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Climate change, traditional ecological knowledge, and riverine biodiversity conservation: a case in Aklan, Central Philippines

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Abstract
We framed climate change (CC) discourse through its disruptions to local culture and livelihood in a subsistence riverine fishing community in Central Philippines. Our main goal was contextualizing how local communities' traditional ecological knowledge (TEK) related to climate, fisheries, and taboos can strengthen freshwater fisheries management and biodiversity conservation. We adopted a mixed-method purposive sampling of the 126 fishing households in the Nabaoy River Watershed in the municipality of Malay in Aklan province. The high CC awareness was associated with the increasing frequency and intensity of extreme climatological events and erratic weather patterns. These CC-driven perturbations were primarily attributed to the ballooning human population and deforestation. These threats, in turn, were linked to the diminishing state of the Nabaoy River, heralded by the perceived marked decline of frog and dragonfly populations believed to be indicators of river health. Riverine biodiversity was also perceived as dwindling, with fish catch and their sizes shrinking. Furthermore, the observed fishing taboos guiding local informal (de facto) institutions corroborated formal (de jure) temporal and spatial fisheries management measures. Indeed, local communities have relevant long-term knowledge of management (e.g., TEK) and development-oriented structures and systems (e.g., informal institutions). These invaluable social capital assets are crucial in building resilient governance systems to address local conservation issues and concerns, particularly in data-deficient areas or lacking formal management contexts. Hence, formal management interventions should integrate TEK and the informal institution in which it is embedded and engage local TEK holders as partners in freshwater conservation efforts.

Keywords Climate change · Indigenous knowledge systems and practices (IKSP) · Local and indigenous knowledge systems (LINKS) · Local ecological knowledge (LEK) · Indigenous ecological knowledge (IEK) · Citizen science

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1 Introduction

Freshwater ecosystems worldwide are subjected to multiple threats, such as overexploitation, pollution, habitat degradation, and invasive species, and their interacting impacts are magnified by global climate change (CC) (Rivaes et al., 2021; Su et al., 2021; Tickner et al., 2020; Dudgeon, 2019; Jha et al., 2019a, 2019b; Reid et al., 2019). Indeed, the freshwater biodiversity loss in the Anthropocene is already pervasive in all taxonomic groups (Reid et al., 2019; Rivaes et al., 2021; Tickner et al., 2020), which experienced a more rapid decline (76%) compared to terrestrial and marine environments (39%) (McLellan et al., 2014). According to the most recent report by Su et al. (2021), anthropogenic activities severely affect fish biodiversity in more than half of the 2,456 river basins worldwide. In Southeast Asia (SEA), freshwater environments play critical socioeconomic and cultural roles and host global hotspots of biodiversity and endemism, yet remain among the most threatened in the world (Coleman et al., 2019; Hughes, 2017; Sodhi et al., 2009). The freshwater biota in SEA also received less attention and investments compared to their terrestrial, marine, or temperate counterparts (Coleman et al., 2019; Tydecks et al., 2018), particularly in the Philippines (Magbanua et al., 2017; Papa & Briones, 2017; van der Ploeg et al., 2017).

Located within the Ring of Fire along the Western Pacific, the Philippines is particularly vulnerable to seismic and climatological disturbances (Pulhin & Tapia, 2021; Tolentino et al., 2016). CC-induced warming is expected to aggravate unpredictable weather patterns that could potentially result in drier dry months and wetter wet months in the Philippines. Inland riverine biodiversity, integral to the subsistence livelihood of many vulnerable rural communities in the country, will be harshly affected by changing water levels and increasing incidences of drought and flooding (Tolentino et al., 2016). As many riparian vegetations are non-resilient to drought effects (see Jha et al. (2019a), such perturbations further hinder riverine ecological functioning (Jha et al. (2019b) because the two systems are inextricably connected (Hoppenreijs et al., 2022). Indeed, the current freshwater biodiversity in the Philippines is already severely declining, with many freshwater bodies in poor conditions (Magbanua et al., 2017; Papa & Briones, 2017; van der Ploeg et al., 2017). Approximately 40 (Pineda-Ofreneo, 2019) and 180 (Bengwayan, 2019) of the 421 principal rivers in the country are considered biologically dead or severely polluted, respectively. Considering the perennial widespread lack of government resources to monitor the many rivers in the country, freshwater conservation in the Philippines hinges on local initiatives (van der Ploeg et al., 2017).

The recent reemergence of Citizen Science, a fashionable term for the participation of the local people in scientific activity, has seen widespread utility in local conservation efforts (see the review of MacPhail & Colla, 2020). In the Philippines, many conservation initiatives integrate Citizen Science (see Requilme et al., 2021; Licuanan & Mordeno, 2021; Maliao, 2019). Citizen Science relies on the context-and-location-specific knowledge of local resource users about their immediate environments. This cumulative stock of knowledge regarding the natural world is collectively called traditional ecological knowledge (Berkes et al., 2000). TEK is distinct to a given society of "knowledge holders," spanning from "local" and "Indigenous" peoples around the world. "Local people" refers to a community of people with multigenerational association to a given place who do not necessarily self-identify as Indigenous (Wheeler & Root-Bernstein, 2020). On the other hand, "Indigenous Peoples (IPs)" refer to a society of people that self-identify as Indigenous. According to United Nations (UN) definition,

IPs are descendants of those present in a given location before colonization by another ethnic group (Wheeler & Root-Bernstein, 2020). Hence, TEK of "local people" is synonymous with the term local ecological knowledge (LEK), while those of "Indigenous Peoples" is synonymous with indigenous ecological knowledge (IEK) (see Davis & Ruddle, 2010).

TEK of a given society evolves through social experiences and adaptive processes over centuries of ecological adaptation by its knowledge holders to its respective environments (Berkes et al., 2000). The transmission of TEK across generations can happen in various forms, such as through stories, songs, folklore, proverbs, cultural values, beliefs, rituals, community laws, local languages, and agricultural and fishing practices (Johannes, 2000). TEK is a crucial building block of local social capital. Social capital refers to relationships and structures that make a given social unit more effective, and its theory has been extensively discussed in the last few decades (Putnam, 2000). Social capital is essential for sustainability because it facilitates cooperation and reciprocity among community members (Pretty & Smith, 2004).

The significance of TEK worldwide is reflected in its inclusion in many global environmental governance fora. The World Heritage Convention of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Convention on Biological Diversity (CBD) acknowledge the importance of TEK in achieving the global conservation agenda (see Fajardo et al., 2021; Aswani et al., 2018). TEK is deemed a critical knowledge system for fostering adaptation and resilience to environmental and climatic change (Cinner et al., 2018). TEK use is widespread, covering various contexts and settings (see Berkes, 2010; Berkes et al., 2000). TEK is further regarded as a crucial alternative and/or complementary to traditionally acquired scientific data, particularly in highly complex environments and in data-poor contexts (see Johannes, 1998). As CC magnifies the magnitude and inherent socio-ecological complexity of environmental problems, TEK of local and IPs broadens the knowledge base for more holistic decision-making (see Wheeler & Root-Bernstein, 2020). In the Philippines, TEK contributes to the sustainability and productivity of many systems, including forest management (Landicho et al., 2021), farming practices (Zapico et al., 2019), land management (Geronimo et al., 2016), biodiversity conservation (Salvana & Arnibal 2020), fisheries monitoring (Maliao, 2019; Lavides et al., 2010), and climatic adaptations (Nelson et al., 2019).

The overlying goal of this study was contextualizing how TEK of local fishers can strengthen freshwater fisheries management and riverine biodiversity conservation efforts. We used a case study approach in a riverine fishing community along the Nabaoy River in Aklan province, Central Philippines. The fishing community is not categorically a member of any Indigenous Cultural Communities (ICCs)/IPs group in the country; hence, they can be considered as local people under the TEK holder typology. TEK, in our context, is thus synonymous with local ecological knowledge (LEK). First, we assessed local climate-related TEK to understand the overall awareness of CC. Local perceptions of CC and their determinants are critical for tailoring CC adaptation strategies at the grassroots (Berrang-Ford et al., 2015). Second, we explored local fishing and fisheries-related TEK and how these have changed over time. Due to their proximity and reliance on the river and its bounties, local resource users provide better insights into their fluctuations and changes spatially and temporally (Maliao, 2019). Finally, we collected fishing-related taboos observed in the local community and inferred their implications in riverine fisheries management. These taboos, referred to in Game Theory as rules of the game, ensure complementarity between individual and group interests in a community (Ostrom, 1990) and are integral to TEK comprising locally built informal institutions (Colding & Folke, 2001).

2 Methods

2.1 Study site and sampling method

Our study site was the village of Nabaoy, a riverine fishing community straddling the Nabaoy River in the municipality of Malay. The site is within the province of Aklan, located northwest portion of Panay Island in the Western Visayas of Central Philippines (Fig. 1). The length of the Nabaoy River is 17 km from its head source to its mouth, draining into the Sibuyan Sea. The drainage area of the Nabaoy River is around 2,375 ha, proclaimed as the Nabaoy River Watershed (NRW) and a part of the more expansive Northwest Panay Peninsula Natural Park (NPPNP). The Nabaoy River is the primary source of potable water supply for mainland Malay and the island of Boracay.

We followed a mixed-method research approach using a pretested semi-structured instrument covering the following thematic issues: (1) climate change awareness and understanding, (2) fishing and fisheries knowledge, and (3) fishing-related norms and taboos. We adopted homogeneous purposive sampling based on respondents' residence, fishing livelihood, and duration (≥ 10 years). We sampled the total identified population because the number of respondents who met our criteria was small. There were 369 total households, and only 126 were engaged in riverine fishing, either as a primary livelihood (39 households) or as a source of supplemental income (87 households).

We presented our project to the municipal and village leaders and applied for relevant research permits before the start of our project. We also conducted community dialog at the village level and presented the goals of our project. We solicited Prior Consent from each respondent before each of the interviews. We randomly interviewed the male or female

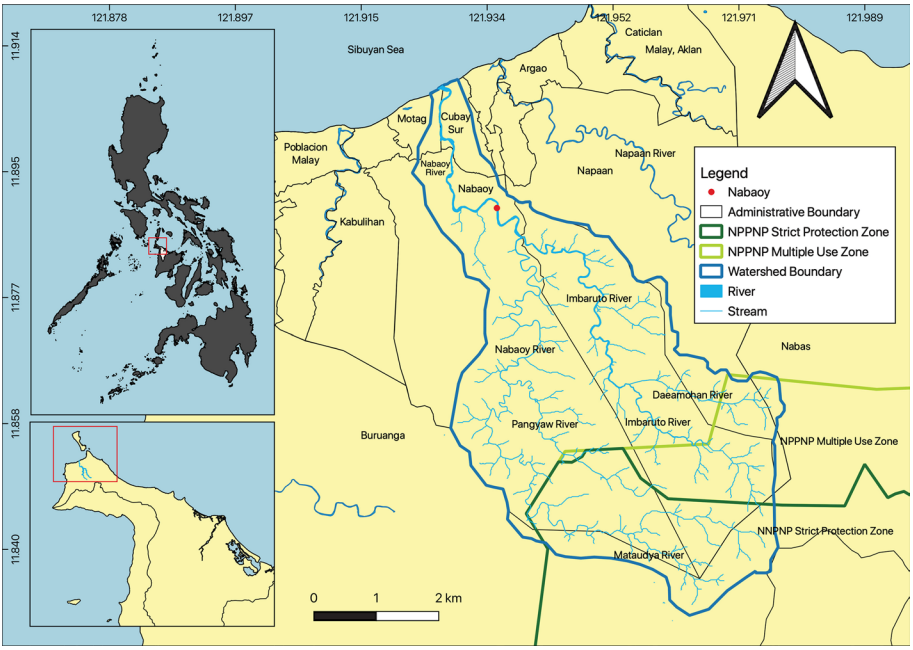


Fig. 1 Map of the study site

representatives of the 126 fishing households (≥ 18 years old) to have a homogeneous representation between the sexes. Contextual attributes of respondents collected include livelihood engagement, years of fishing, household size, age, sex (male or female), and education (years spent in formal schooling). TEK data on climate, fishing and fisheries, and fishing-related norms and taboos were triangulated, verified, and enriched through cultural consensus in the subsequent three Focus Group Discussions (FGDs) with expert fishers (nine participants on each occasion) identified by the community. Field sampling was conducted in July–December 2021. The project's final output was presented to the village and community leaders on two separate occasions in 2022.

2.2 Data analyses

Differences in CC awareness (yes and no), as well as its association with sex (male and female), age groups (≤ 30 years and ≥ 31 years), and education (≤ 10 years and ≥ 11 years of education), were determined by X^2 test ($p < 0.05$). Perceived CC manifestations were verified using empirical climatological data in the region (average and maximum temperatures and precipitation), and their trends were analyzed using simple linear regressions. Respondents were also asked to rate the perceived influence of CC using a 10-point scale (with 10 as the highest) in the following categories: (1) drier dry months, (2) frequent flooding, (3) fisheries decline, (4) heavier rains, (5) potable water shortage, (6) lower river discharge, and (7) increased human ailments. We compared differences in scores between sexes across the above categories using the X^2 test ($p < 0.05$).

We also gathered recollected perceived decadal fish catch (in kg) since the 1960s and their perceived catch 10 years into the future (2031s). We analyzed the perceived catch data using simple linear regression to determine the catch trend. We only reported aggregated river prawn catch (*Macrobrachium* spp., Family *Palaemonidae*) because they were the site's most commercially valuable riverine species. Species identification through specimen photos was verified by the University of the Philippines in Los Banos-Museum of Natural History (UPLB-MNH), Philippines.

3 Results

3.1 Demographics of the respondents

One hundred twenty-six (126) representatives from each of the distinct fishing households were interviewed. The age range of the respondents was 18 to 83 years old ($\bar{x} = 44$ years). They have been residing and fishing on-site for an average of 42 and 26 years. Male and female respondents represented 49% and 51% of the respondents, respectively. The average family size was 4, and the maximum family size reported was 12. The respondents had an average of 8 years of formal education. Approximately 31% ($n = 39$) of the respondents reported fishing as their primary source of income, with no alternative livelihood options. The rest of the respondents ($n = 87$) participated in river fishing as a supplemental source of income. Most households also collected a wide range of non-timber forest products along the river and lowland forest for subsistence and exchange with traders. The majority also engaged in subsistence shifting cultivation and occasional seasonal labor.

3.2 Awareness and knowledge of climate change

The majority (98%) of the respondents perceived that climate was changing as manifested by (1) extreme warming during the dry months of March to May and stronger rainfall during the wet months of June to November (86%) and (2) unpredictable weather patterns (14%). These observations were consistent with empirical regional meteorological data (Fig. 2). The decadal average ($R^2 = 0.76$, $F_{1,10} = 32.2$, $p < 0.001$) and maximum ($R^2 = 0.80$, $F_{1,10} = 39.5$, $p < 0.001$) temperatures were significantly increasing. Although precipitation has increased since 2000, no overall detectable trend existed between 1910 and 2020. However, only 62% of the respondents had putative knowledge of what causes CC, significantly higher than those without (37%) (X^2, $p = 0.008$). In general, CC was perceived as largely human-induced by 90% of the respondents who had putative knowledge of what causes CC (e.g., increasing human population, continuing deforestation, and worsening pollution)

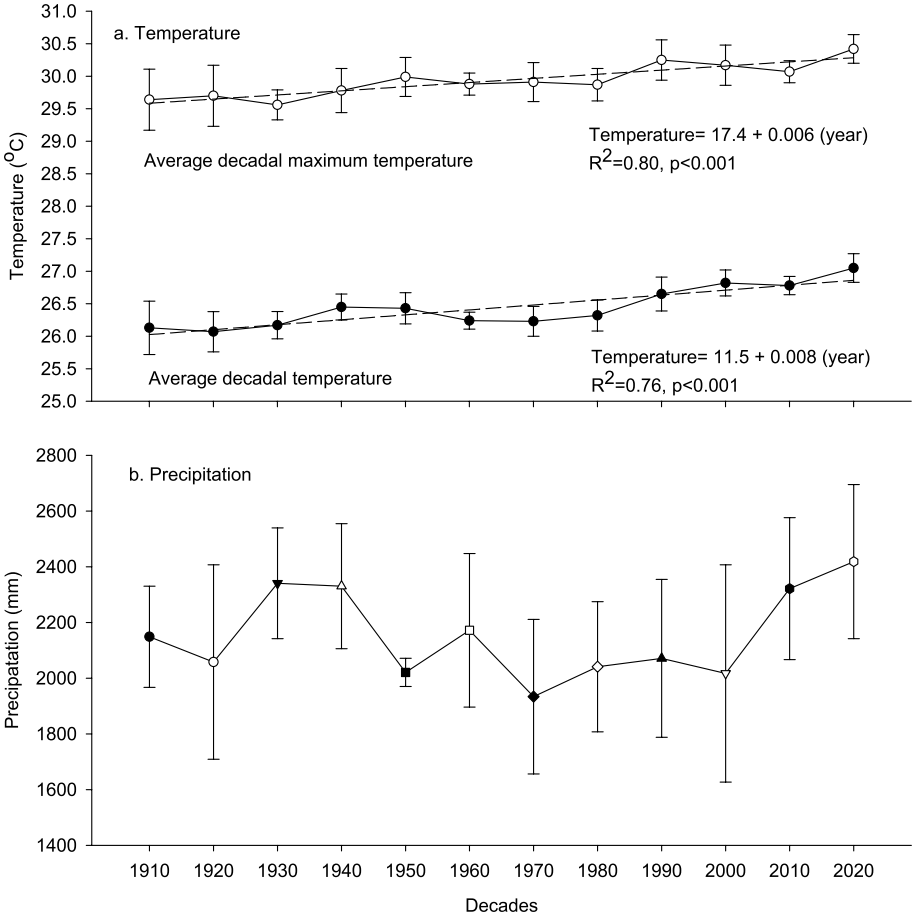


Fig. 2 Average decadal temperatures (**a**) and precipitation (**b**) in the western Visayas (Region 6), Philippines. The error bars are based on SD, and the dashed line is based on simple linear regression. (Data source: Climate Change Knowledge Portal, World Bank Group-https://climateknowledgeportal.worldbank.org/)

(Fig. 3). The remaining 10% of the respondents attributed CC to "Aging Earth," a common understanding among locals and IPs that the planet is getting older and is more vulnerable to perturbations. There was no association between knowledge of what causes CC and sex (X^2, $p=0.958$) or age (X^2, $p=0.0.721$), but it was positively associated with education (X^2, $p=0.008$). CC knowledge was acquired primarily by 60% of the respondents through direct personal experience. The respondents homogeneously perceived that CC was causing (1) extreme dry months, resulting in (2) potable water shortage and (3) low water levels during the dry months, (4) heavier rains in wet months causing, (5) extreme flooding, (6) overall fisheries decline, and (7) increase in human ailments (Fig. 4). These views did not vary by sex, age group, or education.

3.3 Riverine fisheries and fishing-related taboos

The local riverine fisheries are multi-species, multi-gear, and subsistence. The local fish harvesting strategies were primarily traditional, incorporating local knowledge transmitted over generations within the family and the community (Table 1). They harvested finfishes, gastropods, crabs, prawns, and other invertebrates (e.g., river frogs and turtles). The river prawns (*Macrobrachium* spp., Family *Palaemonidae*) were the most widely fished because of their high commercial value. We reported an aggregated perceived catch of river prawns, covering six (6) putative distinct species based on local taxonomy (Fig. 5). Unfortunately, these local identifications were not verified at the species level resolution by the Museum of Natural History at the University of the Philippines in Los Banos, Philippines. It was due to a lack of in-house experts in freshwater crustaceans at the time of consultation and the inadequacy of photos to demarcate intra-species differences. River prawns were caught primarily by *Panagon* (bamboo trap) (Table 1). The harvest of river prawns in 2021 was approximately 0.8 kg per individual per fishing trip, representing only 28% of the perceived catch in the 1960s (Fig. 6). The perceived prawn yields since the 1960s were

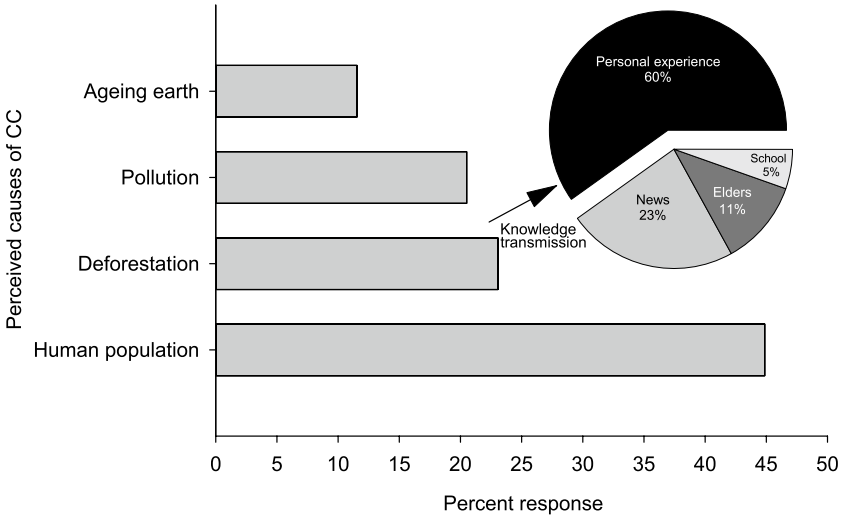


Fig. 3 Perceived causes of CC and CC knowledge acquisition and transmission. Aging Earth belief views the planet as a living entity, and as the planet ages, it becomes more vulnerable to human perturbations

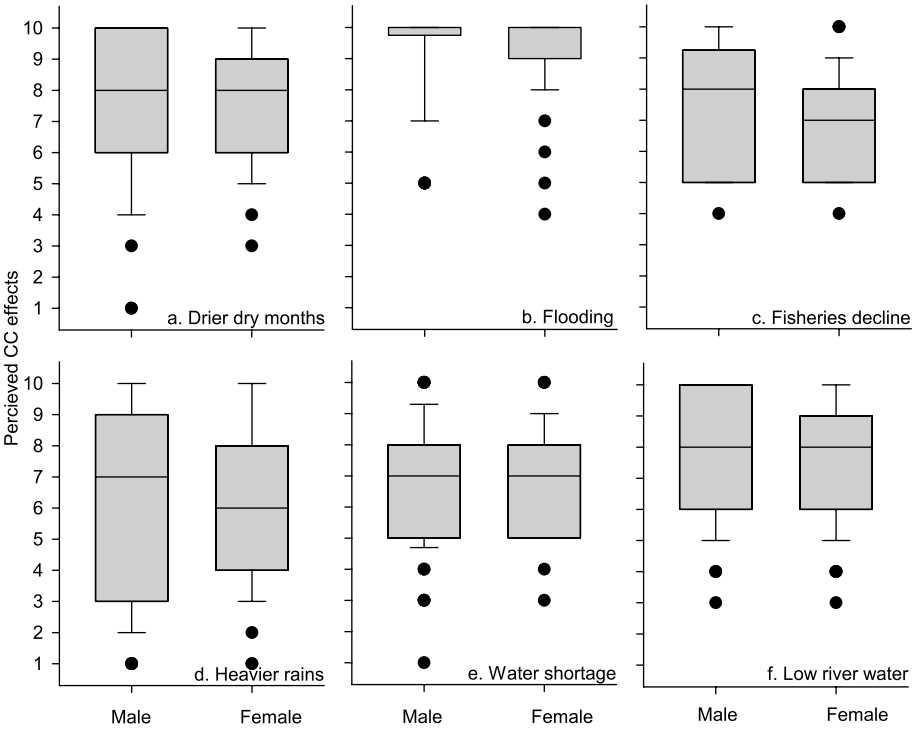


Fig. 4 Perceived impacts of CC. The centerline of the box is the median. The bottom and top of the box are the 25th and 75th percentiles, and the whiskers below and above the box are the 10th and 90th percentiles. Points outside the whiskers are outliers

significantly declining by 10% (0.3 kg) per decade, according to the result of linear regression ($R^2 = 0.95$, $F_{1,6} = 60$, $p < 0.001$). This declining trajectory was perceived to continue in the coming decade.

The fishing-related norms and taboos subscribed to by the local fishers in Aklan were based on mythical spirits pervasive in both local and Indigenous cultures worldwide (Table 2). We only reported taboos that are relevant to riverine fisheries management.

4 Discussion

4.1 TEK associated with climate

The Philippine government has established various legal and institutional frameworks for climate change adaptation (CCA) strategies. The most notable of these legal instruments is the Climate Change Act (RA 9729) of 2009, which established the Philippine Climate Change Commission (CCC). The CCC spearheaded crafting the National Climate Change Action Plan (2011–2028), which targeted seven thematic areas (e.g., ecological and environmental stability and knowledge and capacity development). They are coherent with the UN SDGs and the Sendai Framework for Disaster Risk Reduction. These thematic areas recognized the contribution of TEK of locals and IPs in the country (e.g.,

Table 1 Representative traditional fishing methods with some adaptive innovations

Gears used	Fishing method	Fishing strategy
Aeat is made of bamboo[1], rattan[2], nito[3] strips, or a combination of the materials. It is a hand-woven cylindrical basket, usually at least 0.5 m tall from the base. This hand-woven material is used for catching shrimp, crabs, and fish from the river. 	*Panikop*  	*Panikop* is done by inserting the *Aeat* between the legs and holding it tightly through slight compression. The funnel and the rest of the *aeat* must touch the bottom. Then, the *manugnikop* (the person doing the fishing) will manually flip the stones ahead of the *aeat* and inwardly guide the fish to its mouth. The process is repeated for 2–3 h during the daytime, either in the morning or afternoon. Women and children mainly do this
Baean-an is made of bamboo and is used as a companion gear for *Aeat* that serves as a container for the catch. More recently, locals innovated the 1.5-L PET soda bottle and use as *baean-an*  		

Table 1 (continued)

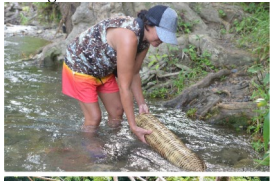
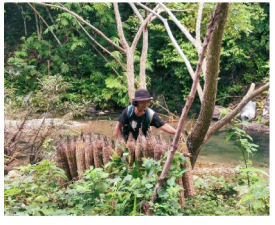
Gears used	Fishing method	Fishing strategy
Taun is made of *bamboo*, *rattan*, or *banban*[4], stripped thinly up to 3 cm in width and woven into a trap for shrimp, fish, and crab. It is approximately 0.5 m tall. It can last for 6 months to 2 years, depending on the material used and the frequency of usage 	*Panagon*  	*Panagon* is a local method of setting fish, shrimp, and crab traps known as *Taun*. The trap is deployed in the afternoon, dipped in the river, covered with rocks, and harvested at dawn the following day. Rotten or fresh but roasted coconut meat is used as bait. Grated coconut wrapped in "*payaw*[5]*"* leaves and tied at the end is also used as bait. Locals typically set up at least 20 *taun*, equivalent to one "*tinggahan"* (a local way of carrying loads like *taun* by attaching and balancing them on a bamboo pole or wood stem). *Panagun* is the preferred method of catching freshwater prawns
Plastic Taun is made of 1.5 L PET soda bottles joined together to make it longer, in which one end is open, and the other has a bottleneck with holes and is closed with a cap. They are considered an innovation by the locals 		

Table 1 (continued)

Gears used	Fishing method	Fishing strategy
Baean-an is made of bamboo, like *Taun,* and is commonly used as a complementary gear of *Aeat*. It is the prepared gear for *Pangatas* 	*Pangatas* 	*Pangatas* fishing includes diverting the water flow in different directions to drain an area and channel the water to where the *Baean-an* is installed. *Pangatas* can last from an hour to half a day. This fishing method is ideal during dry months when water discharge is low
Sungya is a tool used for catching shrimp, fish, and crab. It is made of bamboo and a net. The net is attached to a bamboo triangle, usually about a meter or longer 	*Panungya* 	*Panungya is done* along the riverbanks during flooding. It can catch shrimp, fish, and crab. *Panungya* lasts around 3–4 h. This fishing method is ideal during rainy months when flooding is frequent

Table 1 (continued)

Gears used	Fishing method	Fishing strategy
Dogmon is a pile of rocks layered with dried coconut and banana leaves 	*Padogmon* 	*Padogmon* is a Fish Aggregating Device (FAD). The *Dogmon* is left for three weeks to one month before harvest. During harvest, locals set up four posts around the *Dogmon* with fishnets fixed with rocks to cordon off the area. The harvest lasts around 4 h

[1] *Bamboo* belongs to subfamily *Bambusoideae* in the grass family

[2] *Rattan* belongs to genus *Calamus* in the palm family

[3] *Nito* belongs to genus *Lygodium* in the fern family

[4] *Banban* belongs to genus *Homalomena,* an herbaceous plant growing along rivers

[5] *Bugakay* belongs to genus *Schizostachyum,* an endemic bamboo species characterized by its long internodes

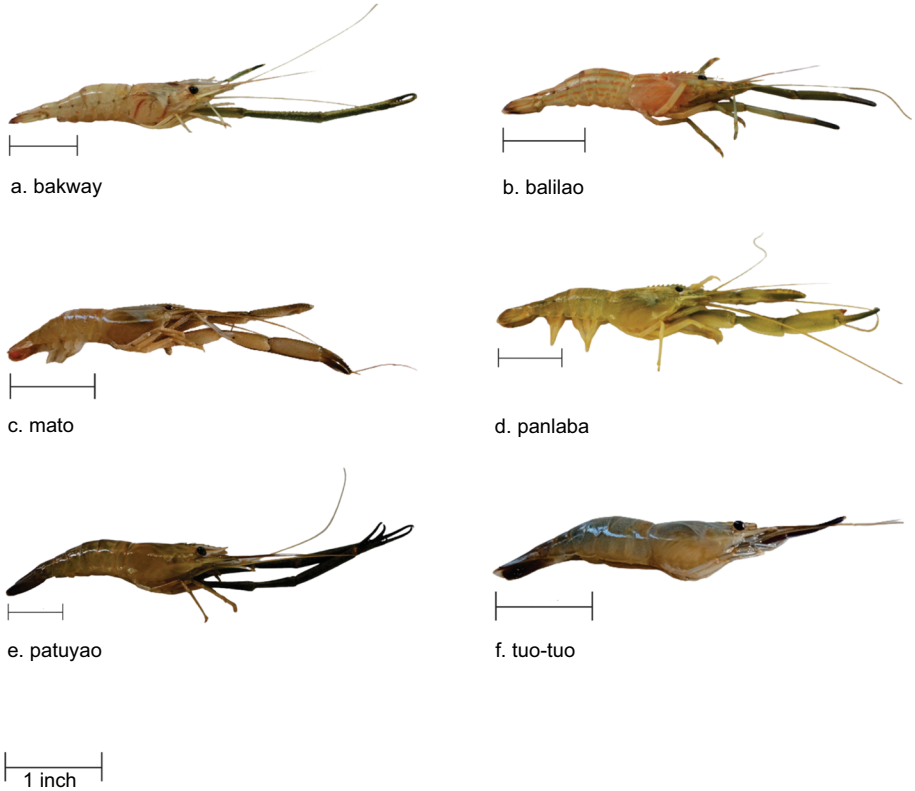


Fig. 5 Based on the local taxonomy, the locals harvested six putative freshwater prawn species (*Macrobrachium* spp.)

CCC Resolution no. 3) following the Paris Climate Accords. The Hyogo Framework for Action also acknowledged TEK as a critical source of knowledge system to build a culture of safety amidst CC. With natural hazards claiming Asian lives representing more than half of the total global casualties in the first decade of the twenty-first century, TEK has been shown as critical for building local community resilience amidst such perturbations (Hiwasaki et al., 2014).

In our site, severe weather was predicted through TEK-reinforced indicators, such as birds (e.g., swallows) flying disjointedly (*gaeinopad nga mga salimbabatang*) or black ants moving out in concert from their mounds (*gaginuwa ag gaparada nga mga itom nga guyom*). As heavy rains often start upriver, murky river water carrying buried, decomposing plant leaves (called *gam-ok*) was also used locally as an early warning signal of incoming heavy rain and flooding. However, there was scant evidence that TEK of local communities, including those of IPs in the country, was integrated into government-orchestrated CCA strategies. Indeed, although the CCA institutional systems have been in the Philippines for at least a decade, CC awareness remained variable among Filipinos. The recent survey by Cabal et al. (2021) of residents in Zambales in Central Luzon showed a low understanding of CC. A more recent national study by Bollettino et al. (2020) covering 5,184 Filipino adults also showed an inadequate knowledge of CC at the national level. In

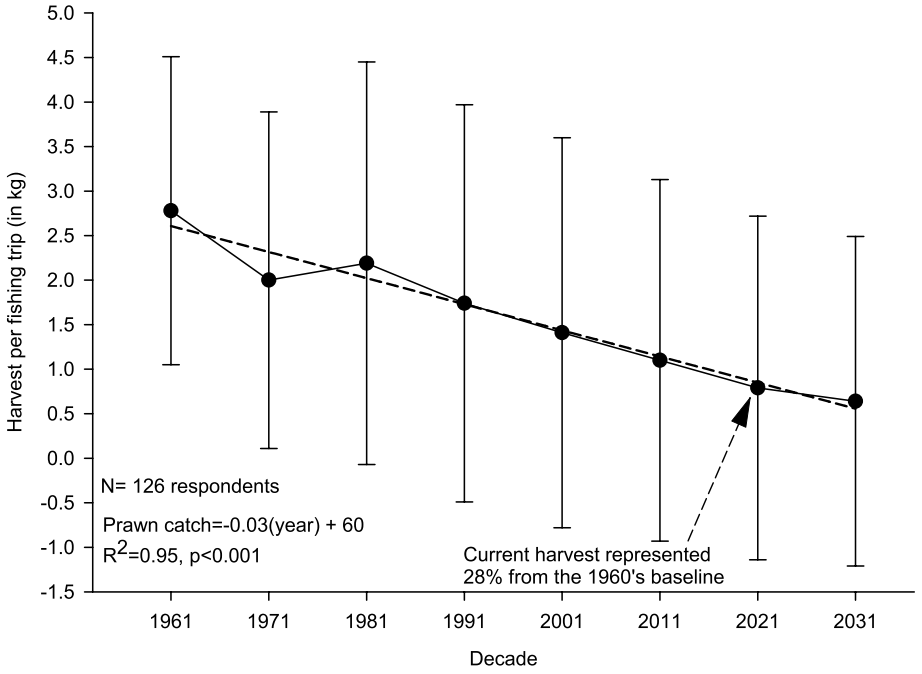


Fig. 6 The trend of perceived aggregated decadal averages (Error bars are based on SD) of river prawn catches in the Nabaoy River. The dashed line is based on simple linear regression

their survey covering 119 countries, Lee et al. (2015) showed that while changes in local temperatures have been the most evident characteristic in Asia, 65% of the respondents in India were unaware of CC. These CC awareness variabilities reflected what Persoon and Minter (2020) claimed that local people in the tropics have relatively insufficient knowledge of the gradual climatic change compared to other climes. Unfortunately, CC awareness is crucial to garnering public support for CC mitigation strategies (Luís et al., 2018).

On the contrary, our study demonstrated high CC awareness. They have a homogenous understanding that CC triggers the following: (1) drier dry months with unprecedented low river discharge, (2) heavier rains and frequent flooding during the wet months, (3) declining riverine fisheries, and (4) increasing human illnesses. Mercado (2016) also found comparable results among the marginalized urban residents of Manila, the economic capital of the Philippines. Similarly, local farmers in the northern Philippines also showed high awareness of CC (Peñalba, 2019), as did coastal residents in the Central Philippines (Combest-Friedman et al., 2012). The heightened and homogenous awareness of CC among these subgroups could be due to shared vulnerabilities and high-risk exposures to CC-induced disasters. The livelihoods and culture of these vulnerable communities, in particular, are heavily intertwined with the land and environment. The reliance on climate-sensitive natural resources made them vulnerable to climatic disruptions, such as heavy rainfall, flooding, and drought. Indeed, local CC awareness was associated with the increasing frequency of these aberrant climatological events. Weather patterns had been perceived to exhibit extremes and instability. Dry months between March and May were perceived to be getting warmer, and rains during wet months between June and November were heavier, occurring

Table 2 Fishing-related taboos practiced at the study site. "E*ngkantos*" are mythical nature spirits based on local folklore

Observed taboos	Local meaning	Practical implications
1. Fishing is prohibited on Tuesdays and Fridays, especially during mid-afternoon	Malevolent "*engkantos*" are most active during these times	Limits fishing temporally
2. Avoid huge, old trees and rocks because they are the abode of "*engkantos*"	Huge trees and rocks are considered the preferred abode of "*engkantos*"	Limits fishing spatially
3. Say "*tabi-tabi po*" (excuse me)" and bring ginger[1] when venturing into more remote upstream areas of the river	Remote upstream areas of the river are considered sacred, where "*engkantos*" are believed to dwell; ginger is believed to ward off malevolent "*engkantos*"	Promotes respect for nature and avoids overfishing in those areas
4. Going alone in the river or forest is dangerous because "*engkantos*" can cause you to drift off track and go in circles	Some people are referred to locally as "*baeaueons,*" to refer to individuals who entice and/or are susceptible to "*engkantos*" attention	Reflect on camaraderie and strengthen social bonds within the community
5. Do not announce where you will fish or where you have been fishing loudly, as this will result in bad luck	Announcing your fishing spot loudly is considered unethical behavior, and river "*engkantos*" will punish the offender with a low catch	Avoid aggregate fishing
6. Silence must be observed during fishing in the river	Unnecessary noise will disturb river "*engkantos*" and will cause reduced catches	Avoid disturbing nearby fishers; respect nature
7. The roasting of river prawns, snails, and crabs is prohibited	Roasting river shrimp, snails, and crabs are considered a local taboo, and malevolent "*engkantos*" will punish the violator	This practice limits how these species are cooked

[1]Ginger (*Zingiber officinale*), a perennial herbaceous plant of the family *Zingiberaceae*, is widely used in ethnomedicine and as a talisman to ward off malevolent spirits

earlier and lasting longer. The cold months between December and February were also characterized to exhibit unprecedented cooling. These trends in perceived CC impacts agreed with other findings in the Philippines (Macusi et al., 2021; Nelson et al., 2019; Peñalba et al., 2019; Combest-Friedman et al., 2012) and worldwide (Peerson & Minter, 2020; Mihiretu et al., 2021; Ncubc & Tawodzera 2019). These locally perceived weather irregularities were consistent with empirical meteorological data in the region (Fig. 2) and national trends (Cinco et al., 2014). This result was also compatible with global meta-analyses of Savo et al. (2016), demonstrating subsistence communities detecting an increase in temperature and changes in seasonality and rainfall patterns worldwide. Over the years, the increasing frequency and intensity of river flooding compelled many households living near riverbanks to move to the mountainside or embrace *in situ* flooding adaptations such as elevating house structures. Those engaged in farming adapted to changing weather conditions by changing the traditional cropping calendar. For example, upland rice farming shifted from March–April to May to avoid heavy rainfall.

Despite this high local CC awareness, putative knowledge of what causes CC was average (68%). The knowledge of what causes CC was positively associated with education, not gender or age. It means that while formal education contributed to understanding the causes of CC, it was not crucial for CC awareness. The causes of CC were attributed to the ballooning population, extensive deforestation, and rising pollution. These attributions agreed with the current scientific consensus that the underlying mechanisms of CC are primarily human induced. Other studies have also shown the same trends in perceived CC causes by local communities (Mihiretu et al., 2021; Ncubc & Tawodzera, 2019). A small proportion of respondents attributed CC to the "Aging Earth," a widely held understanding among locals and IPs in the Philippines and elsewhere that regards the planet as a living entity. As the Earth ages, it becomes weaker and more vulnerable to human abuse. This worldview is reminiscent of Lovelock's Gaia hypothesis positing that Earth and its biological systems behave as a single colossal living entity. But one of our crucial findings was the transmission mode of local CC knowledge. Most (60%) of those who claimed to know about the causes of CC acquired their knowledge through direct personal experience. It has three relevant implications. First, not all LEK is traditional (e.g., handed down generationally). However, the knowledge gained within a lifetime of interaction with the local environment remains relevant, particularly in Citizen Science-driven conservation interventions. Second, current environmental changes may be unprecedented; hence, previous generations lack experience and knowledge regarding CC. Finally, this also meant that the CC awareness efforts in the Philippines had not penetrated the grassroots. Indeed, Philippine CCA strategies remained in the planning stage, and concrete evidence that such plans were translated into local CC resiliency was lacking (Pulhin & Tapia, 2021).

4.2 TEK associated with fisheries and environment

Berkes et al. (2000) highlighted TEK as an adaptive tool in natural resource management. For example, the TEK of locals and IPs can provide critical information on harvested species, such as their interannual, seasonal, lunar, and habitat-related differences (Johannes et al., 2000). In Bohol, Philippines, Lavides et al. (2010) pointed out that TEK can be utilized as a basis for fisheries assessments and conservation plans. In addition, Maliao (2019) has demonstrated in Aklan, Philippines, the importance of TEK in untangling the long-term impacts of coastal fishing exploitation without empirical historical data.

The Nabaoy River in Aklan, Philippines, is a typical data-deficient area in the country. We could find no local studies or government records on fisheries biodiversity or catch monitoring. However, the TEK of local riverine fishers demonstrated an overall perception of declining biodiversity. Some exploited species, considered abundant in the past, are now regarded as rare. These include the *pantat* (native bighead catfish, *Clarias macrocephalus*), *sile* (freshwater eel, *Anguilla* spp.), *haeoan* (snakehead murrel, *Channa striata*), and *damagan* (flagtail, *Kuhllia* spp.). In particular, the current freshwater prawn catches of 0.8 kg per individual per fishing trip only represented roughly a quarter of their recollected catch in the ’60 s. It signified that the local freshwater prawn harvest had declined steadily by 0.3 kg per decade. The other exploited freshwater finfishes and crabs also mirrored this trend. Similarly, exploited riverine species were perceived to be decreasing in size. These local observations reflected national and global trends of overexploited fisheries (e.g., Pauly et al., 2002).

The local fishers associated the loss of some species, reduced size of exploited species, and decline of fisheries harvest to the perceived diminished state of the Nabaoy River. These include the deterioration of river water quality associated with pollution and siltation, weakened riverbank integrity prone to erosion, and flow and discharge alterations. The diminished state of the Nabaoy River was heralded by the perceived marked decline of frog and dragonfly populations, perceived to be indicators of river health. However, while these observed changes were inexorably magnified with the changing climate, they were more the result of decades of deforestation, alteration of riparian vegetation, and land and river misuse that overall diminish riverine health (see Coleman et al., 2019; Hughes., 2017; Sodhi et al., 2009). Other ongoing local threats include river mining for gravel and sand, unsustainable farming practices, and increasing domestic sewage. In tandem with CC, these localized threats have far-reaching and long-term consequences for riverine biophysical characteristics. Thus, local CCA strategies should address the root causes of these prevailing threats rather than using CC rhetoric as a blanket excuse for environmental degradation (e.g., Persoon & Minter, 2020). Such strategies should include, among others, protecting riparian vegetation and implementing measures ensuring drought mitigation resiliency (see Jha et al., 2019a, 2019b).

The most urgent issues locally in the context of freshwater fishing were associated with the dwindling harvest and changes in the river hydrological regimes. Some households have recently explored backyard fishpond operations to augment the diminishing riverine fisheries. Many families have also traveled farther from the riverbanks during floods or when the river is low to coastal areas for gleaning to supplement household food. Fishing households have also recently engaged in mushroom farming and weaving of native bags and curios for the booming ecotourism industry in the province. Moreover, the local fishers have adapted to riverine hydrologic changes by adjusting and innovating their fishing strategies and technologies. One of these innovations is called "*Panungya,"* a fishing strategy specifically adopted during flooding events in the wet months (Table 1). Another fishing innovation is *Pangatas,* mainly used when the river water is low during the dry months. *Padogmon* is another fishing strategy that reflects a local understanding of fish ecology. Local fishing gears are traditionally made of local materials, including bamboo (subfamily *Bambusoideae*) and rattan *(*genus *Calamus*) complexes. Recently, fishing gears have employed innovations incorporating non-indigenous materials (Table 1). The local fishers have transformed the ubiquitous PET soda bottle into modernized versions of fish traps (Table 1). Aside from the sheer availability of PET bottles, one of the driving forces of this innovation is the diminishing local knowledge of bamboo/rattan weaving. While these may suggest a weakening of local TEK (e.g., Aswani et al., 2018), the adoption

of non-indigenous materials into their traditional fishing methods also demonstrates the adaptability and flexibility of the community.

4.3 Fisheries-related taboos and their conservation implications

TEK is essentially a knowledge–practice–belief complex and thus encompasses taboos based on local folklore. Folklore is the collection of local traditional beliefs, customs, and stories passed through generations by word of mouth. The existence of "*engkantos*" (Demetrio, 1969), which can be broadly interpreted as nature spirits, is one of the most widespread folktales in the Philippines. *Engkantos* dwell in locally perceived phenomenal parts of nature, such as giant boulders, earth mounds, and old trees. In Philippine folklore, "*engkanto*" is widely regarded as nature guardians and is thought to be powerful otherworldly beings who can be benevolent or malevolent in their human interactions (Menez, 1978). Folklore gives rise to social taboos (Table 2), which become crucial subsets of local informal institutions (Colding & Folke, 2001). Informal institutions comprise unwritten, socially shared rules created, communicated, and enforced outside officially sanctioned channels.

The local fishers viewed malevolent "*engkantos"* as most active on Tuesdays and Fridays, thus prohibiting fishing on those days. This practice constitutes a local conservation strategy analogous to temporal management measures like seasonal closures. The local fishers also avoid fishing around giant boulders and areas in the river sheltered by old and big trees because they are considered the abodes of "*engkantos."* Such worldviews are comparable to spatial management measures, such as protected areas (van der Ploeg et al., 2017). These worldviews constitute resource and habitat taboos (RHTs) and can simplify local conservation efforts because of the voluntary compliance features implicit in the taboo system (Colding & Folke, 2001). Indeed, local and indigenous cultures worldwide are teeming with similar beliefs that can potentially reinforce local conservation strategies (e.g., Fabiano et al., 2021). These informal (de facto) local practices can be integrated into formal (de jure) conservation policies. For example, local taboos can be contextualized into identifying potential protected riverine areas and spatial and temporal fishing limits and access. Such contextualization enhances community engagement because customary belief systems already sanctioned by local informal institutions are weaved into formal conservation policies.

Finally, various local dietary restrictions associated with spirits (see Meyer-Rochow, 2009) are practiced locally. The local roasting prohibition of prawns, snails, and crabs is attributed to "*Angue,"* a house-dwelling "*engkanto*" that disapproves of such food preparation. Violating this food restriction is understood to result in various maladies, from a simple stomachache to twisting of the neck. The residents were not aware of the etiology of the "*Angue"* view. Given that our site is predominantly Christian, we postulated from the emic point of view that such practice originates in the Bible in the book of Leviticus. The book of Leviticus forbids the consumption of aquatic animals without fins and scales. The significant difference on our site is that the food prohibition is only specific to how they are cooked, not the actual consumption of the animals. Hence, an emic explanation from the book of Leviticus is insufficient. Among the many traditional customs practiced in the predominantly Christian Philippines is the prohibition of roasting during Holy Week (Demetrio, 1991). The possible infusion of these two belief systems into the local social psyche may explain the ban on crab and shrimp roasting. Although these food taboos may not have

local conservation relevance because they do not limit extractive harvesting, they promote community cohesiveness and identity.

5 Conclusions

The Philippines has established various legal and institutional frameworks to combat and adapt to the multifaceted impacts of CC. However, evidence that such initiatives are translated into local CCA resiliency remains meager. Indeed, the direct personal experience as the primary mode of CC knowledge acquisition by local stakeholders signifies the need for more locally tailored CC education drives. While the global CC inexorably affects riverine integrity and biodiversity, localized threats such as continuing upland deforestation, changes in riparian vegetation, and pollution are pervasive. The diminished state of local biodiversity, and the loss of essential services they provide, may result in the progressive erosion of local TEK associated with them. Local ecosystems, in turn, will be adversely affected by TEK erosion as they rely on the resident resource users for management. These combined scenarios could weaken subsistence communities' resiliency and adaptive capacity to adapt to a changing world amidst CC. On the other hand, CCA strategies should avoid using CC rhetoric as a blanket excuse for every environmental woe but instead, address the root causes of the prevailing threats. CCA strategies must also complement context-specific alternative and supplemental livelihood options relevant to local needs and aspirations. In the Nabaoy River fishing community, such interventions may include enhancing local riverine harvest through habitat protection (e.g., protected areas, drought mitigation measures), fish stock enhancement (e.g., reseeding programs), aquaculture (e.g., community fish hatchery, captive grow-out), and fisheries product processing and valorization. Finally, the TEK of local fishers demonstrated an extensive understanding of the changes and fluctuations of riverine fisheries, reflecting subsistence communities' reliance on climate-sensitive natural capital. Fishing taboos, an integral component of TEK, remained a crucial binding force in the local informal institution. Indeed, local communities have relevant long-term knowledge of management (e.g., TEK) and development-oriented structures and systems (e.g., informal institutions). These invaluable social capital assets are crucial in building resilient governance systems to address local freshwater conservation issues and concerns. Hence, formal (de jure) management interventions should integrate TEK and the informal institution it is embedded and engage local TEK holders as partners in freshwater conservation efforts.

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Author contribution RJM was involved in conceptualization, funding acquisition, formal analysis, methodology, supervision, writing—original and final draft. RCC contributed to investigation, funding acquisition, project administration, and validation. RRC contributed to investigation, funding acquisition, and validation. BTJ was involved in funding acquisition, data curation, and investigation.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no competing interests to declare relevant to this article's content.

Human and animal rights Oscar M. Lopez (OML) Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc., based in Manila, the Philippines, approved this study. Informed consent was obtained from all participating respondents during the survey. No individual information of any participating respondents is included in the manuscript. The local fishing community is not part of the Philippines' Indigenous Cultural Communities/Indigenous Peoples (ICCs/IPs). Furthermore, the project results were presented to the community after completion (https://www.facebook.com/kinaiyaitkailayahan).

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