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Fishers' perspectives: the drivers behind the decline in fish catch in Laguna Lake, Philippines

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Abstract

Aquatic ecosystems are strongly affected by global change. Fishers hold local ecological knowledge (LEK) that is especially relevant for improving our understanding of aquatic ecosystems that experience major environmental changes while also providing crucial ecosystem services. This research explores the perceptions of the ecological changes in Laguna Lake (Philippines) among local fisherfolks. In 2019, we conducted 30 semi-structured interviews with fisherfolks with up to 60 years' experience. They reported catching 31 fish species and one shrimp genus as a staple food and income source, with more than one third of the species being exotic or introduced. The fisherfolks noted repeated fish kill events and dramatic changes in their catch such as fewer and smaller fish. Also noticeable were the widespread catch of knifefish, a comparably newly introduced species, and the fact that all native fish species were reported to be less often caught now than in the past. This included the reduced catch of *talilong* (mullet), *dalag* (snakehead) and *ayungin* (silver perch). Locals emphasized various drivers behind these changes, which are linked to one another in complex interrelationships. Invasive species, the deterioration of fish habitats, and increased water turbidity were cited as the main drivers. Interviewees highlighted an additional link between declining catches and the loss of aquatic plant diversity, which has been understudied in Laguna Lake and has not been the focus of regional policy efforts. The empirical evidence provided by the fisherfolks enhances earlier existing scientific evidence of this aquatic ecosystem as well as highlights the importance of contributions coming from different knowledge systems.

Keywords: Laguna de Bay, Laguna Lake, Ethnoichthyological Knowledge, Local Ecological Knowledge, Participatory work, Freshwater Fisheries

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INTRODUCTION

Aquatic ecosystems are strongly affected by global change (e.g. Jones et al. 2018 for a marine context, Reid et al. 2019 and Albert et al. 2021 for freshwater ecosystems). Perhaps most relevant are anthropogenic pressures, including phenomena such as pollution (e.g. Häder et al. 2020), climate change (e.g. Häder et al. 2019; Jiménez Cisneros et al. 2014), the introduction of invasive species (Gallardo et al. 2016), and overfishing (FAO 2020), all with the potential to have devastating consequences for the people who rely on aquatic ecosystems for their food or livelihoods. Inland water bodies, in particular, are experiencing major environmental changes, resulting in a decline in freshwater biodiversity (Reid et al. 2019; Albert et al. 2021), thus threatening local communities that depend on these aquatic ecosystems. Inland fisheries account for 12.5% of the world's fish catch and are particularly important in Asia and Africa, both in absolute and relative terms (FAO 2020). However, fish stocks and fisheries in inland water bodies are not monitored on a regular basis, which has led the Food and Agriculture Organization of the United Nations to call for an improved assessment of global inland fisheries (FAO 2020).

Local ecological knowledge (LEK), otherwise known as indigenous and local or traditional ecological knowledge (ILK or TEK, respectively), is based on long term-experiences of using a local resource as it is acquired from previous generations and then culturally transmitted to the next; therefore, it is not homogenous or static, but evolves over time and differs among individuals and user groups (Berkes et al. 2000; Crona 2006). Because of this and the valuable information LEK can provide for enriching our understanding of ecosystems, Berkström (2019) suggested a co-management approach in small-scale fisheries where both scientific and local knowledge systems are incorporated. Recent studies conducted among small-scale fishing communities have highlighted the potential of documenting the local ecological knowledge (LEK) of fishers to improve our understanding of the complex economic, ecological, and social changes fishers are facing, as well as to illuminate the ways in which fishers interact with local aquatic resources. "The extensive personal observation of and interaction with local ecosystems" is one of the pillars of LEK (Charnley et al. 2007: 15). For instance, Chan et al. (2019) examined the LEK of fisherfolks concerning the decline in the body size and abundance of fish, while Braga et al. (2018) revealed the distinctive perspectives held by fishers about the complex interactions between fish species (Brazilian sardines in the particular case) and their natural environment, such as local fluctuations in weather patterns and water temperature, interspecies competition, and predator-prey dynamics. LEK has also been studied in regard to the potential of integrating fishers' knowledge into the study of fish abundance. For instance, Eckert et al. (2017) found that recent and historical approximations of size and abundance shared by the Indigenous fishing communities of Canada were in line with current biological survey data. Conversely, a study on small-scale fisheries in Norway found that fisherfolks also hybridize LEK with scientific knowledge (Harrison et al. 2018). Such an integration of knowledge makes it clear that no knowledge system is superior to the other, but rather, as formulated in the context of indigenous knowledge under the keyword "two-eyed seeing" (Reid et al. 2021), both knowledge systems coexist, and both have their strengths. Taking into account the perspectives and perceptions of local communities can help to understand the conditions of and changes in aquatic ecosystems and the resulting challenges and adaptation strategies of

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local resource users. However, the LEK of various ecosystems has yet to be explored, which is the case for Laguna Lake in the Philippines. To date, only a few published sources reflect on community knowledge of the changes in Laguna Lake, e.g. reports from a Community Forum held in 2012 (Tuble 2013).

This study focuses on LEK among the Laguna Lake community, which is situated near the capital of the Philippines (Masuda 2019) located on Luzon Island. Ecological studies have classified Laguna Lake as "critically endangered" (Legaspi et al. 2015) and in "need of restoration" as indicated by the Philippine Millennium Ecosystem Assessment (Philippines MA 2005). Social and environmental issues, which are visible across the Philippines (e.g. Salvacion 2020; Boquet 2017; Concepcion and Nilo 2019), are gaining additional significance due to the high annual growth rate of the general population (1.4%) (World Bank 2018), and Laguna Lake is no exception. For example, as identified by Masuda (2019), no municipality possesses a sewerage treatment system and thus the polluted water of sub-basins enters Laguna Lake (e.g. Philippines MA 2005). An official assessment of Laguna Lake (The Laguna De Bay Ecosystem Health Report Card 2013) as well as more recent studies (e.g. Castro et al. 2018, Guerrero 2014) have discussed the additional threat to fish stocks posed by the appearance of invasive species, e.g. *Chitala ornata.* Laguna Lake biodiversity, water quality, and fish productivity also suffer from unsustainable aquaculture practices and overfishing (Tamayo-Zafaralla et al. 2002; Santos-Borja and Nepomuceno 2006). Several legal organizations (e.g. Laguna Lake Development Authority (LLDA), Local Government Unit, *Barangays*) have initiated activities regarding Laguna de Bay Basin resource management (Masuda 2019). Nevertheless, Laguna Lake still has poor scores for water quality and fisheries (LLDA 2019a: 17-25). The diversity of ecological and social issues linked to Laguna Lake provides a suitable ground for LEK research.

Acknowledging the ecological issues facing Laguna Lake (LLDA 2019a; UPLB 2018) and the importance of fishers' knowledge in conservation, our study focuses on the LEK held by local fisherfolks in Mabato-Azufre village in order to better understand the ecological changes in Laguna Lake and how these changes have impacted fish catch. The specific aims of the research were 1) to document the ecological changes in Laguna Lake perceived by fishers and 2) to identify the main drivers of the observed changes as named by the fishers. We will also discuss the management implications derived from the findings with particular focus on the role played by fishers in the co-creation of knowledge and the development of policies for the recovery of Laguna Lake. However, the authors want to stress that the study does not aim to validate the fishers' knowledge, as numerous scholars have already acknowledged the complementary and collaborative role of fishers while discussing natural resource management; see, for example, Berkström et al. (2019), Mamun (2010 – references within), Le Fur et al. (2011), Deshpande et al. (2019), Vidal et al. (2020), and Mustonen and Huusari (2020).

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STUDY AREA AND METHODS

The research took place in the fishing community of Mabato-Azufre, situated on the banks of Laguna Lake, Northern Philippines. The Laguna Lake Basin ecosystem serves as a habitat for rich biodiversity including globally threatened bird species (15), endemic reptile species (27) (Philippines MA 2005), and endemic fish species (Aquino et al. 2011).

The study area

Laguna Lake is the third largest inland water system in Southeast Asia (Figure 1) and the largest freshwater lake in the Philippines by surface area (900 km^2). Laguna Lake is eutrophic (Cuvin-Aralar et al. 2004), extremely shallow (average depth 2.5-2.8 meters (Herrera et al. 2015; Cuvin-Aralar et al. 2004), depending on the source), and turbid throughout most of the year, with a Secchi disk transparency of less than 1 meter (Cuvin-Aralar et al. 2004). The inhabitants of Mabato-Azufre village, which is part of Pangil municipality, are employed in fishing, rice cultivation, and handicraft activities. The number of fish species varies among sources: according to the Philippines MA (2005) the number of taxa is 33, whereas other sources refer to 47 or more (Aquino et al. 2011).

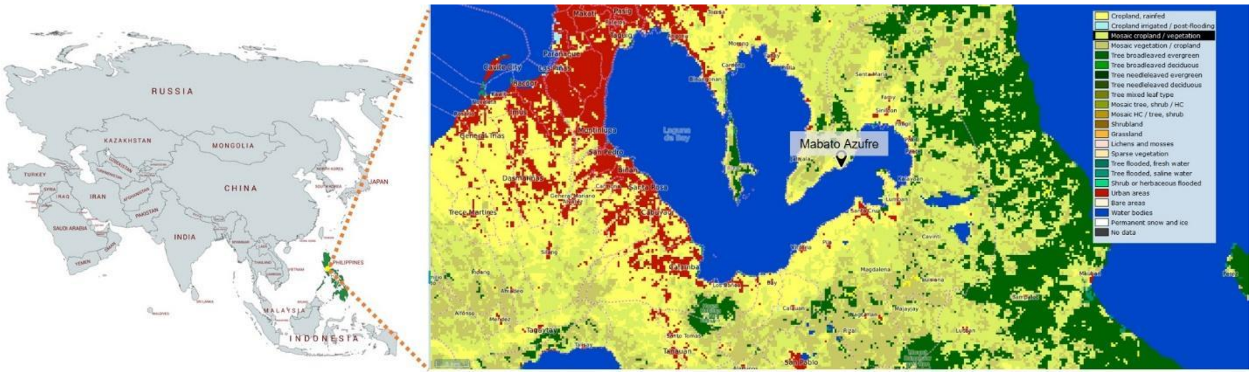

Fig. 1 Study area: Mabato-Azufre, Laguna province, Philippines – East Bay of Laguna Lake. Source: CCI-LC visualization interface.

Laguna Lake has one outlet, the Pasig River (27 km), which connects the freshwater system with the marine waters of Manila Bay, where during the dry season the intrusion of seawater occurs (Nauta et al. 2003; Herera et al. 2015). As emphasized by Nauta et al. (2003), the total watershed encompassing 3820 m^2 has been highly modified through land use activities, e.g. deforestation, mineral extraction, and urban expansion. Laguna Lake supports multiple uses including a water source for domestic use, agriculture (irrigation of rice fields (Palma et al. 2002)), navigation, poultry production, livestock production, aquaculture, and traditional fishing (Blanco et al. 2019) (Figure 2). However, "the lake's most dominant use is fisheries" (Masuda 2019: 158).

Overview of fisheries across the Laguna Lake

The Laguna Lake Development Authority (LLDA) notes 11 814 registered fisherfolks in their database (LLDA 2018a) but estimates a total number of 22 000 small-scale fisherfolks in Laguna Lake (LLDA 2018b). To note,

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high fishing pressure in Laguna Lake was noted more than half a century ago by Delmendo (1966) and in more recent study by Palma et al. (2002).

According to Lacanilao (1987), until 1970 only open-water fishing took place, which was later mainly overtaken by fishpen activity. In the Philippines, a fishpen is described as "an artificial and stationary water enclosure for the culture of fish and other aquatic animal species" whereas a fishcage is "an artificial and stationary or floating water enclosure smaller than a fishpen but made up of similar construction materials" (Israel 2008: 62). As emphasized by Israel (2008): "corporations dominated fishpen culture, sole proprietorships dominated fishcage culture, and cooperatives formed only a small percentage of fishpen and fishcage culture in Laguna de Bay" (p.64). Saguin (2015) notes that aquaculture in Laguna Lake was introduced in the 1970s in order "to help improve rural livelihoods and urban fish provisioning" (p. 2). To add, "pen and cage structures in the lake have significantly reduced the area for open water capture fisheries resulting to conflicts between fishpen operators and sustenance fishermen" (Philippines MA 2005).

On the national level, numerous frameworks exist for water management in the Philippines (see Masuda 2019 and references within). In particular, the Bureau of Fisheries and Aquatic Resources (BFAR) is responsible for Philippine fisheries and aquatic resources (BFAR 2014). According to BFAR laws and regulations, licenses and permits are preferably issued to local fishers within municipal waters to gain access to fishery resources, which should be based on, but not limited to, the Maximum Sustainable Yield or Total Allowable Catch and must take into consideration environmental conditions and international agreements (BFAR n.d.). For Laguna Lake, several administrative bodies exist including the LLDA and local government units. Laguna Lake has specific zoning areas dedicated to aquaculture, sanctuary, and navigation (LLDA 2019b).

Fig. 2 Mabato-Azufre: village center and agricultural area. Credit: First author

Data collection

The data collection took place between March and December 2019 in the fishing community of Mabato-Azufre, Laguna province. Initial contact with communities took place through fisheries managers and community leaders, such as the head of the village and the Barangay Fisheries and Aquatic Resources Management Council, to whom the first author, a local inhabitant and fisherman's daughter, presented the study goals and process. The key informants who have been engaged in fishing activities for nearly their entire lives were identified by community members, and additional participants were selected through the snowball technique. The field work with the fisherfolks took place in two rounds, in which the same fisherfolks were approached a second time for more detailed follow-up questions. For the second round, the interview guide

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was adapted during the interview process following the fisherfolk's emphasis on certain topics like the importance of plants in the Laguna Lake.

In total, the interviewee sample included a total of 30 local fishers, three-quarters active and one-quarter retired, some of whom have been involved in aquatic resource management groups (Figure 3). Due to accessing the community through key informants and selecting interviewees via the snowball technique, all but one of the interviewees were male, and all but three interviewees were over 40 years of age. Half of the fisherfolks did not complete an educational degree beyond primary school level, and more than three quarters took over the practice of fishing from their parents. One third of the interviewees had 0-20 years of fishing experience, one third 21 to 40 years, and one third 41 to 60 years. Older fisherfolks who have always lived in the community, but may have started fishing late, stopped fishing at some point in their life, or worked in other sectors in between, have also personally seen Laguna Lake's transformation. Likewise, younger fishers have also taken stock of certain changes by benefiting from the experiences of previous generations and other, more experienced fishers. Therefore, both age and fishing experience can only be regarded as proxy variables. However, the high proportion of older and experienced fisherfolks in the sample allows for the conclusion that, overall, we likely interviewed people who personally experienced the changes in Laguna Lake.

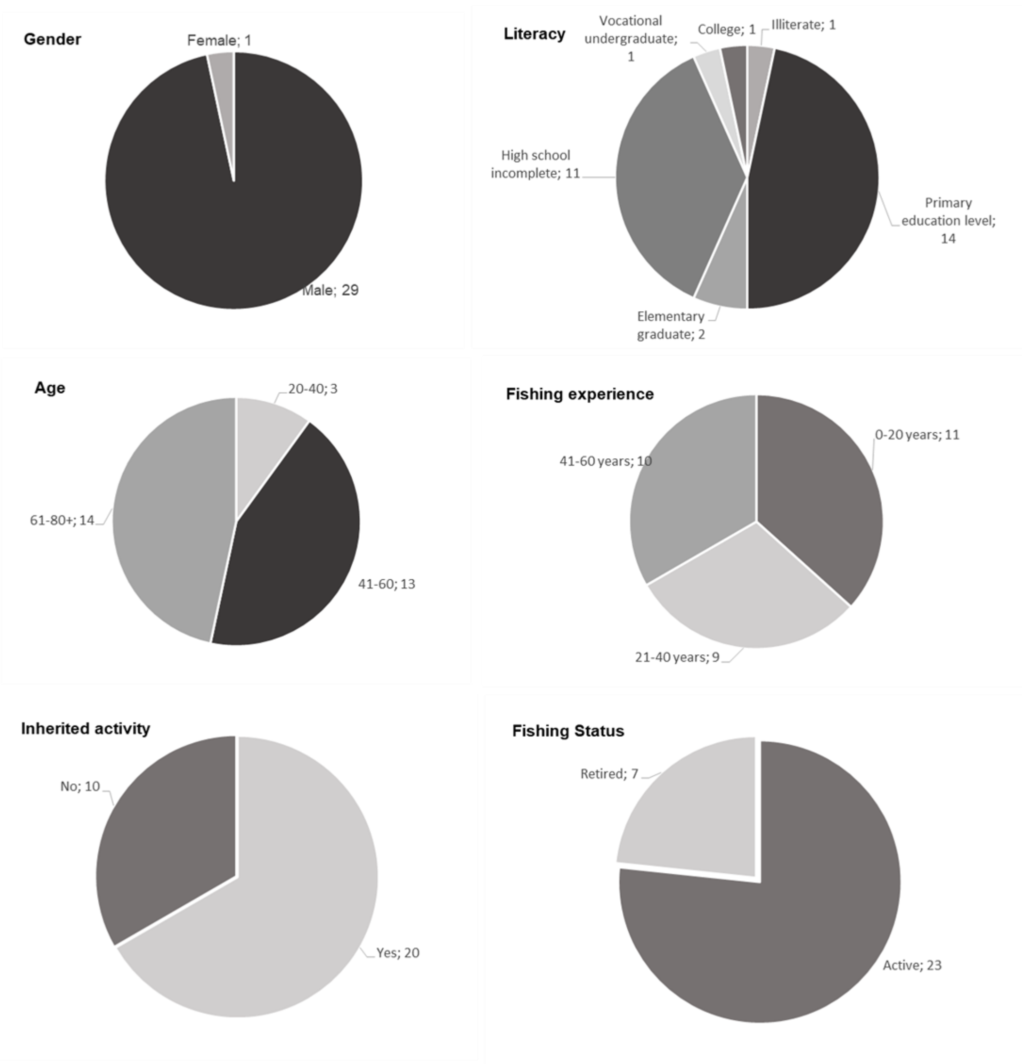

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Fig. 3 Social profile of the interviewees in Mabato-Azufre, Laguna Lake, Philippines.

Semi-structured interviews, both individually and in groups, and participant observation were conducted during fishing activities. The interview questions included details about the social profile of the interviewee, their local ecological knowledge, their perception of fish, and their uses across their lifetime. The uses of fish for food were reported in Mendoza et al. (2021). The interview guiding material also included specific questions related to fish kill events and the important plants in Laguna Lake as well as their benefit to fisheries. The study employed the Code of Ethics of the International Society of Ethnobiology which provides a framework for conducting ethnobiological research (ISE 2006). Considering the nature of the study area, written approval from the head of the village was obtained prior to starting the interview process. Acknowledging the diversity in literacy level both written consent forms and oral consent were acquired.

Data analysis

Field notes and voice recordings were taken upon agreement of the interviewee. The obtained data were anonymously transcribed and translated into English by the first author. The fishers' narratives were organized into an Excel spreadsheet according to topic. Narratives were then incorporated into a mental map reflecting the observed drivers of fish kill events in Laguna Lake. The fish taxa named by the interviewees were structured according to the time caught, i.e. past vs present catch.

The FishBase online encyclopedia, the Philippines MA (2005), and the Plants of the World database, as well as regular consultation with the Provincial Office of the Bureau of Fisheries and Aquatic Resources, Los Baños, Laguna, Philippines, were used to link fish ethnotaxa (fish populations defined in local terms by the fishers) and local aquatic plant names with their scientific names. Difficulties arise when the same Latin name represents more than one fish taxon. In such cases, whenever possible, additional consultation was conducted with the fisherfolks by the first and fifth authors. A similar approach was used for plant taxa. In order to maintain an emic approach, the local names of fish species were retained, including the names used to explain changes in the Laguna Lake ecosystem. The study by Aquino et al. (2011) and also the Philippines MA (2005) were consulted in order to define the characteristics of the species, i.e. native or introduced. The IUCN Red List (2021) served as the primary source to define conservation status.

RESULTS

The fishers noted a decline in the catch of certain species and the appearance of invasive species. Several drivers have contributed to this decline including the introduction of invasive species, the deterioration of fish habitats and increased water turbidity.

Observed changes in fish catch in Laguna Lake

Fishers reported 31 fish species and one shrimp genus, corresponding to 32 local names. Fishers reported both past and present catches. For example, the silver perch (*Leiopotherapon plumbeus*), which is endemic to the Philippines and used to be the most abundant fish in Laguna Lake, is now considered "vulnerable" (IUCN Red List 2021). At the time of the survey, nine fishers reported still catching silver perch, whereas in the past this fish was caught by 17 of the interviewed fisherfolks (Table 1). Over one third of the fish species named by the fishers were exotic or introduced species (Table 1), which confirms the strong anthropogenic impact on the ecosystem. Of the fish that are native or endemic to the Philippines, most species were classified as of "least concern" by the IUCN Red List (2021). However, several native and endemic species are considered "data deficient" (Table 1).

Table 1. Fish species reported by the fishers of Laguna Lake, Philippines

Family	Scientific name	Category (based on Fishbase.se and Aquino et al. 2011) and [IUCN RED LIST]	Category (based on the Philippines MA (2005))	Local name as reported by fishers	Past catch	Present catch
Anabantidae	*Anabas testudineus* B.	Introduced^ [LC]	Indigenous	Tinikan / Martiniko	3	0
Ariidae	*Arius dispar* H. / *Arius manillensis* V.	Native [DD] / Endemic [-]	Indigenous	Kanduli	19	13
Channidae	*Channa striata* B.	Native [LC]	Indigenous	Dalag	24	14
Chanidae	*Chanos chanos* F.	Introduced	Exotic or introduced	Bangus	6	2
Cichlidae	*Oreochromis aureus* S.	Introduced	Exotic or introduced	Tilapia	25	21
	Oreochromis niloticus L.	Introduced	Exotic or introduced	Plapla	4	9
	Cichlasoma trimaculatum G.	Introduced	-	Dugong, Duterte, Digong	1	6
	Sarotherodon melanotheron R.	Introduced	-	Arroyo	5	4
	Tilapia zillii G.	Introduced	Exotic or introduced	Bruce lee	6	0
Clariidae	*Clarias macrocephalus* G. and *C. batrachus* L.	Native [NT] / Introduced	Indigenous / Exotic or introduced	Hito	8	5

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Cyprinidae	*Hypophthalmichthys nobilis* R.	Introduced	-	Bighead	17	17
	Cyprinus carpio L.	Introduced	Exotic or introduced	Karpa	24	15
	Barbonymus gonionotus B.	Introduced	Exotic or introduced	Tawis	12	2
	Carassius auratus L.	Introduced	Exotic or introduced	Karpita	2	0
	Labeo rohita H.	Introduced	Exotic or introduced	Rohu	1	0
Eleotridae	*Giuris margaritacea* V.	Native [LC]	-	Palu-palo	3	0
Elopidae	*Elops hawaiensis* R.	Native [DD]	-	Bidbid	1	0
Eleotridae / Gobiidae	*Oxyeleotris marmorata* B. / *Glossogobius giuris* H.	Native [LC] / Native [LC]	-	Biya	22	11
Gobiidae	*Gobiopterus lacustris* H.	Endemic [DD]	Indigenous	Dulong	2	1
Loricariidae	*Pterygoplichthys pardalis* C. / *P. disjunctivus* W.	Introduced / Introduced	-	Janitor fish	3	4
Mugilidae	*Liza subviridis* (Delmedo and Bustillo 1968)	Native [LC]	-	Talilong	8	0
Notopteridae	*Chitala ornata* G.	Introduced	-	Knifefish	2 (only recently)	15
Osphronemidae	*Osphronemus goramy* L.	Introduced	Exotic or introduced	Gurami	12	1
Palaemonidae	*Macrobrachium* spp. **			Hipon	22	11

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Synbranchidae / Anguillidae	*Ophisternon bengalense* M. / *Anguilla marmorata* Q.	Native [LC] / Native [LC]	- / migratory	Palos, Igat, Kiwit	9	4
Terapontidae	*Leiopotherapon plumbeus* K.	Endemic [VU]	Indigenous	Ayungin	17	9
Zenarchopteridae	*Zenarchopterus philippinus* P.	Endemic [LC]	-	Kansusuwit	1	1

*** - freshwater shrimp, based on the Laguna Lake Development Authority (LLDA) website; Fishbase.se and Aquino et al. 2011 definitions: "native/ endemic/introduced to the Philippines"; IUCN definitions: LC - least concern; NT - nearly threaten; DD - data deficient; VU - vulnerable; [-] not reported in the IUCN Red List; ^ - Recorded as Introduced by Herre (1953), but museum records date back to the early 20th century and fishers consider it native (Anon 2012); "-" - not listed in the source.*

The taxa *Channa striata*, *Cyprinus carpio*, *Hypophthalmichthys nobilis*, and *Sarotherodon melanotheron* were among the most commonly used fish species as a food source in the past (Table 1). Among others, fishers named *Cyprinus carpio*, *Oreochromis niloticus*, *Hypophthalmichthys nobilis*, and *Channa striata* as important, but less abundant, fishes in the present. As recalled by one fisherman: "In the 1950s and 1960s, fishers had a bigger fish catch. In those years, during the summer season, we went fishing in the lake and during the rainy season we went to the mountains for other activities." However, fish taxa like *Chitala ornata* were not typically caught at the beginning of a fisherman's career, and now they are regularly harvested. Aquino et al. (2011) notes that "a steady decline has been observed in the abundance and diversity of native fishes in the lake due to anthropogenic disturbances" (p. 143). One fisherman sums up the changes as follows:

> "(…) there were abundant fishes before, like *gurami* [*Osphronemus goramy*]. That helped me provide for my family. The fishes were sold to "*rigaton* [local fish traders]." There was no *knifefish* [*Chitala ornata*] before, also *Janitor fish* [*Pterygoplichthys* spp.]. We caught up to 40 kilos of *biya* [*Oxyeleotris marmorata* and *Glossogobius giuris*] per day in the 1980s, about 60-70 kilos of shrimp." (Fisher: 66 years old)

In addition, one elderly fisherman, recalling his earliest fishing experiences in the 1950s and 1960s, emphasized that at that time he could not lift his net after a typhoon because so many fish were caught. In addition, a fisherfolk with 53 years of fishing experience noted the change in fish size: "Before, one piece of *karpa* [*Cyprinus carpio*] could weigh as much as 5 to 10 kilograms." Another fisherfolk added:

> "(…) Also, *dalag* [*Channa striata*], *biya* [*Oxyeleotris marmorata* and *Glossogobius giuris*], and *karpa* [*Cyprinus carpio*] were some of the most important before because these were the fishes abundant in the lake. In the case of *gurami* [*Osphronemus goramy*], in the past, we could even get it near the lakeshore. Nowadays, we do not catch that much compared to before. These days, there is less fish catch, unlike in the past. Now, sometimes in one month, I cannot even catch one piece of *karpa*, while

> in the past, every day, there was always *karpa* in my catch to sell, now there is none." (Fisher: 70 years old)

The fishers of Laguna Lake also reflected on the socio-economic aspects of the observed ecological changes. Most importantly, the decline in certain fish taxa in the catch, e.g. *Channa striata*, affects their livelihoods due to a decrease in their income. Another negative effect is the higher cost resulting from changed fishing practices, since, as in the case of *Osphronemus goramy*, longer fishing trips are necessary as there are few fish remaining near the shore.

Drivers of change in fisheries catch

The fishers living in Mabato-Azufre reported three main causes for the decline in the catch of some important fish species: (i) the introduction of invasive species, (ii) the loss of fish habitat, and (iii) increased water turbidity. The interviewees also mentioned a specific link between the decline in some aquatic plants, fish kills and the potential effect on fish catch.

Introduction of invasive species

One driver of fish catch decline was invasive species, such as *Chitala ornata* and *Pterygoplichthys* spp. Fishers mentioned a direct link between the decline in certain fish taxa, e.g. *Oxyeleotris marmorata* and *Glossogobius giuris*, and the dominant nature of the invasive fish. According to Joshi (2006), across the Philippines the general understanding of invasive-alien species and their effect on native biota is based on limited data and the "failure to realize the potential ecological damage to Philippine biodiversity" (p.11-2). The report of Laguna Lake (The Laguna de Bay Ecosystem Health Report Card 2013) adds that "the proliferation of knifefish has caused significant declines in cultured and native fish production". The fishers describe the dramatic changes as follows:

> "*Biya* [*Oxyeleotris marmorata* and *Glossogobius giuris*] was very abundant in the past. Almost hundreds of kilos per capture. Now *biya* is almost gone, this fish is now rare because it's being eaten by *knifefish* [*Chitala ornata*]; *digman* [*Hydrilla verticillata*] is almost gone as well. *Biya* does not have many breeding grounds. These fishes are the main source of income. There was an abundant fish catch before. Our boat was always full of fishes." (Fisher: 70 years old)

> "I found out that this fish is causing a problem as they eat other fishes' fingerlings. When it started to appear in the lake, the fish catch decreased." (Fisher: 65 years old)

However, a fisherman also noted that during "*habagat* [southwest monsoon] season, many *tilapia* [*Oreochromis aureus*] are present in the lake". Although fishers noted the negative consequence of *Chitala ornata*, some fisherfolks also provided suggestions for possible solutions.

> "One solution to having too many *knifefish* [*Chitala ornata*] is to add value to them by processing, and LLDA/ BFAR are working hand in hand in retrieving *knifefish*, such as buying the *knifefish* captured by fishermen." (Fisher: 54 years old)

Loss of fish habitat

Fishers reported that the decrease in the catch of some species is due to a loss of fish habitat, which is driven by a decrease in the presence of floating, emergent, and submerged macrophytes (and yet some were reported to be present in a nearby village): *Nymphaea pubescens*, *Hydrilla verticillata*, *Vallisneria natans*, *Scirpus grossus*, *Cyperus imbricatus*, and *Salvinia molesta*.

On the importance of plants in the lake, the fisherfolks noted the following:

> "*Digman* [*Hydrilla verticillata*], *sintas* or *hinlalabiw* [*Vallisneria natans*], *beno* [*Nymphaea pubescens*], because they serve as breeding grounds, and where the fish can hide; also *waterlilies* [*Eichhornia crassipes*]. These help the fishery in the lake as these serve as the breeding ground of almost all the fishes. These days these plants are still present, but very rare, unlike before. In some parts of the lake where these plants are still present, there are many fishes present there." (Fisher: 70 years old)

Fisherfolks also noted a possible change in the reproduction of fish as a consequence of the loss of certain aquatic plants.

> "*Beno* [*Nymphaea pubescens*] and *digman* [*Hydrilla verticillata*], these plants serve as breeding grounds of many fishes, these plants help to increase the quantity of fish in the lake. When these plants disappear, there will be no place for the fishes to reproduce." (Fisher: 53 years old)

Besides the loss of breeding grounds, several fishers stressed the importance of aquatic plants, e.g. *Vallisneria natans*, as hiding places for fish during bad weather.

> "*Hinlalabiw* or *sintas* [*Vallisneria natans*], *digman* [*Hydrilla verticillata*], *beno* [*Nymphaea pubescens*], *tikiw* [*Scirpus grossus*], *bayakibok* [*Cyperus imbricatus*], all these help the fishery in the lake, as these serve as their hideout during bad weather, from predators, and also serve as their breeding grounds." (Fisher: 64 years old)

Fishers also noted a link between the loss of certain aquatic plant species and hydropower activity, i.e. the use of chemicals for cleaning moss from pipes. As identified during the interviews, the chemical used for cleaning pipes is believed to be chlorine.

> "*Waterlilies* [*Eichhornia crassipes*], *tikiw* [*Scirpus grossus*], *sintas* [*Vallisneria natans*], *digman* [*Hydrilla verticillata*], these are still present in the lake, some of these plants die because of the hydropower, when they perform the cleaning of their pipes, they apply a chemical that can remove/ kill the moss in their pipes, so the aquatic plants like these are also affected; it is good that after sometime, these plants still grow." (Fisher: 56 years old)

In fact, the effect of chlorine on aquatic ecosystems has been a topic of scientific discussions (e.g. Sedlak and Gunten 2011; da Costa et al. 2014). For example, the results of Watkins et al. (1984), who worked on a controlled laboratory experiment on selected aquatic plant taxa, indicate that "high-level chlorine discharges from wastewater facilities and electric generating plants could be a contributing factor impacting nearby submerged aquatic vegetation".

Although *Eichhornia crassipes* was named by some fisherfolks as a breeding ground, there are also side effects in terms of overgrowth. In addition, the recent review by Ayanda et al. (2020) provides a comprehensive list of challenges related to *Eichhornia crassipes* across the world, including issues associated with transportation. Fisherfolks at Laguna Lake put it this way:

> "Now, waterlilies [*Eichhornia crassipes*] become a problem when they cover large parts of the lake, where the fishers cannot even go out in the lake to fish because we cannot even pass through the thick waterlilies, up to the villages nearby. In this case, it also causes problems to fishers. It will help if there's not much of it covering a large part of the lake as it could serve as a habitat for fishes. (…) It also could multiply very quickly." (Fisher: 39 years old)

Increased water turbidity

Water turbidity has changed according to the fishers, and they identified several reasons for this, including the change in water exchange through Pasig River (i.e. the closure of Napindan Channel through the Napindan Hydraulic Control System (NCHS)) and the decline in the presence of aquatic plants. Some fishers mentioned a link between the closure of Napindan Channel (which according to the fishers also blocked the saltwater entrance to Laguna de Bay) and the establishment of a drinking water facility. According to Santos-Borja (1994), "when the lake level is lower than Manila Bay, the Pasig River enters the lake via the Napindan Channel". The complexity of the hydraulic system in Laguna Lake leads to various viewpoints. As explained by Santos-Borja (1994), the barrier for salt intrusion was recommended in the 1970s, but from the fishers' perspective the salt intrusion was viewed positively for its effect on fisheries and water turbidity. According to a recent webpage post by the fisherfolk group: "[the] Napindan Channel is the only outlet of the lake to Manila Bay, but since the construction of the NCHS, saltwater from Manila Bay has been blocked from entering the Laguna de Bay, causing the 90-thousand-hectare brackish lake to gradually deteriorate" (Pamalakaya-Pilipinas 2017). The interviewees shared this point of view:

> "In the past, the salt water could enter to the lake through Pasig River; now that is closed, the salt water cannot come in anymore; because the salt water can make the lake water clearer, that helps the fishes to grow faster. Now, it takes a few years before the fishermen can harvest the fish in their cages, as the water has increased its turbidity." (Fisher: 62 years old)

> "Before, there were lots of plants in the lake, such as *digman* [*Hydrilla verticillata*], so the water was clean and clear. Now that there is not so much of this plant, when the water flows, the lake water easily increases its turbidity, unlike before; the parts of the lake where there are *digman*, the lake water in those parts is still very clear – which helps the lake fishery. This plant also serves as a habitat of the fishes. Now, the fishes cannot multiply because most of the time, they are easily captured by fishers." (Fisher: 64 years old)

The closure of the saltwater entrance is also linked to the disappearance of certain fish species, like *Liza subviridis.* As one fisher noted, "now, there is no more *talilong* [*Liza subviridis*] because the Pasig River where salt water could enter to Laguna Lake is closed, so the lake water does not flow (which allowed the water to be clear) like before." (Fisher: more than 60 years old)

Additional drivers and fish kill events

The fishers reported various links to fish catch decline beyond the ones named above, including pollution. Fishers named wastewater as well as inflow from the shore as factors negatively affecting fish catch.

> "I also experienced fish kills before, just recently. Because the water has a bad odor, the polluted water from somewhere along the shore probably flows into the lake sometimes; the water flowing from there can also be a source of nutrients for the fishes." (Fisher: 78 years old)

> "Another problem is that when there is flooding, domestic wastewater, maybe waste from some other activities like backyard raising animals - this wastewater goes to the lake along with the flood waters; this *bahong tubig* [smelly water from domestic/agriculture waste] mostly comes from river tributaries when the rainy season starts - this also caused the death of our fishes (*bighead* [*Hypophthalmichthys nobilis*]) before, right before we were about to harvest them." (Fisher: 56 years old)

More than 20 fisherfolks had observed fish kills and listed several possible reasons for them (Figure 4). According to Cuvin-Aralar et al. (2001), mass fish kills in Laguna de Bay have been reported since the 1930s, but only became a focal point of attention with the introduction and expansion of aquaculture. They attribute the majority of fish kill events to low dissolved oxygen, often associated with phytoplankton blooms, but they also recognize other causes such as the impacts of typhoons, and household, agricultural and industrial waste.

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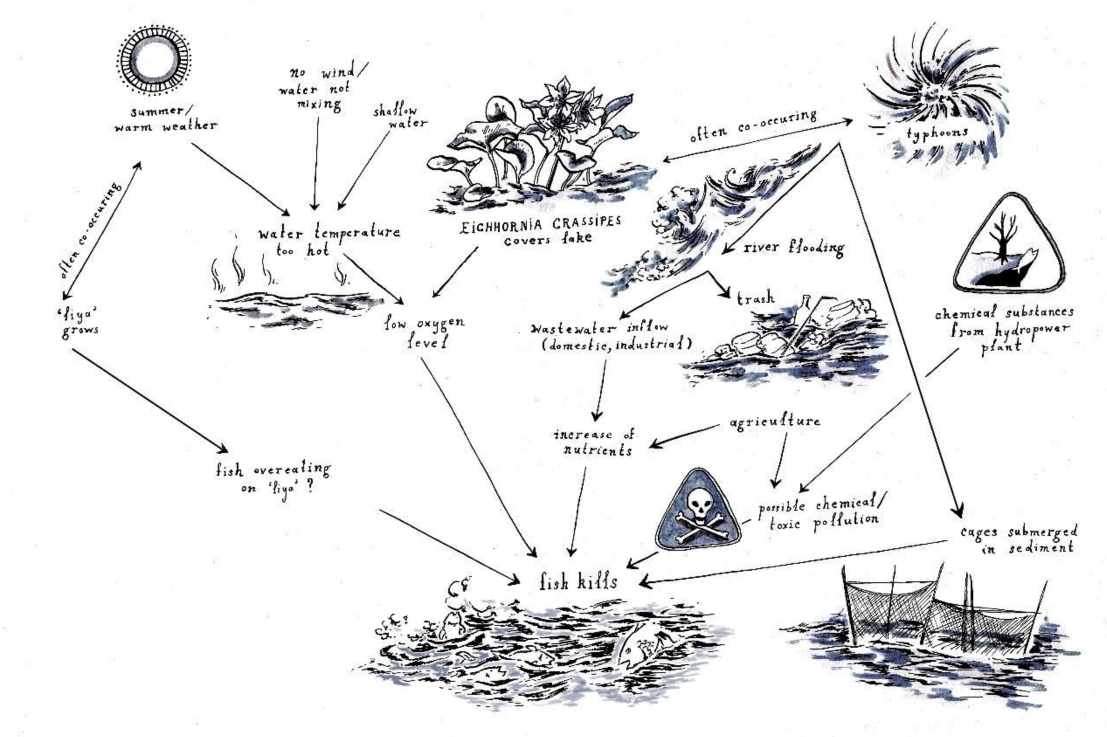

Fig. 4 Mental map based on fishers' perceptions of fish kill events. "*Liya*" – according to the LLDA official web page (n.d.) and fisherfolks descriptions (e.g. specific smell), the local name refers to the cyanobacteria *Microcystis aeruginosa* (however, the Philippines MA (2005) considers "*liya"* as *Lemna persilla*). Credit: Johanna Lohrengel

> "We already experienced a fish kill event, around April; I remember I came back from working abroad and the *tilapia* [*Oreochromis aureus*] in our cages died; and this occurs almost every year when there is too much *liya* [*Microcystis aeruginosa*] present in the lake; the oxygen in the water decreases when the weather is too hot, also because now the depth of the water is shallow." (Fisher: 39 years old)

As repeatedly noted by fisherfolks, fish kill events occur with the appearance of *Microcystis aeruginosa* and *Eichhornia crassipes* and the subsequent decrease in oxygen level. However, some fisherfolks noted *Microcystis aeruginosa* as a source of food for fish, e.g. *Oreochromis aureus* (although the caught fish are put in cages and not sold because of the bad taste of these fish during the intensive growth period of *Microcystis aeruginosa*). Additional emphasis was put on the change in water level depth. The decaying of dead fish and other organic matter was also mentioned as having an effect on fish kills. Furthermore, the fishers reported a link between the increased air temperature and the increase in water temperature, emphasizing the appearance of *Microcystis aeruginosa* and *Eichhornia crassipes* during the summer months (June–July). Inflow with polluted water (wastewater, runoff from agriculture fields) and chemical substances from hydropower plants as well as the appearance of trash were also reported as contributing to fish kills. The damage caused by typhoons and the appearance of a bad smell and darker water color were also named by the fisherfolks in respect to fish kills. The opinions of fishers are not consistent in regard to fish feeding patterns as some noted the negative effect of overfeeding on *Microcystis aeruginosa*, which causes fish to die. Although not directly linked to fish kills, the saltwater entrance through Pasig River, (which is now closed) according to the fisherfolks, was associated with better fish growth.

DISCUSSION

Our results show that the fisherfolks of Laguna lake, Philippines, perceived a decline in the abundance and catch of certain fish species (e.g. *Cyprinus carpio*, *Oreochromis niloticus*, *Hypophthalmichthys nobilis*, and *Channa striata*) and linked this phenomenon to three main drivers, namely the introduction of invasive species, a loss of fish habitat because of the change in the abundance of aquatic plants (i.e. *Nymphaea pubescens*, *Hydrilla verticillata*, *Vallisneria natans*, *Scirpus grossus*, *Cyperus imbricatus*, and *Salvinia molesta*), and increased water turbidity. Our results suggest that fishers' LEK about the lake has the potential to advance fisheries management by providing new information regarding the abundance, ecology and behavior of fish and other aquatic animals (see also Silvano & Valbo-Jørgensen 2008). Therefore, we follow the principle of Mistry and Berardi (2016: 1274): "that any effort to solve real-world problems should first engage with those local communities that are most affected, beginning from the perspective of indigenous knowledge and then seeking relevant scientific knowledge – not to validate indigenous knowledge, but to expand the range of options for action". As emphasized by Hill et al. (2020), "humanity's diverse knowledge systems" shall be celebrated while also recognizing their respective shortcomings." For Laguna Lake, this means that policy initiatives should embrace the holistic vision of fishers and promote ad hoc policy actions that consider the interlinkages among species in Laguna Lake. In general, the perspectives of local communities need to be integrated into local, national, and international policy frameworks.

Critical analysis of the major findings

This study focused on Laguna Lake, the largest inland water body of the Philippines, which has undergone tremendous change over the last century and is home to over 10 000 fishers (LLDA 2018a). Local fishers from the Mabato-Azufre community reported in semi-structured interviews that they catch a great variety of fish species, a typical feature of small-scale fisheries. In accordance with other studies of Laguna Lake (Palanca-Tan 2020), the four main species caught in 2019 were *Oreochromis aureus*, *Hypophthalmichthys nobilis*, *Cyprinus carpio*, and *Chitala ornata*. However, when comparing the list of fish species provided by fishers and the Philippines MA (2005) and Aquino et al (2011), some discrepancies appear, e.g. regarding the reported fish species. Of the fish species mentioned by the fishers, 18 species (58%) were recorded in the Philippines MA (2005) and 45% of the species matched the data presented in the Laguna Lake ichthyofauna study by Aquino et al. (2011). These differences and similarities show that the fishers' information can complement scientific surveys of the current composition of fish species in Laguna Lake or, given the different years of our sources for comparison (Philippines MA 2005, Aquino et al. 2011), help to update them. In this way, LEK

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can contribute to better understanding the ecosystem and managing fishery resources in a sustainable and collaborative way.

Our work represents an example of how LEK provides the basis to better understand complex and interconnected socio-ecological transformations when confronted with changes that threaten the benefits provided by fisheries and aquaculture in terms of employment (FAO 2020), food security, and nutrition (Béné et al. 2016). In Laguna Lake, fishers have recently caught fewer and smaller fish due to several factors including the introduction of invasive species like *Chitala ornata*, increased water turbidity, and the loss of fish habitats. Over the course of their careers, fishers were able to adapt to changing conditions by switching their target species, an adaptation strategy also described for fisheries in marine environments (see Faraco et al. 2016). However, the ecological changes have had important impacts on both their opportunities to sell fish and their personal use of fish (Mendoza et al. 2021). The fisherfolks of Mabato-Azufre named drivers behind this decline in fish catch that are similar to those mentioned earlier in the Philippines MA (2005), e.g. fish kills, and in the notes of the Community Forum held in 2012, e.g. the change in aquatic plant taxa (Tuble 2013). As reviewed by Moyle and Leidy (1992), the combined impact of several effects (e.g. pollution, habitat alteration, the introduction of exotic species, and commercial exploitation) is the basis for fish decline globally, and this very much resembles the fishers' narratives. For fish kill events, the fishers named more than five drivers and various interlinkages. This in particular demonstrates the fishers' complex understanding of the ecosystem.

The importance of aquatic plants, in the perception of fishers, for fish in Laguna Lake is particularly noteworthy. Although the overabundance of certain taxa such as *Hydrilla verticillata* was previously reported as a problem in several areas across the world (see the review of Murphy 1988) including the Philippines (Gangstad 1976, Cook and Lüönd 1982), the situation in Laguna Lake had changed compared with the earlier report by the Philippines MA (2005): "*E. crassipes* and *Hydrilla verticillata* were strongly decimated" (…) "floating macrophytes are virtually gone except in the outskirts, primarily of South Bay and East Bay" (p. 109). The Philippines MA (2005) also emphasized the possible consequences of and the lack of information about this problem in Laguna Lake: "Such a diminution in a usual component of the aquatic biota could have tremendous impact on associated fauna, but this has not been investigated. Submersed macrophytes are not an exception" (p. 109). The interviewed fisherfolks noted that the low abundance of certain aquatic plants (e.g. *Hydrilla verticillata*, *Cyperus imbricatus*) remains a problem nowadays. This is troublesome because aquatic plants are of crucial importance for the survival of other aquatic species and provide a range of ecosystem services (FAO 2012), including the aspects named by the interviewed fishers such as the provision of habitat, spawning, and nursery areas for several important fish species. Our study results, gained from the knowledge of fisherfolks, therefore suggest a direct link between the loss of the submerged macrophyte *Hydrilla verticillata* and the decline in numerous fish species, directly impacting local fishers' livelihoods.

Limitations and future directions

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Although only a small fishing community along Laguna Lake was interviewed for this study and LEK is likely to vary within and between groups (Berkström 2019). However, since few socio-cultural studies exist for Laguna Lake, such local studies are needed to monitor changes in the lake and in the socio-economic structures of the community. One of the main limitations of the study is that the interviewee sample only included one female fisher. This small number mirrors recent data from the LLDA database, which indicates that only 2% of the registered 11 814 fisherfolks are women (LLDA 2018a). However, as emphasized by Müller et al. (2015), "if a policy maker were to come into the region and only survey men or only survey elders, they might derive a false impression of the needs of the community and the level of pressure that this community puts on its natural resources". As stressed by Harper et al. (2017), the female contribution to fisheries such as processing, retail activities, and the repairing of fish gear are not given much attention considering the fact that men and women are both involved, although with different roles leading to the exclusion of women in many decision-making processes in fisheries research, management, and policy worldwide. For future analysis, female involvement in fisheries management in the Laguna Lake region should be studied as well as the effect of other factors, e.g. age and fishing experience, on the perception of environmental change in the Laguna de Bay Basin.

This study also provided several lessons for future socio-cultural research projects in the fisheries field. Firstly, the authors recognize the need for visual material while discussing Laguna Lake biota with the interviewees, particularly the use of photographs of fish species. Such an approach is widely used across the field of ethnobiology (e.g. de Medeiros et al. 2014; Silva et al. 2014) and helps to identify the species of interest (e.g. Thomas et al. 2007). Secondly, the ability to reach out to the local authorities while discussing fish and plant taxa was invaluable for species recognition on a scientific level due to the scarcity of available datasets for taxa at Laguna Lake. Thirdly, the authors also want to acknowledge their methodologically open approach, which included a modification of the interview guide, as the attention towards the importance of plants for Laguna Lake was primarily initiated by the fisherfolks. Overall, the authors would like to emphasize the importance of involving community members as research guides while exploring specific ecosystems.

In the case of the Philippines, the report of the World Bank (2003) recommends developing "more partnerships with qualified civil society and private sector groups to increase local capacity for natural resource management" (p. xv) which could be useful for improving the water quality of Laguna Lake (Tamayo-Zafaralla 2017). In addition, in line with the Intergovernmental Platform on Biodiversity and Ecosystems Services (IPBES 2012), Reyes-García et al. (2021) note one key point which resonates greatly in the respective study, i.e., "Indigenous peoples and local communities hold knowledge essential for setting realistic and effective biodiversity targets that simultaneously improve local livelihoods". Fish farming, fish stocking, and the introduction of non-native fish species for fishing purposes are widespread in Laguna Lake, putting pressure on native biodiversity. Our results show the paramount importance of these introduced species to fisheries and how this has increased compared to previous years (Table 1). Conserving biodiversity and restoring a healthy ecosystem in Laguna Lake can only be successful if the needs of fisherfolks are taken into account and if they are involved in ecological efforts early on to facilitate co-management and thereby increase fishers' engagement and compliance. However, significant barriers including structural and cultural differences, such as differences in goals, research timeframes, skills, values and mindset, as well as the mismanagement of conflicts arising from interpersonal disagreements and traditional outlook on knowledge between practitioners and academics, are impeding the co-production of knowledge (Woodley & Gilsenan 2019; McCabe et al. 2021). For Laguna Lake, we regard the cooperative attitude of the fisherfolks toward this study as a positive sign for future collaborative work between academic science, governance agencies, and the local fisherfolks.

Management implications of the study

Our study supports the position of various agencies (e.g. United Nations Sustainable Development Goals, UNESCO, Aichi Biodiversity targets) with respect to the importance of integrating local people into natural resource management (e.g. Azzurro et al. 2019; Martins et al. 2018; Mazumdar et al. 2018; Cavole et al. 2020). Numerous scholars have considered LEK and its direct applicability in environmental monitoring across the Philippines, e.g. pangolin distribution (Archer et al. 2020), fish behavior (Macusi et al.2017), and agroforestry (Galang & Vaughter 2020). For Laguna Lake and other lakes in the Philippines, most studies have focused on biological-technical information useful for fisheries development plans (Fortes 1995). More recently, there have been several water governance agencies in the Philippines and the Laguna de Bay Basin, e.g. local government units, village and local community units (*barangay*), and the Yaman ng Lawa, which integrate traditional knowledge into their action projects in villages across the lake from Mabato-Azufre (Paterno et al. n.d.; Masuda 2019; 2021). The question is whether these efforts go far enough and are recognized as sufficient by fisherfolk. Over the years, and despite varying political rhetoric, fisherfolk in Laguna Lake have struggled to make their voices heard due to outside interests in privatizing the use of the lake and a technocratic, depoliticized management approach (Saguin 2019). Our results suggest that many fishers have a negative outlook on the socio-ecological situation of Laguna Lake despite the LLDA's vision: "by 2020, the Laguna de Bay Basin will be transformed as the focal center for sustainable development through sound ecological governance" (Masuda 2019: 161). Likewise, the discussions of, for example, the Laguna de Bay Development Forum (LLDA 2018) and a recent news article titled "Program for Laguna de Bay good, but fishers feel forgotten" (Cinco 2021)indicate that the dialogue among stakeholders needs to be further improved. Therefore, we suggest that the recommendation proposed by Tamayo-Zafaralla et al. (2002) is still highly relevant twenty years later: "Government and non-government agencies as well as academic institutions should consult with the open water fisherfolks and fish-pen operators to integrate their concerns in the plans and programs for lake restoration and enhancement activities and programs" (p.135).

CONCLUDING REMARKS

Laguna lake fisherfolks, some with up to 60 years of experience, reported several causes for the decline in the catch of fish species including invasive species, the loss of fish habitat, and the increased water turbidity which according to fisherfolks are inter-linked with the decline in certain aquatic plants and fish kill events. We recommend including factors such as gender, age, and fishing experience in future LEK studies in Laguna

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Lake to further deepen our understanding of social-ecological change processes. Our findings confirm that involving local knowledge keepers - namely fisherfolks - enhances scientific discussions about the decline of fish stocks in the region. However, to truly foster knowledge co-creation among fisherfolks, researchers and policy makers in Laguna Lake, LEK needs to be appreciated as an equally important and rich source of information in its own right. It is crucial to recognize LEK and the plurality of knowledge systems for enabling collaboration and expanding our understanding of freshwater aquatic ecosystems that experience major environmental changes.

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Declarations

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