanzania Fisheries Research Institute, Mwanza, Tanzania
[d] Kenya Marine and Fisheries Research Institute, Kisumu, Kenya
[e] National Fisheries Resources Research Institute, Jinja, Uganda

ARTICLE INFO

Keywords:
Socio-ecological system framework
Expert-expert differences
Environmental management
Stakeholders
Causal beliefs

ABSTRACT

Within socio-ecological systems, actors' interaction with the system may differ greatly, which is likely to result in differences in system understanding. The current work investigated this assumption in the Nile perch fishery at Lake Victoria. Specifically, a survey on Nile perch stock level and the drivers behind stock fluctuations was conducted with 225 participants with formally versus informally acquired knowledge across Kenya, Tanzania, and Uganda. Whereas most participants agreed that the stock has declined, several differences in system understanding were found between types of knowledge acquisition. Specifically, participants with informally acquired knowledge focused on examples of fewer drivers related to tangible human activities (e.g., the use of illegal fishing gear), whilst participants with formally acquired knowledge used more abstract and a larger variety of drivers related to the presence of humans (e.g., overpopulation). These findings confirm that the type of knowledge acquisition affects system understanding in small-scale fisheries and highlights the importance of assessing system understanding of various actors for successful resource management.

1. Introduction

The threat of climate change, the dramatic loss of biodiversity, and increasingly limited resources are just some examples of great challenges humanity is currently facing. To tackle these issues, it is important to understand the larger system within which these challenges exist. Broadly speaking, environmental challenges occur at the interface of human behavior and the natural environment. That is, both the origin and the potential solution of environmental problems are grounded in human behavior. For instance, scientists agree that human activities are the main driver behind global warming (IPCC, 2014) and hence, strategies for slowing climate change down focus on changes in human behavior such as specified in the Paris Agreement (UNFCCC, 2015).

Socio-ecological system approaches explicitly assume that humans can act individually and collectively to affect and manage a system (McGinnis and Ostrom, 2014). Thus, socio-ecological system approaches have often been used to investigate environmental challenges such as the management of fisheries (Guevara et al., 2016; Partelow, 2015; Rahimi et al., 2016) or forestry (Fleischman et al., 2010; Oberlack et al., 2015; Partelow, 2018). In the current work, we investigate actors' system understanding of the Nile perch fisheries and Nile perch stock fluctuations at Lake Victoria in East Africa, a socio-ecological system that is crucial for the livelihoods of millions of people (Mkumbo and Marshall, 2015. Specifically, we investigate how actors with formally versus informally acquired knowledge and actors from the three riparian countries differ in their understanding of the fluctuations of the stock and the drivers behind these fluctuations. Thereby, we aim to gain insights into both general effects of knowledge acquisition on socio-ecological systems and the specific environmental challenges at Lake Victoria.

1.1. Socio-ecological systems: The importance of actors' system understanding

The actors of a resource system constitute a key subsystem in a socio-ecological system (Ostrom, 2007, 2009) since they can influence all other parts of the system through their decisions and the resulting behavior, either directly or indirectly (Elsewah et al., 2015). Decisions and behavior, in turn, are determined by the actors' theories and beliefs about both the world and the effect of their actions (Ajzen, 1985; Fishbein & Ajzen, 1975). For instance, individuals tend to show more

* Corresponding author.
E-mail address: sina.klein@awi.uni-heidelberg.de (S.A. Klein).

https://doi.org/10.1016/j.cresp.2021.100018
Received 22 April 2021; Received in revised form 7 August 2021; Accepted 30 August 2021

support for those policies on climate change mitigation that target factors which the individual perceives to be relevant for climate change (Bostrom et al., 2012). Similarly, farmers who indicated that biological control factors play a role in farming also showed more sustainable conservation practices than farmers who did not indicate biological control factors as important (Bardenhagen et al., 2020). As a consequence, investigating actors' system understanding is of utmost importance to understand how actors decide, behave, and eventually affect the system itself. Without this understanding, sustainable management of a resource will be difficult if not impossible.

Importantly, different types of actors in a socio-ecological system can differ in their system understanding (Argent et al., 2016; Hovardas & Poirazidis, 2007), which likely is due to disparate learning processes. Specifically, knowledge about a socio-ecological system can be gained formally or informally. These two types of learning differ in four key attributes, namely process, setting, purpose, and content (Malcolm et al., 2003). Formal knowledge acquisition is structured by a teacher or a trainer (process), takes place in a university or school context (setting) with the goal of learning (purpose), and focuses on the acquisition of expert knowledge of a specific field (content; Malcolm et al., 2003). Informal knowledge, in turn, is more incidental and happens during everyday activities, takes place at the workplace or the local community without a specific curriculum or learning objectives but with the purpose to be productive in whatever one is doing, and therefore focuses on understanding everyday practice (Malcolm et al., 2003). Others have described formal knowledge as being acquired through a formal set of rules such as the scientific method, and informal knowledge as being acquired through an unstructured process (Raymond et al., 2010; Reed, 2008), reflecting and summarizing the key attributes described above. The key attributes of formal and informal knowledge acquisition processes will have implications for the way individuals think and organize their worldview. Specifically, individuals with formally acquired knowledge might learn to apply their global, overarching set of rules allowing them to have a very nuanced and broad view of a system. Furthermore, their knowledge is likely to be explicit as these individuals acquired scientific knowledge that has been written down and published and thus has been made explicit before (Raymond et al., 2010). Individuals with informally acquired knowledge, in turn, might focus on key variables of a system that they encounter on a daily basis, and their knowledge is likely to be more implicit or even tacit. However, in general, definitions of knowledge are overlapping and boundaries are fluid, meaning that informal knowledge can also be explicit and – vice versa – formal knowledge can be implicit (Raymond et al., 2010).

Indeed, research showed that disparate types of knowledge acquisition within a socio-ecological system can lead to different kinds of system understanding[1]. One study, for instance, compared biologists (i.e., individuals with formally acquired knowledge) and long-term hobbyists (i.e., individuals with informally acquired knowledge) with regard to their amount and type of knowledge about these systems (Hmelo-Silver et al., 2007). Whereas both groups showed comparable amounts of knowledge about aquarium systems, there were qualitative differences in their knowledge. Specifically, biologists focused more on global relationships and scientific explanations such as the components of a system, whereas hobby aquarists focused more on local relationships and gave more functional concerns and specific examples. A similar study comparing scientists and local land managers of a national park also showed that scientists with formally acquired knowledge used more generic knowledge with a global perspective, whereas local land managers with informally acquired knowledge showed more practical knowledge (Avriel-Avni and Dick, 2019). Similar expert-expert differences in types of knowledge have also been demonstrated for other complex systems such as forestry (Lynch et al., 2000), water management (Hundemer and Monroe, 2020; Mehryar et al., 2017), vineyards (Brulé and Labrell, 2014), or genetics Smith (1990), and show that there are "multiple paths to expertise" (Hmelo-Silver et al., 2007).

The differences in actors‘ knowledge acquisition and resulting system understanding highlight the importance of a broad assessment of all actor types' to gain a comprehensive system understanding, as the steadily growing literature on stakeholder engagement and participation underlines (Djenontin & Meadow, 2018; Reed, 2008; Tiller et al., 2016; van den Broek, 2019; van den Broek et al., 2020). Specifically, for a successful integration of knowledge – and ultimately successful system management – it is vital to not only identify key groups of stakeholders whose system understanding is critical, but also to find specific experts within these groups that have the relevant knowledge (Patalas-Maliszewska and Krebs, 2016; Vitari, 2011). Only when all key actors' system understanding is assessed correctly and considered in decision making, policies can target the most important factors which increases the chances of successful management of resources (Elsewah et al., 2015). In the current work, we test whether the effects of formal and informal knowledge acquisition also apply to the specific case of small-scale fisheries at Lake Victoria and therefore, whether the assessment of a wide range of actors can contribute to the management of these fisheries. With this, we aim to extend the literature on the effects of knowledge acquisition on decision-making and behavior by extending them to a new setting. Furthermore, we aim to contribute to literature on the management of small-scale fisheries by applying a psychological perspective based on learning.

1.2. Small-scale fisheries: The case of Lake Victoria

Small-scale fisheries such as at Lake Victoria (Downing et al., 2014) are a prime example of complex and dynamic socio-ecological systems facing environmental challenges. With a surface area of 68,800 km^2, Lake Victoria is Africa´s largest lake and is shared by Tanzania (51%), Uganda (43%), and Kenya (6%). In the 1950s, the Nile perch (*Lates niloticus*) was introduced in Lake Victoria, which resulted in the decline and extinction of more than 500 endemic fish species (Mkumbo and Marshall, 2015). However, the introduction of the Nile perch also led to an extremely valuable export-orientated fishery that generates significant revenue and earnings for the three riparian countries and their populations (Josupeit, 2006; van der Knaap, 2006; van der Knaap and Ligtvoet, 2010). Currently, Lake Victoria provides the largest fresh water small-scale fishery in the world (M. Njiru et al., 2008).

As many small-scale fisheries, Lake Victoria faces a multitude of socio-ecological, economic, and institutional challenges ranging from destructive fishing gears and methods, illegal, unreported, and unregulated fishing, open access, overfishing, weak management regimes and complex co-management structures, to pollution and climate change (FAO/RAP/FIPL, 2004; Luomba et al., 2016; J. Njiru et al., 2018; Song et al., 2020; van den Broek, 2019). Most of these environmental challenges have anthropogenic origins and heavily affect the entire fisheries ecosystem. Specifically, growing populations, high levels of unemployment, and few alternative livelihood opportunities in the region contribute to the attraction of the fisheries for employment, thereby exacerbating unsustainable levels of fishing. Illegal fishing gears such as small-meshed nets and beach/boat seines that target small, juvenile fish may negatively impact total stock levels (Mkumbo and Marshall, 2015). Furthermore, urbanization, industrialization, and intensive agricultural practices lead to pollution of fish habitats. These factors, coupled with a lack of joint regulations and enforcement strategies across riparian

[1] Importantly, previous literature often refers to "knowledge" without explicit definition of this term or related constructs such as beliefs (Southerland et al., 2015). If constructs are defined, definitions vary substantially: Some scholars argue that knowledge is objective and factual and beliefs are not, whereas others argue that knowledge also entails beliefs (Ennis, 1994; Joa et al., 2018; Reo, 2011) and that these two constructs are hard to separate empirically (Southerland et al., 2015). Given this interconnectedness of the constructs and our focus on complex systems, we will use the term "system understanding" for the conglomerate of knowledge, facts, and beliefs, but will refer to "knowledge" if this specific term was used in the cited literature.

countries and environmental degradation resulting from climate change, pose a complex environmental challenge at Lake Victoria (J. Njiru et al., 2018).

Considering the importance of the Nile perch fishery for the livelihood in the riparian countries and their populations (Mkumbo and Marshall, 2015), assessment and monitoring of the fish stock and the prevention of a possible tipping point is of utmost importance. Hydro-acoustic surveys from 1999 until 2011 showed an overall decline in Nile perch biomass (Taabu-Munyaho et al., 2014), whereas the most recent hydro-acoustic survey suggests an increase in Nile perch biomass from 2018 to 2019, though limited to Tanzania and Uganda (LVFO, 2019). Importantly, research is inconclusive regarding the factors influencing the Nile perch stock (Taabu-Munyaho et al., 2014), so called *drivers*. Some argue that the main drivers of the fluctuating Nile perch stock are fishing effort (Mkumbo and Marshall, 2015; Mkuna and Baiyegunhi, 2019; M. Njiru et al., 2008) and related factors such as illegal fishing gear and methods (Luomba et al., 2016), while others argue that eutrophication levels are the key issue at the lake (Kolding et al., 2008).

This lack of scientific consensus regarding the drivers of the Nile perch stock makes effective policy-making difficult, as it remains unclear what factors should be prioritized to manage the stability of the Nile perch stock. Furthermore, other, non-scientific system actors' such as fishers might perceive the Nile perch stock and its drivers differently, thus hindering acceptance of and adherence to polices targeting drivers that they perceive as irrelevant. Additionally, given the extensive surface area of the lake and the different policies and enforcement strategies in the riparian countries, actors in different areas might have entirely different experiences and will thus differ in their understanding about the Nile perch stock and its drivers as well.

1.3. Aims of the present research

The main aim of the current work was to investigate similarities and differences in key actors' perceptions of Nile perch stock level and system understanding regarding the drivers of the Nile perch stock at Lake Victoria. Key actors represented groups with formal and informal knowledge acquisition from the three riparian countries. Different aspects of system understanding were compared across these types of actors: the type of perceived drivers, the number of perceived drivers, and level of abstraction of the perceived drivers. Differences in types of perceived drivers reflect the specific focus of knowledge, whereas differences in the number and level of abstraction of perceived drivers may reflect differences in terms of complexity thinking in relation to the socio-ecological system. Thereby, this work aims to provide insights into the effect of knowledge acquisition and regional residence on (i) actors' understanding of complex socio-ecological systems in general and (ii) the environmental challenges of the Nile perch fishery at Lake Victoria in specific.

2. Methods

2.1. Sample

To assess individuals from both types of knowledge acquisition, we relied on different professions. The main profession groups in the Lake Victoria fisheries are crew members (the individuals going out on the boat to fish), boat owners (normally stay at the shore), workers in the fishing industry (fish traders/processors, individuals loading the trucks with fish), gear makers/repairers, fish agents, and gear sellers (URT, 2016). For the group with informally acquired knowledge, we assessed those who tend to have direct system interactions at the lake without the explicit goal of learning but working productively, that is, crew members, boat owners, and workers in the fishing industry. For the group with formally acquired knowledge, we assessed those who tend to have indirect system interactions through structured learning processes with the purpose of learning about the system, that is, policy-makers and researchers. Furthermore, we assessed these two knowledge acquisition groups in all three riparian countries to assess potential regional differences. Crew members, boat owners, and fishing industry staff were recruited directly at the landing site. At the landing site, crew members return to the shore and deliver their catch to the boat owner, who will sell it to fish agents. The fish agents will load the fish into trucks, supplying fish to processing companies. Recruitment at the landing site was done with the help of landing site leaders including the Local Council, Beach Management Unit leaders (BMUs), and fisheries officials. The landing sites included Kiyindi and Masese in Uganda, Bukoma and Marenga in Kenya, and Igombe and Mihama in Tanzania. Researchers and policy-makers were recruited at a regional project meeting, at a large international conference on African Great Lakes, and at local fisheries research institutions of the respective countries. Approval for conducting the survey was given by the Lake Victoria Fisheries Organization and the national research institutes in the riparian countries.

In total, $N = 225$ respondents participated in the survey. Participants were aged between 18 and 67 years ($M = 38.61$, $SD = 10.92$) and the majority was male (85.3%). Furthermore, 41.9% of participants were from Tanzania, 30.6% from Uganda, and 26.6% from Kenya. A total of 45.3% of participants were fishing crew members, 19.1% were boat owners, 16.4% were researchers, 11.1% worked in the fishing industry, and 7.1% were policy-makers, thus 75.5% of participants were classified into the group with informally acquired knowledge (crew members, boat owners, workers of the fishing industry) and 23.5% into the group with formally acquired knowledge (researchers and policy-makers).

2.2. Measures

2.2.1. Perception of past/future Nile perch stock

To check whether participants actually perceived changes in the stock level, two items assessed participants' perception of the past Nile perch stock level and their prediction of the future Nile perch stock level in comparison to current stock level. Participants were asked to think about the past and indicate whether there was "a lot less" (coded as 1), "less", "the same", "more", or "a lot more" (coded as 5) Nile perch than today. Afterwards, participants were asked to think about the future and indicate on the same scale whether there will be more or less Nile perch in the future than today if all circumstances stayed exactly the way they are.[2]

2.2.2. Drivers of the Nile perch stock

To assess the drivers of the Nile perch stock, participants listed all the factors influencing the Nile perch stock they could think of. Each driver was written on a separate sticky note. After participants could not think of any more drivers, they were given a list of pre-specified driver categories based on previous research (van den Broek, 2019). Then, participants placed their sticky notes with the drivers under the category they thought matched the specific driver best. The pre-specified driver categories were as follows: Destructive fishing gear, pollution of the lake, destructive fishing methods, corruption, overpopulation, regulations, monitoring, open access, poverty, demand for Nile perch, fishing capacity, water level, awareness of sustainable fishing practices, and climate change. Participants were provided with these categories to guide

[2] These questions were only included after the first participants (almost exclusively researchers and policy-makers) had difficulties using a graph drawing exercise designed to assess changes in the Nile perch stock. Therefore, the graph drawing task was removed and these two questions were added, leading to missing values on these two items for the first participants. Furthermore, following these two items, the survey also included items assessing specific changes of the Nile perch stock (see materials online). However, the reliability was not satisfactory (α =.40), which was likely due to very specific wording that is not translatable to some of the local languages. Therefore, these items were not analyzed further.

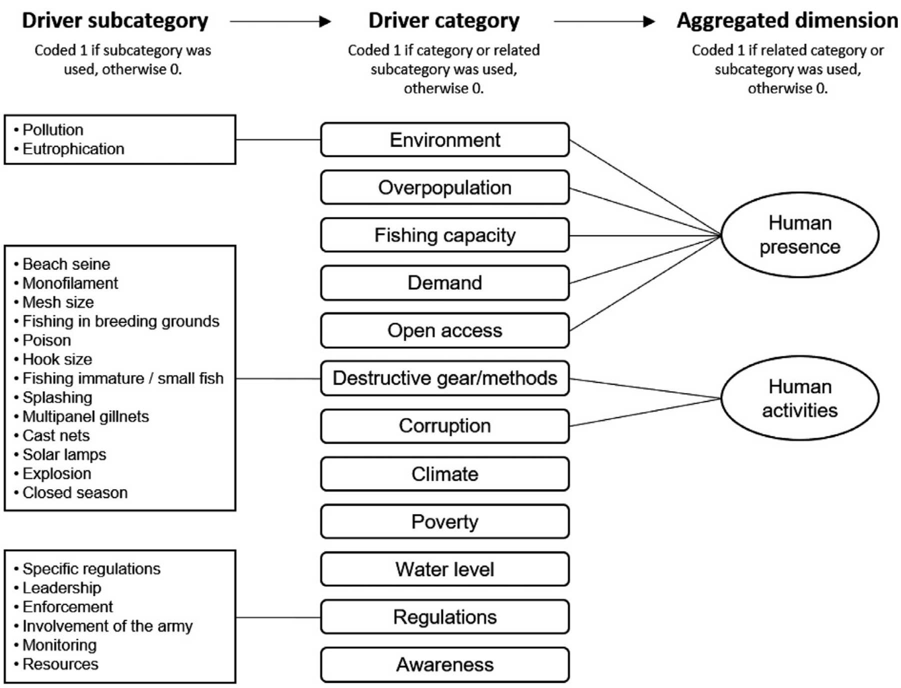

Fig. 1. Overview of the final driver subcategories, categories and the relation of categories to aggregated dimensions from a multiple correspondence analysis.

the clustering of the listed drivers by reducing the number of semantic categories. Participants could also add new categories in case one or several of their listed drivers did not fit the existing categories.

The drivers provided by the participants were coded in the following way (see also the coding sheet on the OSF): We (i) coded whether drivers were classified consistently under a matching pre-specified category, (ii) coded whether a pre-specified driver category was used at all, that is, even when a belonging driver was placed under another category, (iii) merged driver categories when their respective drivers were consistently classified in several driver categories, and (iv) created subcategories when specific driver categories included various examples. The following sections will provide more details on this process, Fig. 1 provides an overview of the final coding and (sub-)categories.

Specifically, we first created one variable for each pre-specified driver category with the values 0 and 1 indicating whether the pre-specified driver category was used (1), that is, whether a fitting driver was placed in it, or not (0). However, during coding it became apparent that participants did not consistently classify their drivers into matching driver categories. For instance, one participant listed the driver “pollution” but instead of classifying it under the category “pollution”, the participant sorted it to the category “water level”. Furthermore, the classifications indicated that some participants might have used causal relationships when sorting the drivers. For instance, one participant listed the driver “pollution increase” in the driver category “overpopulation”, perhaps indicating that an increase in pollution is a result of overpopulation. As it was impossible to judge whether the participants did not read the categories carefully, whether the task was too difficult, or whether they indicated causal relationships between the mentioned driver and the category, we adapted the coding approach: We created an additional variable for each pre-specified driver category with the values 1 and 0 indicating whether the pre-specified driver category was mentioned anywhere at all (1), either with the category per se or a specific example, or not (0). To illustrate, the variable for the pre-specified driver category “Use of destructive gear” was coded as 1 if a participant placed a sticky note saying either “destructive gear” or “small mesh size” under *any* pre-specified driver category. We used this coding for all following analyses that refer to whether driver categories were mentioned or not. Furthermore, we merged pre-specified driver categories when participants used them interchangeably. This applied to the driver categories “destructive fishing gear” and “destructive fishing methods”, which were merged into “destructive fishing gear/methods”, as well as the pre-specified categories “monitoring” and “regulations” which were merged into “regulations”. Lastly, the category “pollution” was expanded to “environment” as many participants mentioned environmental degradation and changes in the pollution category, however, without explicitly mentioning pollution as the cause. Lastly, we created subcategories for the driver categories that were mentioned most often and had a variety of examples. This was done to get a more fine-grained insight into the meaning and uses of these driver categories and to examine potential differences in the use of driver categories or specific examples across knowledge acquisition groups. For instance, for the driver category “destructive gear/methods”, we created subcategories for specific examples of destructive fishing gear and methods, such as “small mesh size”, “small hooks”, or “poison”.

To sum up, the coding process resulted in a total of 12 driver categories, with 13 subcategories for “destructive fishing gear/methods”, 2 subcategories for the category “environment”, and 6 subcategories for the category “regulations” (see Fig. 1). Each participant had either a value of 0 or 1 for each of the 12 categories and the 13 subcategories, indicating whether the participant mentioned this driver (sub-)category anywhere throughout the questionnaire or not.

2.3. Procedure

Questionnaires were translated to Luganda in Uganda, Kiswahili in Kenya and Tanzania, and Luo in Kenya by at least two research assistants per language. To assure high quality translations, the research assistants were native speakers in the to-be-translated language, fluent in English, and familiar with the research topic. To standardize the data collection process, research assistants were thoroughly trained by the authors to conduct the survey in a consistent and non-suggestive manner. This included practices such as following the script with the exact formulation of the question and not suggesting answers to the participant.

Research assistants first explained to participants that the survey was about their views on the Nile perch fishery and sought participants’ informed consent, after which participants were asked about their demographic information (age, gender, nationality, profession, country of work place). Subsequently, participants worked on the two questions assessing past and future stock and the task assessing the drivers of the Nile perch stock. Depending on the level of literacy of the participant, participants worked on the questionnaire independently (researchers, policy-makers) or were guided through the survey by the research assistant (crew members, boat owners, workers of the fishing industry) to ensure the questions were interpreted correctly.

Interviews with crew members, boat owners, and fishing industry staff were conducted directly at the landing sites where community leaders helped with recruitment. Participants were seated with a research assistant in a private room (where possible) and guided through the questionnaire. Research assistants read out both the questions and the reply categories and marked the respective answers on the questionnaire. For the drivers, research assistants noted down the stated drivers on sticky notes for the participant and read out all pre-specified categories. Once the participant had classified a driver under a category, the research assistant moved on to the next driver, reading out all categories again for the participant if necessary and asking the participant to choose a category for the respective driver. This was repeated until all drivers had been classified by the participant. Researchers and policy-makers worked on the questionnaire independently and were told to ask the present researcher for assistance where needed. After completion, participants were thanked and, in case of a data collection at a landing site, compensated according to local standards (5000 TZS in Tanzania and 200 KSH in Kenya, both worth approx. 2 USD; and laundry soap worth approx. 1 USD in Uganda). The researchers were available after data collection in case participants had any questions or concerns. All materials, the complete data set, a coding sheet, and the code for analysis can be found online (https://osf.io/mc945/?view_only=63aea8f6f8b74554bf17fec32d1d8f02).

3. Results

3.1. Perception of past/future Nile perch stock

Participants indicated that they believed that the Nile perch stock was higher in the past than present (M = 4.29, SD = 0.99) and tended to predict similar stock levels in the future compared to the present (M = 2.80, SD = 1.38). Table 1 summarizes these assessments across countries, professions, and knowledge acquisition groups. Kruskal Wallis tests showed that, across countries, there was no significant difference in the assessment of the past stock in comparison to today ($\chi^2(df=2)$ = 3.05, p = .218), but there was a significant difference in the prediction of future stock ($\chi^2(df=2)$ = 28.99, p < .001). A post-hoc Dunn test with Bonferroni adjustment revealed that Kenyans assumed a heavier decline of Nile perch in the future than both Ugandans (p < .001, p_{adj} < .001) and Tanzanians (p < .001, p_{adj} < .001), whereas there was no significant difference between the latter two countries (p = .505, p_{adj} = 1.00). Across knowledge acquisition groups, Mann-Whitney U tests showed significant differences for both past (W = 2653.5, p = .035) and future stock levels (W = 2422.5, p = 0.030). Specifically, the group with informally acquired knowledge perceived a stronger decline from past to present stock levels but predicted a weaker decline in future stock than the group with formally acquired knowledge.

3.2. Drivers of the Nile perch stock

To analyze the drivers mentioned by participants, we assessed (i) how frequently each specific driver category was mentioned across all participants to investigate the types of mentioned drivers, (ii) how many driver categories and subcategories were mentioned by the participants on average, (iii) whether driver categories could be aggregated into higher-order dimensions to investigate the level of abstraction, and (iv) whether there were differences across countries and knowledge acquisition groups for any of these analyses.

Table 1
Means (standard deviation in parentheses) of perception of the past Nile perch stock, prediction about the future Nile perch stock, and number of mentioned driver categories and subcategories across countries, professions, and knowledge acquisition groups (K=Kenya, T=Tanzania, U=Uganda).

	Overall	K	T	U	Crew members	Boat owners	Industry workers	Policy makers	Re-searchers	Informal knowledge	Formal knowledge
Past	4.29 (0.99)	4.54 (0.70)	4.23 (1.07)	4.23 (1.03)	4.31 (1.04)	4.31 (0.95)	4.56 (0.58)	3.40 (1.07)	4.30 (0.99)	4.35 (0.96)	4.05 (1.08)
Future	2.80 (1.38)	1.90 (0.96)	3.04 (1.40)	3.19 (1.37)	2.80 (1.40)	3.12 (1.40)	3.00 (1.35)	2.90 (1.52)	2.15 (1.06)	2.91 (1.39)	2.35 (1.23)
Number of driver categories	2.73 (1.64)	3.00 (1.65)	2.56 (1.54)	2.71 (1.80)	2.08 (1.16)	2.58 (1.14)	2.24 (1.59)	4.13 (1.20)	4.47 (1.99)	2.23 (1.24)	4.37 (1.78)
Number of subcategories	2.44 (2.02)	1.64 (2.12)	3.10 (1.87)	2.37 (1.92)	2.60 (1.92)	3.07 (1.96)	1.52 (1.36)	2.13 (1.63)	2.08 (2.70)	2.56 (1.91)	2.10 (2.40)

Table 2
Proportions of mentioned driver categories, subcategories (indented), and aggregated driver dimensions aross countries, professions, and knowledge acquisition groups (K=Kenya, T=Tanzania, U=Uganda).

	All	K	T	U	Crew members	Boat owners	Industry workers	Policy makers	Researchers	Informal knowledge	Formal knowledge
Destructive gear/methods	.88	.73	.98	.90	.94	.95	.84	.94	.61	.93	.71
Beach seine	.27	.08	.44	.19	.39	.28	.04	.06	.14	.31	.12
Monofilament	.27	.05	.44	.24	.36	.37	.08	0	.11	.32	.08
Mesh size	.25	.19	.28	.29	.27	.44	.16	.19	.06	.30	.10
Fishing in breeding grounds	.19	.15	.27	.13	.21	.28	.12	.13	.14	.21	.13
Poison	.18	.02	.37	.09	.23	.30	.08	.13	.03	.22	.06
Hook size	.09	.07	.06	.16	.12	.09	.12	0	.06	.11	.04
Fishing immature/small fish	.08	.08	.01	.18	.08	.07	.08	.13	.08	.08	.10
Splashing	.07	0	.15	.03	.12	.09	0	0	0	.09	0
Multipanel gillnets	.05	0	.12	0	.08	.05	.04	0	0	.06	0
Cast nets	.03	0	.01	.09	.04	.07	0	0	0	.04	0
Solar lamps	.02	0	0	.06	.04	0	0	0	0	.02	0
Explosion	.02	0	.04	.01	.03	.05	0	0	0	.03	0
Closed season	.02	.02	.03	.01	.03	.02	0	0	.03	.02	.02
Regulations	.46	.42	.47	.47	.31	.53	.56	.75	.53	.41	.60
Specific regulations	.24	.17	.32	.16	.18	.28	.20	.50	.22	.21	.31
Leadership	.18	.20	.17	.19	.09	.26	.16	.38	.28	.14	.31
Enforcement	.11	.14	.10	.10	.04	.12	.08	.19	.25	.06	.23
Involvement of the army	.08	.08	0	.21	.10	.07	.12	.07	.06	.09	.06
Monitoring	.07	.03	.11	.06	.07	.07	.08	.06	.08	.07	.08
Resources	.01	.03	0	0	0	0	0	0	.06	0	.04
Fishing capacity	.36	.61	.20	.34	.21	.30	.12	.69	.86	.22	.81
Environment	.28	.39	.24	.19	.14	.19	.16	.38	.83	.15	.69
Pollution	.19	.25	.16	.16	.14	.16	.16	.31	.33	.15	.33
Eutrophication	.03	.07	.01	0	0	0	0	0	.17	0	.12
Climate	.17	.17	.13	.19	.14	.09	.04	.25	.42	.11	.37
Demand	.15	.22	.10	.15	.07	.02	.08	.56	.42	.06	.46
Awareness	.10	.08	.16	.04	.05	.16	.04	.25	.14	.08	.17
Corruption	.09	.08	.05	.16	.06	.12	.20	0	.14	.09	.10
Overpopulation	.09	.14	.09	.06	.07	.05	.08	.13	.17	.06	.15
Open access	.07	.08	.03	.12	.02	.14	0	.06	.19	.05	.15
Poverty	.04	0	.06	.06	.02	.02	.08	.13	.08	.03	.10
Water level	.04	.07	.04	.03	.06	0	.04	0	.08	.04	.06
Dimension 1 (Human presence)	.52	.75	.41	.44	.35	.49	.28	1	.97	.38	.98
Dimension 2 (Human activities)	.88	.75	.98	.90	.94	.95	.84	.94	.64	.93	.73

3.2.1. *Types of mentioned driver categories*

The first column of Table 2 shows the proportion of participants who mentioned each of the driver categories and the subcategories. The most frequently listed driver categories across the total sample were “destructive gear/methods”, “regulations”, and “fishing capacity”. The least frequently mentioned driver categories were “water level”, “poverty”, and “open access”. Table 2 shows the proportion of mentioned driver categories across countries, professions, and knowledge acquisition groups. Interestingly, across countries as well as across professions, “destructive gear/methods” was mentioned most often with the only exception being researchers who mentioned “fishing capacity” and “environment” more often than “destructive gear/methods”.

Comparing the three countries, Kenyans mentioned “destructive gear/methods” less often (73%) than Tanzanians (98%) and Ugandans (90%), but “fishing capacity” more often (61%) than Tanzanians (20%) and Ugandans (34%). “Regulations”, the second most frequently mentioned driver category, was mentioned equally often across countries. Furthermore, the proportions with which the subcategories were mentioned also suggest differences across countries. For instance, especially Ugandans mentioned the involvement of the army, which makes sense given that at the time of data collection, Uganda was the only country employing their army to enforce regulations. Another key difference across countries is the focus on the use of the different types of illegal gears/methods such as poison, which seemed to be more prevalent in Tanzania than in the other countries.

When comparing knowledge acquisition groups, the group with formally acquired knowledge mentioned the driver categories “fishing capacity” (81%), “regulations” (60%), “environment” (69%), “demand” (46%), and “climate change” (37%) more often than the group with informally acquired knowledge, who, in turn, mentioned “destructive gear/methods” (93%) more often. This difference is also represented when comparing the proportions with which the subcategories were mentioned across knowledge acquisition groups. Specifically, the examples for destructive gear/methods were almost all mentioned more often by the group with informally acquired knowledge. In contrast, the subcategories for environment, namely pollution and eutrophication, were mentioned more often by the group with formally acquired knowledge.

3.2.2. *Number of mentioned driver (sub-)categories*

On average, participants mentioned 2.74 driver categories ($SD = 1.64$, range from 0 to 11 driver categories) and 2.44 subcategories ($SD = 2.03$, range from 0 to 11 subcategories). The average number of mentioned driver categories and subcategories across countries, professions, and knowledge acquisition groups are listed in Table 1. Across countries, there was no difference in number of mentioned driver categories ($\chi^2(df{=}2) = 4.34$, $p = .114$), but there was a difference in the number of mentioned subcategories ($\chi^2(df{=}2) = 30.68$, $p < .001$). A post-hoc Dunn test with Bonferroni adjustment showed that this was driven by Kenyans mentioning less subcategories than both Ugandans ($p = .006$, $p_{adj} < .017$) and Tanzanians ($p < .001$, $p_{adj} < .001$), and Ugandans mentioning less subcategories than Tanzanians ($p = .008$, $p_{adj} = .023$). Across knowledge acquisition groups, there was a significant difference in both number of mentioned driver categories ($W = 7571.5$, $p < .001$) and subcategories ($W = 3471$, $p = .017$). The group with formally acquired knowledge mentioned significantly more driver categories than the group with informally acquired knowledge. However, for the subcategories the effect was reversed: the group with formally acquired knowledge listed significantly less subcategories than the group with informally acquired knowledge.

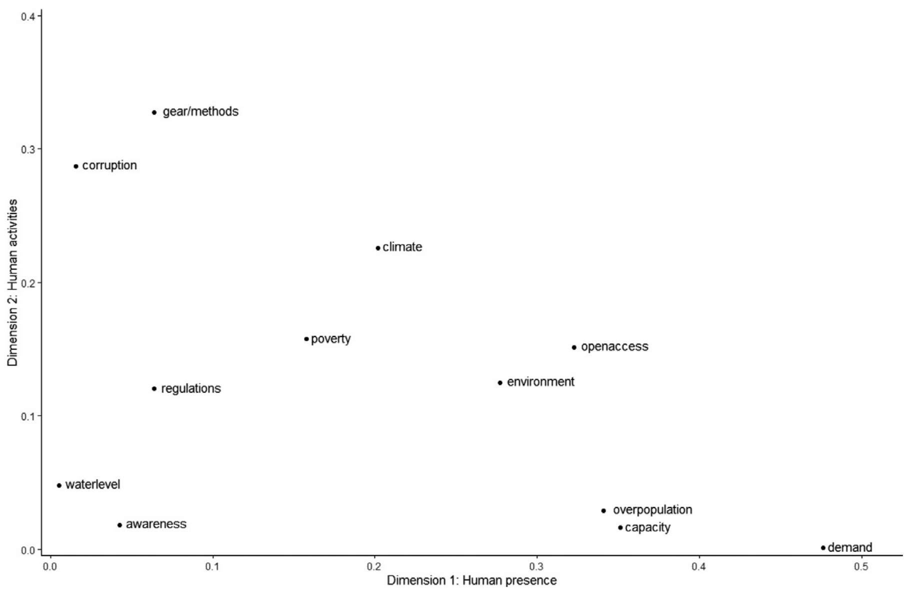

Fig. 2. Association of the single driver categories with the two aggregated driver dimensions.

3.2.3. Level of abstraction of mentioned drivers

Next, we investigated the underlying dimensions between the driver categories with a multiple correspondence analysis, which can be seen as a generalization of principal component analysis with categorical variables (Abdi & Williams, 2010). A scree plot (see OSF) indicated one or two underlying dimensions according to the scree criterion. Since one dimension would not be very informative, we decided to investigate two underlying dimensions. Figure 2 shows the association of the driver categories with these two dimensions. The driver categories that were most strongly associated with the first dimension were “demand”, “capacity”, and “overpopulation”. Albeit being also associated with Dimension 2, “environment” and “open access” were more strongly associated with Dimension 1 and thus, included in Dimension 1. Dimension 1 was interpreted as “human presence”, as all associated drivers are related to size of the population around the lake and the consequences such as environmental degradation. The associations with the second dimension were strongest for “destructive gear/methods”, and “corruption”. Therefore, this dimension was labelled as “human activities” as it refers to destructive and illegal human activities at the lake. As can be seen in Fig. 2, all other categories lie around the main diagonal and were thus equally related to both dimensions and not uniquely assignable. Specifically, “regulations”, “water level”, and “awareness” were not highly related to any of these two dimensions.

To investigate possible differences between countries and knowledge acquisition groups on these two extracted dimensions and get additional insight into the level of abstraction different key actors use, we created two new variables representing the two dimensions “human presence” and “human activities”. For each of the two new variables, we aggregated across the driver categories belonging to that dimension. That is, the variable “human presence” was coded with 1 if a participant mentioned at least one of the driver categories “demand”, “fishing capacity” “overpopulation”, “environment”, and “open access” and coded 0 if none of these driver categories were mentioned. “Human activities” was coded with 1 if a participant mentioned at least one of the driver categories “destructive gear/methods” and “corruption”, and coded with 0 if none of these categories were mentioned (see Fig. 1). Fig. 3 shows the proportions with which these dimensions were mentioned across countries, professions, and knowledge acquisition groups. Due to ceiling effects (e.g., only two Tanzanians did not mention “human activities”), however, it was impossible to conduct reliable significance tests. Therefore, we only interpreted this data descriptively.

Several descriptive patterns are noteworthy here. First, “human activities” was mentioned very often, which is also in line with the findings from the analysis of the single driver categories where destructive gear/methods was mentioned by 88% of the total sample. Specifically, more than 64% of participants across all countries and professions mentioned this dimension, with the actual proportions in many groups being above 90%, showing that this dimension is important irrespective of country, profession, or knowledge acquisition. Second, “human presence” was overall mentioned less often than “human activities” and there seems to be more variation depending on participants’ country or profession. Focusing on differences between actor groups, there are two noteworthy descriptive differences (see Fig. 3). First, across countries, Kenyans mentioned “human presence” more often and “human activities” less often than Ugandans and Tanzanians. Second, the group with formally acquired knowledge mentioned “human presence” (98%) more often and “human activities” (73%) less often than the group with informally gained knowledge (38% and 93%). Interestingly, the group with formally gained knowledge mentioned both dimensions often, whereas the group with informally gained knowledge mentioned “human presence” a lot less than “human activities”.

4. Discussion

Previous research has demonstrated the importance of actors’ system understanding of a socio-ecological system for successful resource management (Elsewah et al., 2015). Importantly, system understanding differs depending on whether it was acquired through formal or informal processes (Marathe et al., 2007; Raymond et al., 2010; Reed, 2008) and on the regional circumstances. Therefore, the current work mapped the system understanding of diverse actors of the Lake Victoria Nile perch fisheries, a complex socio-ecological system vital for the livelihoods of millions of people that faces fluctuations in Nile perch stock (Mkumbo and Marshall, 2015; Taabu-Munyaho et al., 2014) and scientific disagreement about which factors mainly drive these fluctuations (Kolding et al., 2008; Luomba et al., 2016; M. Njiru et al., 2008).

As drivers of the Nile perch stock, “destructive gear/methods”, “regulations”, and “fishing capacity” were mentioned most often among actors of the Nile perch fisheries, whereas drivers such as “water level” or “poverty” were mentioned least often. However, drivers might be associated with each other, for instance, an increasing population could lead to increased fishing capacity. Therefore, the current work also investigated the underlying dimensions of the mentioned drivers. Two underlying dimensions were found, namely “human activities” (which included the drivers “destructive fishing gear/methods” and “corruption”) and “human presence” (which included the drivers “demand”, “overpopulation”, “environment”, “open access”, and “fishing capacity”). Notably, these two dimensions differ in terms of the control that

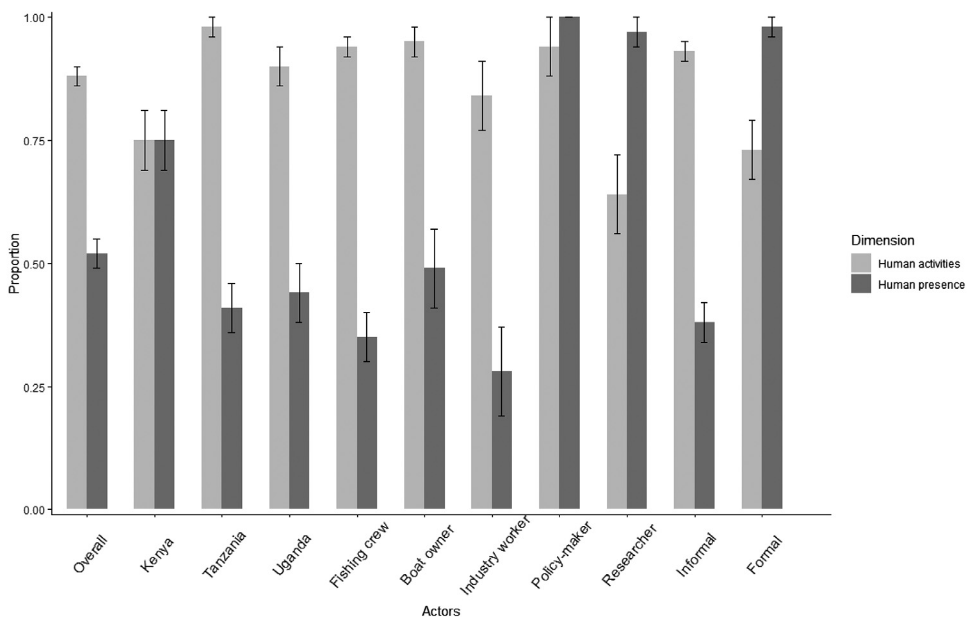

Fig. 3. Proportion with which actors from different countries, professions, and knowledge acquisition groups mentioned the two aggregated driver dimensions from the multiple correspondence analysis (error bars represent standard error of mean).

the actors may have over them. Specifically, the "human activities" dimension refers to the sustainability of fishing and illegalities and can be controlled both by individual actors and by the government. In contrast, the "human presence" dimension may be more difficult to control and cannot be addressed by the individual actor (with the exception of environmental pollution on a small scale).

Actors with formally and informally acquired knowledge differed in types, the number, and level of mentioned drivers. First, actors with informally acquired knowledge mentioned more subcategories than actors with formally acquired knowledge, which is in line with previous research showing that experts with more practical knowledge mention more examples than experts with scientific knowledge (Hmelo-Silver et al., 2007). Specific subcategories, however, were mentioned more often by the group with formally acquired knowledge, for instance pollution and eutrophication, which are rather abstract concepts. Second, in contrast to previous research that showed comparable levels of knowledge between those expert groups (Hmelo-Silver et al., 2007), actors with formally acquired knowledge used more driver categories than actors with informally acquired knowledge, suggesting those with formally acquired knowledge have a more nuanced view on the range of drivers of the stock dynamics.

To sum up, individuals with informally acquired knowledge mentioned several examples of one category, thereby reflecting their extensive knowledge on some (key) categories, whereas individuals with formally acquired knowledge mentioned more categories but with less detail. Together, these findings suggest higher-level, abstract reasoning among the formal knowledge acquisition participants. This is also in line with the finding that the "human activities" dimension was mentioned by nearly the whole sample, whereas the "human presence" dimension was mentioned more by the group with formally acquired knowledge. Importantly, the "human activities" dimension is concrete, tangible, and can be directly observed at the lake, whereas the "human presence" dimension includes drivers and concepts that are abstract, not tangible, and hard to observe, rendering them more accessible to individuals who specifically acquired skills for abstract reasoning or who explicitly learned about those drivers than to individuals who learned through personal experience and observations.

4.1. Limitations

The current work provides important insight into how diverse actors perceive complex socio-ecological systems such as Lake Victoria fisheries, depending on their regional residence and type of knowledge acquisition. However, the current work is also limited in three ways. First, the current methods only assessed whether driver categories were perceived to influence the Nile perch stock or not. However, participants did not weigh the drivers, meaning that relative importance or perceived size of their effect on the Nile perch stock cannot be inferred. For instance, while all actor groups mention destructive fishing gear/methods as a driver, the relative importance of this driver could differ across actor groups. Individuals perceiving destructive gear as very important for the dynamics of the fish stock may perceive the development of future Nile perch stock as more critical and a higher need for action if many fishers use destructive fishing gear than individuals perceiving destructive gear as less important. To investigate this, the next step is to assess a complete mental model of all actors across countries and knowledge acquisition groups. Second, we did not measure whether individuals in the assigned knowledge acquisition groups actually acquired their knowledge in the assumed way. However, fishers around Lake Victoria tend to inherit their occupation and are not formally trained. Therefore, the differentiation between the informal and formal knowledge group via professions seems appropriate. Third, differences between knowledge acquisition groups could also be attributed to a mere artefact of the methodological procedure, given that the research assistants read out the questions only to the group with informally acquired knowledge. This procedure might have made the group with informally acquired knowledge go through the tasks faster without taking the time to come up with more drivers. However, the financial incentive the fishers obtained for their participation could also have stimulated more elaboration on the task. Importantly, sampling non-WEIRD (Western, Educated, Industrialized, Rich, and Democratic) populations often comes with assessment challenges and potential distortions (Henrich et al., 2010; Laajaj et al., 2019). This might be a reason for the drastic overrepresentation of WEIRD samples in environmental psychology. Specifically, a recent review showed that the majority (84% in 2014 and 90% in 2017) of samples in the field come from Western countries, with only one out of 202 samples originating in Africa (Tam and Milfont, 2020). The current work demonstrated the importance of assessing a broad sample and suggests – in line with the call for more cross-cultural research on human-environment relationships (Tam and Milfont, 2020) – that assessing the population that is directly affected by socio-ecological challenges instead of (merely) generalizing from conveniently available but less (or only indirectly) affected samples should become more common.

4.2. Implications for research

The findings of this study provide valuable contributions to the current literature on learning and system understanding. While previous research has demonstrated expert-expert differences in types of knowledge for other complex systems such as forestry (Lynch et al., 2000), water management (Hundemer and Monroe, 2020; Mehryar et al., 2017), vineyards (Brulé and Labrell, 2014), genetics (Smith, 1990) aquarium systems (Hmelo-Silver et al., 2007) and land management (Avriel-Avni and Dick, 2019), the current study is the first to investigate these differences in system understanding in small-scale fisheries. Specifically, the present work is the first to compare different aspects of system understanding (types of drivers, number of drivers, and abstraction level of drivers) across formal and informal knowledge acquisition groups. The findings extent current literature by showing that type of knowledge acquisition also affects system understanding in small-scale fisheries and by providing novel insights into which dimensions of system understanding might be affected by differences in learning. Furthermore, this study is the first to shine a light on actors' causal beliefs of Lake Victoria's socio-ecological system. What emerges from this work is that stakeholders believe that human activities are a key contributor affecting the balance of the socio-ecological system, indicating a sense of control among actors to influence the balance of the fish stock. This may have important implications for research at the nexus of actors' system understanding and their interactions with the system. However, future research should also investigate the effect of power relations among the different system actors, which could also influence their perceptions and locus of control.

Furthermore, future research can leverage the current study's findings by further unpacking the processes that shape different types of actors' system understanding. For example, future research could experimentally test the effect of knowledge acquisition on causal beliefs about a system to disentangle confounding factors from the learning process. Another promising avenue for further research is to assess if similar patterns of results emerge when investigating the effect of knowledge acquisition on a set of causal beliefs, or mental models, which reflect the interactions between system concepts as well as the strength of the connections between the concepts in the mental model. Such research may reveal the underpinnings of heterogeneity of mental models across stakeholders, which may form an important barrier for conservation management (van den Broek, 2018). Additionally, it is important to further investigate forms of knowledge acquisition that have mixed elements from formal and informal knowledge acquisition in terms of the key defining attributes, that is, process, purpose, setting, and content (Malcolm et al., 2003). This might lead to insights that can be used to bridge the differences between formal and informal learning.

4.3. Implications for policies and management

Previous scientific evidence regarding the drivers of the Nile perch stock remains inconclusive, with some researchers pointing to increased fishing effort, overpopulation, and the use of illegal gear (Luomba et al., 2016; M. Njiru et al., 2008), while others focus on the eutrophication process in the lake to explain a declining fish stock (Kolding et al., 2008). Whereas the current work cannot specify or quantify the *actual* relative importance of the drivers of the Nile perch stock, it provides important groundwork to understand diverse actors' understanding of these drivers. To elaborate, regulations and policies targeting the most important drivers through actors' behavior change will only be successful if actors perceive those drivers as relevant. Therefore, the current work focused on actors' understanding of the Nile perch fisheries at Lake Victoria depending on types of knowledge acquisition (formal versus informal) and countries of residence. As a consequence, the findings provide policy-makers with insights into which factors might be easily targeted and which factors might have to be accompanied with a broad information campaign to be accepted.

Importantly, we found substantial similarities between different actor groups. For instance, the ubiquitous perception of higher Nile perch stock levels in the past across countries and professions pave the way for widely supported conservation policies. Regulations targeting destructive fishing gear and methods seem to be a particularly promising target factor. However, previous work has also shown differences in perceptions about which gears and methods are particularly destructive (Luomba et al., 2016), highlighting the difficulties of resource management even with a certain consensus on the fact that destructive gear is problematic. To complicate matters further, the current work showed considerable differences between both groups with different types of knowledge acquisition and the three riparian countries. Individuals with formally gained knowledge seem to assess the drivers of the fish stock level differently than individuals with informally gained knowledge. This highlights the need for knowledge exchange between actor groups (Reed et al., 2014) as policies made without assessing the system understanding of all affected actor groups might not be accepted by the broad population. Furthermore, differences between countries suggest that policies have to target the specific situational factors in each region. For instance, Kenyans mentioned both "human activities" and "human presence" equally often and, importantly, the latter one much more often than the other countries. This is in line with the fact that Kenya has the smallest share of the lake which probably makes the "human presence" dimension more salient and more important. Policies should take the different situational circumstances into account while striving for a common approach across riparian countries.

5. Conclusions

In conclusion, the current findings show that different system actors differ considerably in their system understanding. Importantly, this study demonstrates how knowledge acquisition may shape the complexity of a socio-ecological system: Participants with formally acquired knowledge tended to paint a richer picture of the drivers of the Nile perch stock, focusing on more abstract concepts than participants with informally acquired knowledge, who, in turn, used more examples to elaborate on key categories in more detail. As system understanding informs and influences behavior, which ultimately affects the system itself, it is of utmost importance to consider those (and other) actor differences when managing a system and developing policies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research work was supported by the German Federal Ministry for Education and Research (BMBF, 01LC1822A).

References

Ajzen, I., 1985. From intentions to actions: a theory of planned behavior. In: Kuhl, J., Beckman, J. (Eds.), Action control: From cognition to behavior. Springer, pp. 11–39.
Argent, R.M., Sojda, R.S., Guipponi, C., McIntosh, B., Voinov, A.A., Maier, H.R., 2016. Best practices for conceptual modelling in environmental planning and management. Environ. Modell. Softw. 80, 113–121. doi:10.1016/j.envsoft.2016.02.023.
Avriel-Avni, N., Dick, J., 2019. Differing perceptions of socio-ecological systems: Insights for future transdisciplinary research. Advances in Ecological Research, 60. Elsevier Ltd doi:10.1016/bs.aecr.2019.03.001.
Bardenhagen, C.J., Howard, P.H., Gray, S.A., 2020. Farmer mental models of biological pest control: associations with adoption of conservation practices in blueberry and cherry orchards. Front. Sustain. Food Syst. 4, 1–11. doi:10.3389/fsufs.2020.00054.
Bostrom, A., O'Connor, R.E., Böhm, G., Hanss, D., Bodi, O., Ekström, F., Halder, P., Jeschke, S., Mack, B., Qu, M., Rosentrater, L., Sandve, A., Sælensminde, I., 2012. Causal thinking and support for climate change policies: International survey findings. Global Environ. Change 22 (1), 210–222. doi:10.1016/j.gloenvcha.2011.09.012.

Brulé, L., Labrell, F., 2014. Expertise in biological conceptions: The case of the vineyard. Thinking Reasoning 20 (4), 432–453. doi:10.1080/13546783.2014.887030.

Djenontin, I.N.S., Meadow, A.M., 2018. The art of co-production of knowledge in environmental sciences and management: Lessons from international practice. Environ. Manage. 61 (6), 885–903. doi:10.1007/s00267-018-1028-3.

Downing, A.S., Van Nes, E.H., Balirwa, J.S., Beuving, J., Bwathondi, P., Chapman, L.J., Cornelissen, I.J.M., Cowx, I.G., Goudswaard, K.P.C., Hecky, R.E., Janse, J.H., Janssen, A.B.G., Kaufman, L., Kishe-Machumu, M.A., Kolding, J., Ligtvoet, W., Mbabazi, D., Medard, M., Mkumbo, O.C., Mooij, W.M., 2014. Coupled human and natural system dynamics as key to the sustainability of Lake Victoria's Ecosystem services. Ecol. Soc. 19 (4). doi:10.5751/ES-06965-190431.

Elsewah, S., Guillaume, J.H.A., Filatova, T., Rook, J., Jakeman, A.J., 2015. A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models. J. Environ. Manage. 151, 500–516. doi:10.1016/j.jenvman.2014.11.028.

Ennis, C.D., 1994. Knowledge and beliefs underlying curricular expertise. Quest 46 (2), 164–175. doi:10.1080/00336297.1994.10484118.

FAO/RAP/FIPL. (2004). *A research agenda for small-scale fisheries* (p. 42).

Fishbein, M.A., Ajzen, I., 1975. Belief, Attitude, Intention and Behaviour: An Introduction to Theory And Research. Addison-Wesley.

Fleischman, F.D., Boenning, K., Garcia-Lopez, G.A., Mincey, S., Schmitt-Harsh, M., Daedlow, K., Lopez, M.C., Basurto, X., Fischer, B., Ostrom, E., 2010. Disturbance, response, and persistence in self-organized forested communities: analysis of robustness and resilience in five communities in Southern Indiana. Ecol. Soc. 15 (4), 9. doi:10.5751/ES-03512-150409.

Guevara, L.E.T., Schlüter, A., Lopez, M.C., 2016. Collective action in a tropical estuarine lagoon: adapting Ostrom's SES framework to Ciénaga Grande de Santa Marta, Colombia. Int. Jo. Commons 10 (1), 334–362. doi:10.18352/ijc.623.

Henrich, J., Heine, S.J., Norenzayan, A., 2010. The weirdest people in the world? Behav. Brain Sci. 33 (2–3), 61–83. doi:10.1017/S0140525X0999152X.

Hmelo-Silver, C.E., Marathe, S., Liu, L., 2007. Fish swim, rocks sit, and lungs breathe: expert-novice understanding of complex systems. J. Learn. Sci. 16 (3), 307–331. doi:10.1080/10508400701413401.

Hovardas, T., Poirazidis, K., 2007. Environmental policy beliefs of stakeholders in protected area management. Environ. Manage. 39 (4), 515–525. doi:10.1007/s00267-006-0053-9.

Hundemer, S., Monroe, M.C., 2020. A co-orientation analysis of producers' and environmentalists' mental models of water issues: Opportunities for improved communication and collaboration. Environ. Commun. doi:10.1080/17524032.2020.1828128.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Joa, B., Winkel, G., Primmer, E., 2018. The unknown known – A review of local ecological knowledge in relation to forest biodiversity conservation. Land Use Policy 79, 520–530. doi:10.1016/j.landusepol.2018.09.001.

Josupeit, H., 2006. The market for Nile Perch. Globefish Res. Programme (FAO) 84, 1–100.

Kolding, J., Van Zwieten, P., Mkumbo, O., Silsbe, G., Hecky, R., 2008. Are the Lake Victoria fisheries threatened by exploitation or eutrophication?. Towards an ecosystem-based approach to management. Ecosyst. Approach Fisheries 309–345. doi:10.1079/9781845934149.0309, *December 2015*.

Laajaj, R., Macours, K., Hernandez, D.A.P., Arias, O., Gosling, S.D., Potter, J., Rubio-Codina, M., Vakis, R., 2019. Challenges to capture the big five personality traits in non-WEIRD populations. Sci. Adv. 5 (7). doi:10.1126/sciadv.aaw5226.

Luomba, J., Chuenpagdee, R., Song, A.M., 2016. A bottom-up understanding of illegal, unreported, and unregulated fishing in Lake Victoria. Sustainability 8 (10), 1–14. doi:10.3390/su8101062.

LVFO. (2019). *A report of the lake-wide hydro-acoustic survey*.

Lynch, E.B., Coley, J.D., Medin, D.L., 2000. Tall is typical: Central tendency, ideal dimensions, and graded category structure among tree experts and novices. Mem. Cogn. 28 (1), 41–50. doi:10.3758/BF03211575.

Malcolm, J., Hodkinson, P., Colley, H., 2003. The interrelationships between informal and formal learning. J. Workplace Learn. 15, 313–318. doi:10.1108/13665620310504783.

Marathe, S., Hmelo-Silver, C.E., Liu, L., 2007. A qualitative analysis of expert-expert differences in understanding aquariums. Proc. Ann. Meeting Cogn. Science Society 29, 1265–1270.

McGinnis, M.D., Ostrom, E., 2014. Social-ecological system framework: Initial changes and continuing challenges. Ecol. Soc. 19 (2). doi:10.5751/ES-06387-190230.

Mehryar, S., Sliuzas, R., Sharifi, A., Reckien, D., van Maarseveen, M., 2017. A structured participatory method to support policy option analysis in a social-ecological system. J. Environ. Manage. 197, 360–372. doi:10.1016/j.jenvman.2017.04.017.

Mkumbo, O.C., Marshall, B.E., 2015. The Nile perch fishery of Lake Victoria: Current status and management challenges. Fisheries Management and Ecology 22, 56–63. doi:10.1111/fme.12084.

Mkuna, E., Baiyegunhi, L.J.S., 2019. Determinants of Nile perch (Lates niloticus) overfishing and its intensity in Lake Victoria, Tanzania: A double-hurdle model approach. Hydrobiologia 835 (1), 101–115. doi:10.1007/s10750-019-3932-9.

Njiru, J., van der Knaap, M., Kundu, R., Nyamweya, C., 2018. Lake Victoria fisheries: Outlook and management. Lakes and Reservoirs 23 (2), 152–162. doi:10.1111/lre.12220.

Njiru, M., Kazungu, J., Ngugi, C.C., Gichuki, J., Muhoozi, L., 2008. An overview of the current status of Lake Victoria fishery: opportunities, challenges and management strategies. Lakes and Reservoirs 13 (1), 1–12. doi:10.1111/j.1440-1770.2007.00358.x.

Oberlack, C., Walter, P.L.H., Schmerbeck, J., Tiwari, B.K., 2015. Institutions for sustainable forest governance: Robustness, equity, and cross-level interactions in Mawlyngbna, Meghalaya, India. Int. J. Commons 9 (2), 670–697. doi:10.18352/ijc.538.

Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. PNAS 104 (39), 15181–15187. doi:10.1073/pnas.0702288104.

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

Partelow, S., 2015. Key steps for operationalizing social-ecological system framework research in small-scale fisheries: a heuristic conceptual approach. Mar. Policy 51, 507–511. doi:10.1016/j.marpol.2014.09.005.

Partelow, S., 2018. A review of the social-ecological systems framework: applications, methods, modifications, and challenges. Ecol. Soc. 23 (4). doi:10.5751/ES-10594-230436.

Patalas-Maliszewska, J., Krebs, I., 2016. A model of the tacit knowledge transfer support tool: CKnow-board. Commun. Comput. Inform. Sci. 639, 30–41. doi:10.1007/978-3-319-46254-7_3.

Rahimi, S., Gaines, S.D., Gelcich, S., Deacon, R., Ovando, D., 2016. Factors driving the implementation of fishery reforms. Mar. Policy 71, 222–228. doi:10.1016/j.marpol.2016.06.005.

Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., Evely, A.C., 2010. Integrating local and scientific knowledge for environmental management. J. Environ. Manage. 91 (8), 1766–1777. doi:10.1016/j.jenvman.2010.03.023.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biol. Conserv. 141 (10), 2417–2431. doi:10.1016/j.biocon.2008.07.014.

Reed, M.S., Stringer, L.C., Fazey, I., Evely, A.C., Kruijsen, J.H.J., 2014. Five principles for the practice of knowledge exchange in environmental management. J. Environ. Manage. 146, 337–345. doi:10.1016/j.jenvman.2014.07.021.

Reo, N.J., 2011. The importance of belief systems in traditional ecological knowledge initiatives. Int. Indigenous Policy J. doi:10.18584/iipj.2011.2.4.8.

Smith, M.U., 1990. Knowledge structures and the nature of expertise in classical genetics. Cogn. Instr. 7 (4), 287–302. doi:10.1207/s1532690xci0704_1.

Song, A.M., Scholtens, J., Barclay, K., Bush, S.R., Fabinyi, M., Adhuri, D.S., Haughton, M., 2020. Collateral damage? Small-scale fisheries in the global fight against IUU fishing. Fish and Fisheries 21 (4), 831–843. doi:10.1111/faf.12462.

Southerland, S.A., Sinatra, G.M., Matthews, M.R., 2015. Belief, knowledge, and science education. Educ. Psychol. Rev. 13 (4), 325–351.

Taabu-Munyaho, A., Nyamweya, C.S., Sitoki, L., Kayanda, R., Everson, I., Marteinsdóttir, G., 2014. Spatial and temporal variation in the distribution and density of pelagic fish species in Lake Victoria, East Africa. Aquatic Ecosyst. Health Manage. 17, 52–61. doi:10.1080/14634988.2014.876886.

Tam, K., Milfont, T.L., 2020. Towards cross-cultural environmental psychology: a state-of-the-art review and recommendations. J. Environ. Psychol. 71, 101474. doi:10.1016/j.jenvp.2020.101474, August.

Tiller, R., De Kok, J.L., Vermeiren, K., Richards, R., Van Ardelan, M., Bailey, J., 2016. Stakeholder perceptions of links between environmental changes to their socio-ecological system and their adaptive capacity in the region of Troms, Norway. Front. Marine Sci. 3, 1–16. doi:10.3389/fmars.2016.00267, (DEC).

UNFCCC, 2015. Paris Agreement.

URT. (2016). *Lake Victoria fisheries frame survey reports 2000-2016*.

van den Broek, K.L., 2018. Illuminating divergence in perceptions in natural resource management: A case for the investigation of the heterogeneity in mental models. J. Dyn. Decision Making 4, 1–5. doi:10.11588/jddm.2018.1.51316.

van den Broek, K.L., 2019. Stakeholders' perceptions of the socio-economic and environmental challenges at Lake Victoria. Lakes and Reservoirs 24 (3), 239–245. doi:10.1111/lre.12275.

van den Broek, K.L., Luomba, J., Onyango, H.O., Musobya, M., Klein, S.A., 2020. A framework for co-developing conservation research projects with stakeholders: a Lake Victoria case study. Lakes and Reservoirs 1–10. doi:10.1111/lre.12342.

van der Knaap, M., 2006. An analysis of the social and economic effects of Western consumption of Nile perch from Lake Victoria of Western consumption of Nile perch. Netherlands Environ. Assess. Agency (MNP) *April*.

van der Knaap, M., Ligtvoet, W., 2010. Is Western consumption of Nile perch from Lake Victoria sustainable? Aquatic Ecosyst. Health Manage. 13 (4), 429–436. doi:10.1080/14634988.2010.526088.

Vitari, C., 2011. The success of Expert Recommending Services and the part played by organizational context. Knowledge Manage. Res. Practice 9 (2), 151–171. doi:10.1057/kmrp.2011.6.