Anthropocene Coasts

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Mangrove social-ecological system of Batan, Aklan, Philippines

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Abstract

Commodity-based land use change is a major contributor to the worldwide loss and degradation of mangrove forests. There are, however, few studies exploring the local context of mangrove loss and degradation. This is problematic since land-use change does not uniformly degrade mangroves; these impacts on social-ecological systems (SES) are contextual. For mangrove systems, this means that conservation efforts require mangrove ecological knowledge (MEK) to understand the effects of forest loss, as well as, other drivers of change on local livelihoods. This paper aims to examine the local context of mangrove forest loss by studying mangroves and their use in Batan, Philippines. The study includes two different research methods. First, mangrove vegetation was recorded in mangrove forests. Second, perceptions of local users of coastal change, desired coastal resource management, and the local use of mangrove resources were investigated in 107 household surveys across five neighbouring study sites. The vegetation survey listed a total of 12 tree species, including one endangered mangrove species *Camptostemon philippinensis*, and another mangrove species *Nypa fruticans*, which is an important material resource. Local people perceived several changes leading to the degradation of the estuary. Regarding management solutions, the interviewees advocated increased mangrove reforestation efforts, more frequent coastal waste cleanups, and coastal zoning for fisheries. Based on the findings, we conclude that even degraded mangrove ecosystems remain important for biodiversity and local livelihoods and should therefore be conserved.

Keywords *Camptostemon philippinensis*, mangrove forests, Philippines, social-ecological system (SES), small-scale fisheries (SSF), mangrove ecological knowledge (MEK)

1 Introduction

Mangrove forests contribute to the health and well-being of millions of people who live in the tropical coastal zone (Barbier et al. 2008; Walters et al. 2008; Brander et al. 2012; Lee et al. 2014). Some examples of ecosystem services provided by mangal systems are carbon sequestration, protection from storm surges, and sediment stabilization that prevents coastal erosion (Duke et al. 2007; Brander et al. 2012; Lee et al. 2014). In addition to providing critical ecosystem services to human communities, mangrove forests serve as essential habitat for a wide range of species, including many that are threatened or endangered (Polidoro et al. 2010; Spalding et al. 2010). Concurrently, these mangrove forests function as nurseries and habitats to ecologically and economically important species, including shellfish, crabs, and finfish (Barbier 2000; Lee 2008; Carrasquilla-Henao and Juanes 2017; Stiepani et al. 2021; Come et al. 2023). The species that inhabit mangrove forests are vital to the food security of many coastal communities in tropical regions (Barbier 2000; Selig et al. 2019; Zu Ermgassen et al. 2020). As mangrove ecosystems make important

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contributions to people's livelihoods, they are often studied as social-ecological systems (SES) to understand how societies depend on the benefits and services they provide (Dahdouh-Guebas et al. 2000, 2021, 2022).

Local Ecological Knowledge (LEK) is defined as the knowledge, practices, and beliefs gained through extensive personal observation of and interaction with local ecosystems, shared among community members and resource users (Gaspare et al. 2015; Stiepani et al 2023a, b). LEK emerges from generations of firsthand experience and environmental perception, which forms a practical, culturally embedded understanding of a community's surrounding ecosystems (Berkes and Folke 1992). Perception, in this sense, is foundational to LEK because it is through direct, sensory experience that individuals interpret their environments (Tengö et al. 2014). Perception, however, is often subjective; it varies from one individual to another based on personal experiences, cultural background, and social context (Tengö et al. 2014). Mangrove Ecological Knowledge (MEK) exemplifies LEK while also serving as a bridge to transdisciplinary and indigenous knowledge frameworks, as it integrates local, traditional, and scientific understandings of mangrove ecosystems. MEK encapsulates the nuanced, place-based wisdom that coastal communities have developed over time in relation to mangrove ecosystems. By recognizing MEK as a form of locally grounded knowledge, researchers can engage in transdisciplinary approaches that combine ecological science, social science, and community expertise to inform sustainable mangrove management.

While the importance of mangrove forests for biodiversity and well-being provides a strong argument for their conservation, there has been a loss of 20%–35% of global mangrove forests over the last 50 years, resulting in the degradation of mangrove landscapes worldwide (Polidoro et al. 2010; Giri et al. 2011; Bryan et al. 2018; Bryan-Brown et al. 2020). Mangrove forest loss is considered to be a major cause for the degradation of ecosystems and ecosystem services due to the isolation of forest patches, the reduction of species connectivity within the landscape, and the loss of biological integrity (Altamirano et al. 2010; Bryan-Brown et al. 2020).

A number of studies have identified the global drivers of mangrove forest loss, which include urban development and tourism, and conversion of mangrove forests into commodity-based land use (i.e. palm plantations, fishponds, or agriculture), as well as extreme weather events and sea level rise from climate change (Alongi 2002; Proisy et al. 2018; Bryan-Brown et al. 2020; Stiepani et al. 2021). Commodity-based land use change (Bryan-Brown et al. 2020) is identified as the most significant driver of mangrove loss. Studies highlight, however, that land use changes do not degrade mangrove landscapes uniformly (Alongi 2002; Friess et al. 2012, 2019; Curnick et al. 2019; Bryan-Brown et al. 2020). Degraded mangrove systems can lead to a loss of local biodiversity and, consequently, a decline in the ecosystem services they provide. Existing studies often focus on specific aspects, such as the environmental impact of runoff from aquaculture (Herbeck et al. 2020; de Lacerda et al. 2021) or changes in mangrove forest area, either gain or loss (Altamirano et al. 2010; Van der Stocken et al. 2019; Bryan-Brown et al. 2020; Goldberg et al. 2020). Fewer studies have explored the broader ecological and socio-economic implications of mangrove degradation. Fewer studies consider the multiple dimensions of these environmental issues, such as the loss of mangrove forests and the links to livelihoods. Mangroves are known to be an important part of local livelihoods, directly (through the delivery of provisioning ecosystem services) or indirectly (e.g. mangroves being important habitats for fish that local communities depended on) (Manson et al. 2005; Walters et al. 2008; Conchedda et al. 2011; Carrasquilla-Henao and Juanes 2017; Lefcheck et al. 2019). This article aims to address this through an explorative study of mangrove fragmentation in relation to livelihood security in Batan, a rural fishing municipality in the province of Aklan, in the Philippines.

Mangrove forest loss resulting in fragmented mangrove landscapes has been particularly severe in the Indo-West Pacific (IWP) (Giri et al. 2011; Bryan-Brown et al. 2020; Goldberg et al. 2020; Stiepani et al. 2021), and in the Philippines, especially (Primavera 1995, 2005; Primavera and Esteban 2008a). Mangrove systems across our global sphere have been mapped to the extent of 145,068 km^2 as of 2020, Asia contained the largest mangrove coverage (39.2%) (Jia et al. 2023). The Philippines was selected for this study because it is one of the ten countries where the rate of mangrove fragmentation is highest globally (Bryan-Brown et al. 2020). Since the 1950's, the country has nearly lost half of its 279,000 hectares of mangrove forests, mostly because of the conversion to fishponds (Primavera 1992; Primavera et al. 2004; Primavera 2005; Primavera and Esteban 2008).

To investigate the impacts of commodity-based land use change on mangrove systems, we conducted this study in Batan, a rural fishing municipality in the province of Aklan in the Philippines. The municipality of Batan has a history of conversion of mangrove forests into fishponds, contributing to the fragmentation and loss of 76% of mangrove forest area (Altamirano et al. 2010; Altamirano and Kurokura 2010). The study includes a survey of mangrove vegetation and an investigation of the mangrove use by the local communities, their perceptions of coastal change, and management needs. This knowledge contributes to future coastal

resource management interventions that aim to account for local communities' dependence on mangrove landscapes for their livelihood and ecosystem services.

2 Methods and materials

2.1 Study location

This study was conducted across the mangrove ecosystems and coastal villages (called barangays, which form the lowest administrative authority in the Philippines), of the municipality of Batan (11°35′07″ N, 122°29′53″ E) between April and May 2022 and June 2023. Batan is located within the province of Aklan on the northwestern portion of Panay, the sixth largest island of the 7,640 found in the Philippines archipelago (Fig. 1). Batan is a rural fishing municipality where the majority of coastal livelihoods are dependent upon small-scale fisheries (SSF), and the use of a fish corral is the most common form of fishing gear (Altamirano et al. 2010; Altamirano and Kurokura 2010; Kamiyama et al. 2015; Local Government Unit, Batan 2022). The total population of Batan is 32,032 inhabitants, and the total land area is 79.22 km^2 (Local Government Unit, Batan 2022). The municipality of Batan includes 20 barangays of which 19 are coastal (Local Government Unit, Batan 2022). The coastal geomorphology of Batan is a semi-enclosed estuary leading to the Sibuyan sea. Coastal ecosystems in Batan include coral reefs, seagrass meadows, and algae mats, but mangrove forests are the most prevalent coastal ecosystem (Altamirano et al. 2010; Altamirano and Kurokura 2010; Local Government Unit, Batan 2022).

2.2 Theoretical framework and mixed methodological approach

This study draws inspiration from research on social-ecological systems (SES) (Berkes and Folke 1992; Ostrom 2007, 2009; McGinnis and Ostrom 2014). SES are made up of different components such as actors, resource units, resource systems, and governance systems (Ostrom 2009; Delgado-Serrano and Ramos 2015; Partelow 2018; Refulio-Coronado et al. 2021). Describing these different components is one way to better understand them individually and their interactions as a SES (Carlsson and Berkes 2005; Schultz et al. 2007; Gaspare et al. 2015; Stiepani et al. 2023a). Place-based SES research is important

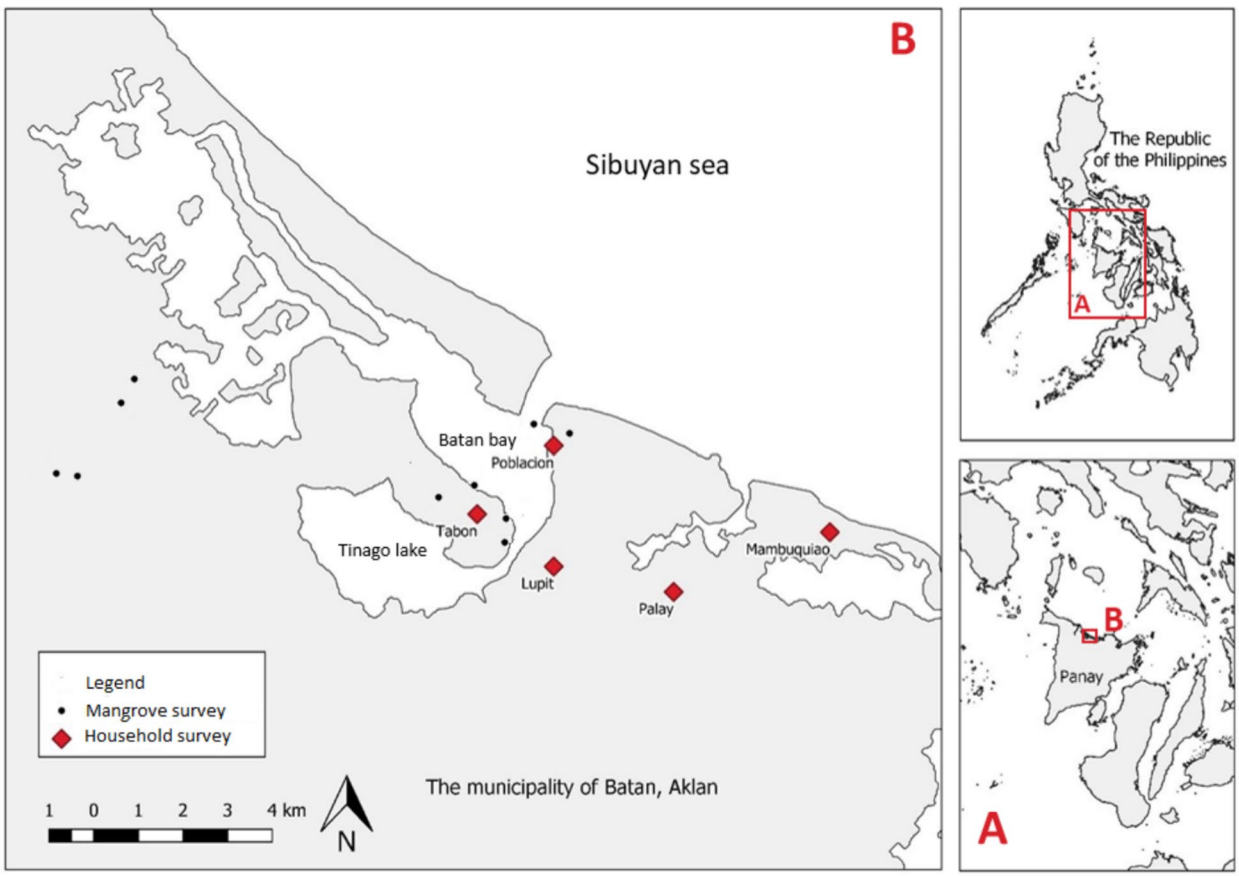


Fig. 1 Map of Batan, Aklan, on the island of Panay in the Republic of the Philippines

to inform and strengthen local management and governance while understanding human dependencies on natural capital (Berkes and Folke 1992; Ostrom 2009; McGinnis and Ostrom 2014; Colding and Barthel 2019). To study the different components of a SES, resource managers, scientists, and a variety of actors and stakeholders can draw on research methods from different disciplines to connect different types of knowledge and information about a SES (Jackson et al. 2014; Tengö et al. 2014; Reyers et al. 2018; de Vos et al. 2019; Stiepani et al. 2023a). For example, local perception and knowledge are studied to learn about, for instance, ecological or social change or the use of resources by local people, particularly in data-poor systems such as SSF (Johannes et al. 2000; Gaspare et al. 2015; Stiepani et al. 2023a). At the same time, ecological research is applied to understand, for example, the system's biodiversity or how land use change impacts the ecosystems (Macintosh et al. 2002; Ashton et al. 2003; Hinrichs et al. 2009; Geist et al. 2012; Stiepani et al. 2021).

Since SES are complex with many different components interacting that compose much larger systems, this study decidedly narrows its scope. The estuary of Batan, Aklan, offers an opportunity to investigate a mangrove system that has been mostly converted by land use change. The long history of this land use change has resulted in a degraded, patchy distribution of mangrove ecosystems along the coastline, with few old-growth mangrove forests and some replanted mangrove sites along a degraded and eroding coastline (Altamirano et al. 2010; Ogawa et al. 2022; Maquirang et al. 2026). Adjusted to this modified and fragmented context, the scope of this research focuses on the links between mangrove forests and society. As such, in this study, two different methods were utilized. We have chosen to conduct a mangrove species survey documenting the biodiversity of the local mangal system, and household surveys to gather data on local livelihoods and people's use of mangrove resources, as well as their perceptions of coastal changes and management needs. In the results, several elements of the SES are presented, including mangrove species, livelihoods of coastal households, mangrove resource use, perceptions of coastal changes, and perceptions of coastal management.

2.3 Mangrove species survey

To assess the present mangrove tree species within the estuary of Batan, a mangrove species survey took place. The method is from the Practical techniques for mapping small patches of mangroves (Altamirano et al. 2010). This method was chosen since it can be implemented rapidly at minimal cost, requires few fieldworkers, few field supplies, and is highly reliable when conducted with care (Altamirano et al. 2010). The survey of mangrove species was done through purposive vegetation sampling while walking in the selected mangrove forests (Figs. 1 and 2) (Altamirano et al. 2010; Mangaoang and Flores 2019; Salk et al. 2020). The species list was used to record the species that were present with the assistance of barangay officials, local government unit staff, and local community members (i.e. fishers, fishpond operators, and local resource users). Pictures of each species were taken, and morphological characteristics of leaves, flowers, propagules, root structures, and tree bark were noted and used in the identification of each species. The species were identified using the Handbook of mangroves in the Philippines – Panay (Primavera et al. 2004). The current endangered status of each mangrove species was listed based on the classification from the International Union for Conservation of Nature (IUCN) red list, as considered by Polidoro et al. (2010). Each mangrove forest was surveyed in two consecutive days, and the survey lasted up to four hours at each site. During the field survey, the edges of each site of the mangrove forest were marked using a GPS device and the total area (ha) was recorded using Google Earth(Altamirano et al. 2010). In total, ten sites were selected for surveying the mangrove tree species of Batan (Figs. 1 and 2) and were selected based on accessibility.

2.4 Household survey

A total of 107 household surveys were conducted within the municipality of Batan, using mostly closed and some open questions (Ritchie and Lewis 2003). The villages surveyed included the island of Tabon ($n = 32$ surveys), Palay ($n = 21$), Mambuquiao ($n = 19$), Poblacion ($n = 16$), and Lupit ($n = 19$) (Fig. 1). The Local Government Unit (LGU) of Batan assisted with facilitation of each household survey by contacting the villages and providing a translator from the agricultural office. Before conducting the household surveys a formal request was sent to the village (barangay) captain and other barangay officials to receive permission. The interviewees were selected by the barangay officials who chose participants based on their availability on the day and time of the survey. The interviews occurred either at the household of the participant within the village, or at the village hall. Each of the interview surveys lasted between 30 and 60 min. Prior to the start of each household survey the interviewee was informed about the purpose of the study, the potential outputs, as well as of the confidentiality of their identity. Only persons over age 18 were interviewed. At each household, one person was interviewed and provided their own perception and information of their household. Survey forms



Fig. 2 Fishponds, mangrove forests and permanent fishing structures, within the coastal zone of Batan. Fig **A**-**C** show fishponds situated in a fragmented mangrove landscape. Photo **D** "fish corrals" made from bamboo. Photo credit: J. Stiepani 2022

were printed and data was collected in written form. All household surveys were conducted in accordance with ethical research practices, including voluntary participation, informed consent, and the protection of participants' identities. Surveys were facilitated with the support of local barangay officials and the Local Government Unit to ensure adherence to local community norms. The survey questions are included in the Supplementary information. The survey was used to collect information on socio-demographic characteristics of the household, sources of livelihoods, usage of coastal resources, perceptions on coastal change, and management needs, and allowed for follow-up questions. Interview responses were analyzed using descriptive statistics, such as percentages by site and for the entire study area. Responses to questions on the perceptions of coastal change and coastal management were coded and then grouped into different categories. The categories were not pre-defined but emerged during the analysis. For information on coastal changes, these categories included: environmental change, changes within small-scale fisheries, and changes within the mangrove forest area. For information on coastal management, these categories included: fisheries-related management, mangrove-related management, and other management.

3 Results

3.1 Overview of the results

The results are presented as key elements, which manifest and operate within the mangrove social-ecological system of Batan, Aklan. Results are presented in five sections: mangrove tree species present, livelihoods of the people of Batan, mangrove resource use, perceptions of coastal changes, and perceptions on coastal management. This framework, with its different elements, is illustrated in Fig. 3.

3.2 Mangrove species

In total, 12 tree species were recorded within the ten mangrove forest sites surveyed. They belong to seven different families, including Acanthaceae, Arecaceae, Combretaceae, Euphorbiaceae, Lythraceae, Malvaceae, and Rhizophoraceae (Table 1). Three understory species from the families Acanthaceae and Pteridaceae were observed on the mangrove forest floor (Table 1). Based on the IUCN list only one of the recorded species, *Camptostemon philippinensis*, was considered endangered. The cluster of these *Camptostemon philippinensis* trees was found within one mangrove forest, near Poblacion, with a sand substrate (Table 1 and Fig. 1). The remainder of the species recorded was considered of least concern and all other forests had a mud substrate.

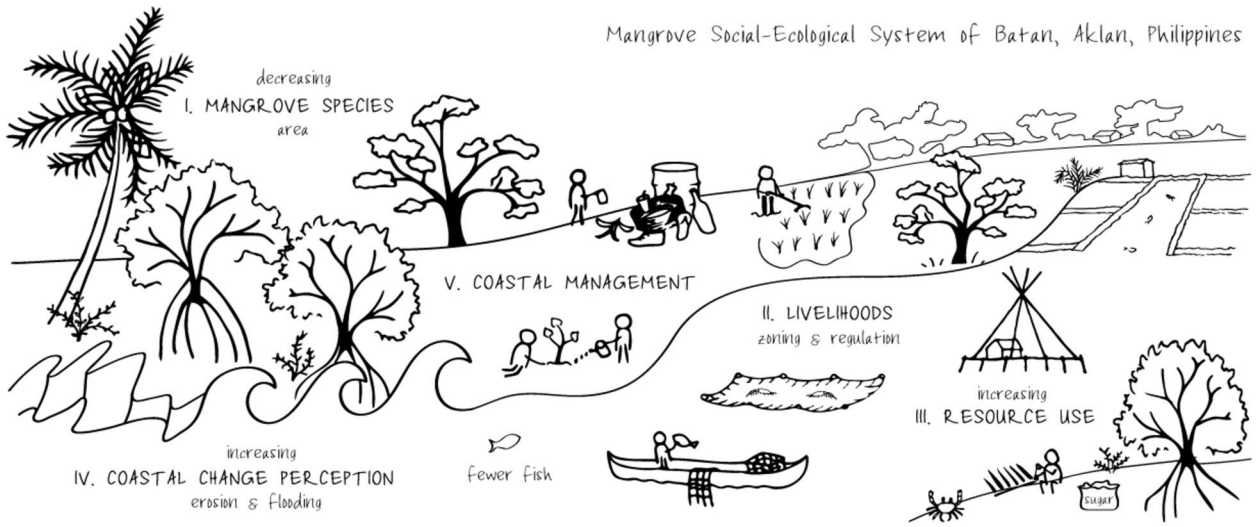


Fig. 3 Illustration of the framework used to analyze the mangrove social-ecological system in Batan, Aklan, Philippines

Table 1 Mangrove species. Presence mangrove tree and understory species within the mangroves of Batan. Each species is listed as EN = endangered; LC = least concern

Family	Species
Acanthaceae	*Avicennia alba* (LC)
	Avicennia marina (LC)
	Avicennia officinalis (LC)
Arecaceae	*Nypa fruticans* (LC)
Combretaceae	*Lumnitzera racemosa* (LC)
Euphorbiaceae	*Excoecaria agallocha* (LC)
Lythraceae	*Sonneratia alba* (LC)
Malvaceae	*Camptostemon philippinensis* (EN)
	Hibiscus tiliaceus (LC)
Meliaceae	*Xylocarpus granatum*
Rhizophoraceae	*Rhizophora apiculata* (LC)
	Rhizophora mucronata (LC)
Understory	
Acanthaceae	*Acanthus ebracteatus* (LC)
Pteridaceae	*Acrostichum aurem* (LC)

* various non-mangrove species were present such as Cocos nucifera

3.3 Livelihoods of the people of Batan

At four of the five study sites, the majority of the household income was derived from SSF (see Supplementary Material for more information). At Mambuquiao all the interviewed households (100%) derived their livelihoods from SSF, followed by households from Tabon (71.88%), Poblacion (66.67%), Lupit (57.90%), and Palay (31.58%). A variety of small-scale fishing practices were reported across the study sites, with fish corrals being the most frequently used method. Other fishing techniques, such as gill nets, lift nets, and fish lures, were also employed, although some methods (e.g., fish traps, oyster farming, gleaning, and crab fishing) were reported less frequently or not at all at certain sites. More detailed information on fishing practices is provided in the Supplementary Material. At Palay, the main source of income for the majority of households was rice farming.

In addition, a high variety of secondary or additional sources of livelihoods were reported. For example, men worked as drivers to transport people and their goods within the community, and as construction workers, maintenance workers, animal husbandry laborers, or farmers. For women, a frequent source of additional income was gleaning of invertebrates from the intertidal zone. Both men and women reported having an additional source of income from mending the nets for fish corrals (Fig. 4D). Other sources of income mentioned were fish vending and financial support from the national government from the Pantawid Pamilyang Pilipino Program (4Ps)[1] from the Department of Social Welfare and Development, and the Local Government Unit maintain to help people with disabilities. Another common secondary source of livelihood was the income people obtained from family-owned convenience stores (called Sari-sari stores).

[1] 4Ps or Pantawid Pamilyang Pilipino Program is a human development measure of the Philippines government that provides conditional cash grants to the poorest of the poor, to improve the health, nutrition, and the education of children aged 0-18.

3.4 Mangrove resource use

While seagrass meadows, coral reefs, and algae are present in the estuary of Batan, the interviewees did not report using these for resources. At the same time, they frequently reported that they used mangrove trees in their day-to-day life, as an alternative source of livelihood, or for the construction of household items. Most commonly, these resources were obtained from mangrove forests within walking distance of the household. The extent to which local communities used mangrove forests differed among the sites, with interviewees from Tabon, especially, reporting a comparatively higher use of nipa palms (*Nypa fruticans*) (Table 2).

Two species were commonly used by the local communities: the nipa palm and the coconut tree (*Cocos nucifera*), with only the former being a true mangrove species. The nipa palm was used in a variety of goods, mostly for roof thatching (referred to as pawod in the local dialect Aklano) (Table 2, Fig. 4A-C), by sewing nipa leaves in consecutive rows (Fig. 4A). Interviewees mentioned



Fig. 4 Local livelihood activities. **A** a woman creating pawod or roof thatching with nipa palm that is sewn together with bamban (*Donax cannaeformis*). **B** the sustainable harvest of nipa palm. **C** a typical nipa palm roof. **D** the mending of a draw net for a fish corral. Photo credit: J. Stiepani 2022

Table 2 Use of mangrove species. *N* = total number of household surveys at each study site; % (number of responses in the brackets)

	Tabon (*N* = 32)	**Palay (*N* = 21)**	**Mambuquiao (*N* = 19)**	**Poblacion (*N* = 16)**	**Lupit (*N* = 19)**	**All sites (*N* = 107)**
Nipa roofing	40.6%(13)	28.6%(6)	26.3% (5)	6.3% (1)	31.6%(6)	29.0%(31)
Vinegar	12.5% (4)	0% (0)	5.3% (1)	0% (0)	0% (0)	4.6% (5)
Alcohol	9.4% (3)	0% (0)	0% (0)	0% (0)	0% (0)	2.8% (3)
Food source	6.3% (2)	0% (0)	0% (0)	0% (0)	0% (0)	1.9% (2)

that the majority of roof thatching was done for their own houses, although some could also be sold for a low price. For example, at the study site Lupit selling of roof thatching was the primary source of livelihood for three female-headed households. Some interviewees also used nipa palm as a main ingredient of vinegar (locally named suka), and for distilling alcohol (locally named tuba). Yet, respondents also explained that coconuts were more frequently used for vinegar and alcohol. Nipa palm could sometimes also be used in gintaang – a traditional Filipino dish with coconut and a variety of vegetables, although only two households in Tabon reported doing so (Table 2). Respondents pointed out that when obtaining the nipa palm, people took care to cut only several of the fronds to make sure the tree could regenerate. During the mangrove survey, it was observed how the nipa palm was indeed cut in this way (Fig. 4B).

3.5 Local perceptions of coastal changes

Most of the households surveyed reported changes that they observed within the coastal zone, with the exception of two-thirds of the interviewees from Poblacion, who did not report any changes (Table 3). The changes observed were classified into three main categories: environmental changes, changes of SSF, and changes of the mangrove forests, with the latter change being less commonly perceived compared to the other two types of changes.

The most frequent perceived environmental change was coastal erosion and siltation, which, according to interviewees, was common after heavy rains. Increased magnitude and frequency of flooding events resulting in a shoaling of the river (i.e. the accumulation of sediment within the river channel) was specifically mentioned by over one third of interviewees from Palay, which is located on an estuary of the river. Other environmental changes mentioned were: an increase in the amount of garbage on the shores; changes within the tidal range,

Table 3 Coastal change as perceived by the interviewees, in % of responses (number of responses in the brackets) *N* = total number of household surveys at each study site

	Tabon (*N* = 32)	**Palay (*N* = 21)**	**Mambuquiao (*N* = 19)**	**Poblacion (*N* = 16)**	**Lupit (*N* = 19)**	**All sites (*N* = 107)**
Have there been changes in the coastal area?	Yes: 31 No: 1 Do not know:0	Yes:21 No:0 Do not know:0	Yes:18 No:0 Do not know:1	Yes:4 No:12 Do not know:0	Yes:18 No:1 Do not know:0	Yes:92 No:14 Do not know:1
Perceptions of coastal change						
Environmental change						
Increase in siltation and coastal erosion	18.8% (6)	47.6% (10)	52.6% (10)	0% (0)	21.1% (4)	28.0% (30)
Increased magnitude and frequency of flooding	0% (0)	61.9% (13)	0% (0)	0% (0)	21.1% (4)	13.1% (14)
Increase in the amount of garbage	18.8% (6)	4.8% (1)	10.5% (2)	6.3% (1)	21.1% (4)	10.3% (11)
Change in tidal regime	25% (8)	0% (0)	0% (0)	13% (2)	0% (0)	9.3% (10)
Increased coastal population	6.3% (2)	5.4% (2)	21.1% (4)	0% (0)	0% (0)	7.5% (8)
Increased magnitude and frequency of storm surges	12.5% (4)	0% (0)	0% (0)	6.3% (1)	21.1% (4)	5.6% (6)
Variability in seasonality	9.4% (3)	0% (0)	0% (0)	0% (0)	0% (0)	2.8% (3)
Changes of the SSF						
Less fisheries resources within the municipal waters	37.5% (12)	4.8% (1)	31.6% (6)	18.8% (3)	38.9% (7)	27.1% (29)
Increase in fish corrals	21.9% (7)	14.3% (3)	36.8% (7)	6.3% (1)	15.8% (3)	24.3% (26)
Encroachment of fishing vessels from other municipalities	12.5% (4)	19.0% (4)	0% (0)	0% (0)	21.1% (4)	8.4% (9)
Increase in fishpond area	6.3% (2)	0% (0)	10.5% (2)	0% (0)	0% (0)	3.7% (4)
Increase in invertebrate gleaners	0% (0)	0% (0)	0% (0)	0% (0)	10.5% (2)	1.8% (2)
Changes in the mangrove forest						
Mangrove area decline	25% (8)	9.5% (2)	0% (0)	0% (0)	5.3% (1)	10.3% (11)
Increase in mangrove areas due to replanting	6.3% (2)	9.5% (2)	10.5% (2)	0% (0)	21.1% (4)	9.3% (10)
Change of mangrove species	12.5% (4)	0% (0)	0% (0)	0% (0)	0% (0)	3.7% (4)
Mangrove cutting	6.3% (2)	4.8% (1)	5.3% (1)	0% (0)	0% (0)	3.7% (4)

with reported greater differences between low and high tides compared to previous years; variability in seasonality in the form of early onset of rainy season; and increases in damage from storm surges (Table 3).

About SSF, the change mentioned most often was a decline in fish and invertebrate catch for fishers and intertidal gleaners (Table 3). But here there are local differences too. The interviewees at Palay did not mention a decline in fishery resources, which could perhaps be linked to the lower number of households taking part in SSF compared to the four other sites surveyed (Table 2, Supplementary information). The second most reported change within SSF was an increase in fish corral structures within the estuary (Table 3). The other changes reported were encroachment upon the Batan fishing waters by small-scale fishers from neighboring municipalities using boats; an increase in fishpond area (only mentioned in Tabon); and an increase in the number of invertebrate gleaners (only mentioned in Lupit).

Finally, some perceived changes were reported with regard to the mangrove forests. For example, it was reported by several interviewees that there was a noticeable decline in the mangrove area and a change in mangrove species composition (Table 3). On the other hand, several interviewees mentioned that the mangrove area had increased in the coastal zone due to mangrove replanting (Table 3). Other changes reported were the cutting of mangrove trees, branches, and stands (Table 3).

3.6 Local perception on coastal zone management

Most of the interviewees argued that there was a need for management of the coastal zone, except for the people of Poblacion, where 75% of the interviewees believed that management was not needed. Management intervention that was most often suggested was mangrove replanting (Table 4), as interviewees found that earlier and more recent mangrove replanting was successful. Respondents informed that mangrove replanting began in the 1990 s with efforts to replant species that previously inhabited these targeted areas, specially from genus Avicennia and Rhizophora, and was conducted by the LGU, the Department of Environment and Natural Resources (DENR), the Bureau of Fisheries and Aquatic Resources (BFAR), Barangay Councils, the Association of Government and Private Employees (AGAPE), international non-governmental organizations (NGOs) and the municipal Fisherfolks Association.

At most of the sites, there were interviewees who suggested the need for more frequent coastal clean-ups (Table 4). These coastal clean-ups focused on removing general waste and debris from the coastal zone and adjacent shorelines, including but not limited to plastic, rubbish, and other discarded materials, and were reported by participants as successful. Another management suggestion was the zonation and regulation of particularly stationary fishing structures, or fish corrals. According to many interviewees, there were too many such structures, which contributed to overfishing within the waters of Batan. However, it was also mentioned that coastal zoning is quite challenging since many of the invertebrate gleaners, vessel-based fishers, and fishers using the fishing corrals prefer to fish without any restrictions. Other management

Table 4 The need for coastal management, as perceived by the interviewees, in % of number of responses household surveys at each study site. (number of responses in the brackets). *N* = total

	Tabon (*N* = 32)	Palay (*N* = 21)	Mambuquiao (*N* = 19)	Poblacion (*N* = 16)	Lupit (*N* = 19)	All sites (*N* = 107)
Management suggestion						
SSF management						
Zonation of fish corral structures within the estuary	12.5% (4)	23.8% (5)	52.6% (10)	0% (0)	15.8% (3)	20.5% (22)
Regulating the use of fishing gear	34.3% (11)	0% (0)	36.8% (7)	0% (0)	5.3% (1)	17.8% (19)
Limiting catch in size	15.6% (5)	4.8% (1)	0% (0)	0% (0)	0% (0)	5.6% (6)
Mangrove management						
Mangrove replanting	50.0% (16)	57.1% (12)	31.6% (6)	25% (4)	47.4% (9)	43.9% (47)
Prevention of illegal cutting of mangrove	15.6% (5)	0% (0)	0% (0)	6.3% (1)	0% (0)	5.6% (6)
Establishment of Marine Protected Areas for mangroves	15.6% (5)	0% (0)	0% (0)	0% (0)	0% (0)	4.7% (5)
Other management						
Coastal cleanup	34.3% (11)	42.9% (9)	15.8% (3)	12.5% (2)	63.2% (12)	34.6% (37)
Strengthened local governance	12.5% (4)	4.8% (1)	31.6% (6)	12.5% (2)	5.3% (1)	13.1% (14)
Increase in environmental education	9.4% (3)	4.8% (1)	0% (0)	0% (0)	0% (0)	3.8% (4)
Building of a seawall	0% (0)	0% (0)	10.5% (2)	0% (0)	5.3% (1)	2.8% (3)

suggestions included improvement of management and governance efforts from the LGU, BFAR, and DENR, and increasing environmental education efforts. Finally, some interviewees from Tabon mentioned that a Marine Protected Area (MPA) for mangrove forests would be beneficial. However, the designation of such a protected area was not mentioned at other sites, besides Tabon.

4 Discussion

The loss of mangrove forests due to land use change occurs worldwide (Alongi 2002; Giri et al. 2011). Commodity-based land use changes are a major driver of these processes and have been particularly severe in the Indo-West Pacific (IWP) (Bryan-Brown et al. 2020; Ashton 2022). However, little is known about the biodiversity of such degraded mangroves and their role in supporting livelihoods (Primavera 2005; Primavera and Esteban 2008). Between 2000 and 2016, land use change and conversion of mangrove ecosystems into rice fields, shrimp farms, and oil palm plantations were responsible for 62% of global mangrove loss (Goldberg et al. 2020). Of these human-driven losses, 80% occurred within six Southeast Asian nations of the IWP, including Indonesia, Myanmar, Malaysia, the Philippines, Thailand, and Vietnam (Goldberg et al. 2020). Studies in degraded systems are essential to better understand SES dynamics, such as local biodiversity, and how these ecosystems and their services relate to the communities that rely on them (Ma et al. 2023).

Our study addresses this research gap by combining a mangrove species survey with a household survey to develop a transdisciplinary understanding of the SES, integrating ecological data with local knowledge, lived experience, and livelihood dependencies. The incorporation of local perceptions through household surveys provides crucial insights into how communities experience and respond to environmental change, reinforcing the importance of participatory and community-based coastal management approaches. Such integration acknowledges local knowledge as a critical component of coastal governance and is essential for developing context-specific, socially legitimate, and sustainable mangrove restoration strategies in Batan. By aligning ecological assessments with community priorities and knowledge systems, policymakers and practitioners can ensure that management interventions are both effective and locally supported.

Social surveys that quantify local perceptions and knowledge play a crucial role in coastal resource management in the Philippines, as shown in Malalison Island, Panay, (Stiepani et al. 2023b, 2025), Cebu, Palawan, Negros Occidental, Bohol, Mindanao, and Luzon (Maliao et al. 2009). Understanding local perceptions and context has guided successful mangrove management by addressing the needs and concerns of those most affected by environmental changes (Primavera and Esteban 2008). To ensure both aspects – a variety of tree species adapted to local circumstances – involvement of local communities who are dependent upon the mangrove resources, together with the local government unit, is crucial (Pomeroy and Berkes 1997; Primavera and Esteban 2008). These studies suggest involving the local community since they have insights concerning mangrove species that suit the local environment, as well as the ways in which communities depend on the forests. Our study of local perceptions of environmental change offers one way in which such mangrove ecological knowledge (MEK) can inform coastal resource management.

In a previous successful mangrove restoration in the community of Bedono, Indonesia, community-based management was crucial for its long term success (Damastuti et al. 2022). Several contributing factors were longer-term funding and maintenance of mangrove restoration, a greater acceptance of protective legislation, high levels of public support, a high number of mangrove species replanted, and a large spatial scale of mangrove restoration (Damastuti et al. 2022). Another study from villages across the coastline of Sri Lanka found that community participation has a significant and positive effect on the performance of mangrove restoration (Sathiyamoorthy and Sakurai 2024). This study along Sri Lanka's coasts also found that post-war attitudes and solidarity within the community were perceived to have led to increased cooperation in mangrove restoration and its long-term success (Sathiyamoorthy and Sakurai 2024).

The survey of tree species diversity in the degraded mangrove landscape of Batan recorded 12 tree species from eight different genera. This is a moderately high tree richness when compared to other to similar case studies that investigated species richness in mangrove ecosystems. Considering mangrove biogeographical regions around the world, the IWP is a biodiversity hotspot with at least 69 known species (Saenger et al. 2019) and the Philippines is known to have at least 40 mangrove species (Primavera et al. 2004). This survey of the mangrove landscape of Batan recorded 12 tree species from eight different genera. This tree richness is moderately high when compared to other similar case studies that investigated species richness in mangrove ecosystems. For example, two species in the Middle East and Egypt (Waleed et al. 2024), three tree species in Punta Mala Bay, Panama (Benfield et al. 2005), three in Matang Mangrove Forest Reserve (MMFR), Malaysia (Goessens et al. 2014), four within Karachi, Pakistan (Saifullah et al. 1994), five in the State of Nayarit, Mexico (Palacios and Cantera 2017), five

in East Java, Indonesia (Isroni et al. 2019), seven in East Lombok, Indonesia (Zulhalifah et al. 2021), and eight on the coastline of mainland Tanzania (Njana 2020), eleven occur in Okinawa Prefecture, Japan (Inoue et al. 2022). At the same time, other locations within the IWP found a higher tree richness, including 15 tree species in Penang, Malaysia (Stiepani et al. 2021), 18 Kerala, southern India (Sreelekshmi et al. 2021), 21 in Java, Indonesia (Hinrichs et al. 2009), 28 in Sarawak, Malaysia (Ashton and Macintosh 2002), and 29 in Sultan Kudarat, Philippines (Mangaoang and Flores 2019). It should be noted that differences in research methods, research questions, and the size of mangrove forests could have contributed to the different number of mangrove tree species reported in each case study.

The survey also recorded an endangered mangrove species, the *Camptostemon philippinensis*, present within one of the natural mangrove sites with sand substrate. This species is sparsely distributed across the IWP, with a limited known distribution in Indonesia and the Philippines (Duke et al. 1998; IUCN 2008; Polidoro et al. 2010). Recent estimates from 2010 suggest that less than 1200 individuals of *C. philippinensis* remain globally (IUCN 2008; Polidoro et al. 2010).

The household survey revealed the importance of mangrove resources for local livelihoods. The interviewees depend on these resources, directly or indirectly, to varying degrees. For female-headed households, the creation of nipa thatching can be a main source of livelihood, but the majority of interviewees depended on mangroves indirectly, for example, many livelihoods depend on fisheries, and the mangroves provide important habitats for the species that they fish (Altamirano and Kurokura 2010; Kamiyama et al. 2015; del Norte Campos et al. 2023). Taken together, these results suggest that conservation and protection efforts should not exclusively target natural mangroves, because degraded mangroves are valuable. As this study discovered, degraded mangroves can be habitats for endangered species and species important for ecosystem services, resource use, and remain integral to local livelihoods.

Millions of people who live along tropical coastlines use mangrove trees as material resources in everyday life (Walters et al. 2008; Baba et al. 2013; Kusmana and Sukristijiono 2016; Palacios and Cantera 2017; Kibria et al. 2018; Baeren and Jusilin 2021; Dahdouh-Guebas et al. 2021; McWilliam 2022). Out of all the mangrove species recorded within our study, only one species, *Nypa fruticans*, was used by the local community in Batan for various purposes, such as roof thatching and food source in the form of alcohol, vinegar, or in a traditional Filipino dish ginataang. Similar uses have also been found in other areas around the tropical coastal regions of the world; however, other uses have also been shown. For example, a study from the State of Nayarit in Mexico noted that mangrove resources have been used in tobacco galleries, as firewood, charcoal, and for building material (i.e. wall fences, posts, and beams) (Kovacs 1999). Another study from Indonesia reported that mangrove materials are common ingredients in traditional medicines (i.e. ointments for hair preservation, dressing for boils or snakebites, and smallpox ulcerations) (Kusmana and Sukristijiono 2016). Additionally, in Indonesia, Malaysia, Kenya, and India, the mangroves species *Rhizophora* spp. and *Ceriops* spp. were commonly used for tannins (i.e. plastics and glues) and as dyes for fishnets and clothing (Dahdouh-Guebas et al. 2000; Walters et al. 2008; Baba et al. 2013; Baeren and Jusilin 2021). In other regions, particularly in West and Central Africa, mangrove wood is also widely used as fuel for smoking fish, an important practice supporting small-scale fisheries and post-harvest processing (Gnansounou et al. 2021).

Overexploited mangrove forests that have been degraded lose their functionality as nurseries and habitats for fisheries resources (Barbier 2000; Walton et al. 2006; Altamirano and Kurokura 2010). Our study of the perception of environmental change by local residents highlights how mangrove loss and degradation might affect the fish resources on which many Batan households depend. Local people perceived a decline of fisheries resources and an increase in fish corrals, which, taken together, indicate a heightened pressure on scarce resources. Indeed, as other studies of the SSF in Batan confirmed, the catch-per-unit effort has declined from 24 kg gear-1d-^{1} in 1970 to 1.65 kg gear^{-}1d-^{1} in 2006 (Altamirano and Kurokura 2010). Within the catch portfolio, there has been a decline in the valuable tiger prawn (*Penaeus monodon*), negatively impacting income for local livelihoods (Altamirano and Kurokura 2010). Even though the majority of fishery resources are in decline, most local communities in Batan continue to rely heavily on biodiversity and ecosystem services of their immediate environment as a main source of livelihood. The combination of such direct dependence and dwindling resources in Batan risks producing self-reinforcing feedback – due to the scarcity, people increase exploitation efforts, resulting in a race to the bottom – a process called a "social-ecological trap" (Cinner 2011; Kittinger et al. 2013).

In relation to the observed changes in their immediate environment, the interviewees suggested the need for more SSF management and mangrove restoration activities. Successful restoration could counteract the coastal changes that the interviewees in Batan observed, as well as their potential impact on local livelihoods. A study by Walton et al. (2006) showed that replanting of mangrove

forests on Aklan River, Panay, Philippines, near the study site of Batan increased economically important fish species. It is also established that mangroves function as buffers against storm surges and flooding, which prevent coastal erosion (Brander et al. 2012; Worthington and Spalding 2018; Gijsman et al. 2021), suggesting that mangrove replanting may help to counteract the risk of self-reinforcing cycles of poverty-environmental degradation. Yet, the return of natural resources and supporting ecosystem services that mangrove forests provide may take years or decades to return, since there is often a time lag for the recovery of biodiversity in restoration (Ram et al. 2021). More research is needed on the implementation, monitoring, and steps for mangrove restoration, since an estimated 50% of all mangrove restoration projects have failed (Lovelock et al. 2022). In many cases, restoration efforts fail due to a lack of mangrove ecological knowledge (MEK), resulting in inappropriate site selection, poor species choice, and restoration designs that do not align with natural hydrological and geomorphological processes (Primavera & Esteban 2008). Without adequate MEK, mangrove restoration is often implemented incorrectly or in ways that are not ecologically or socially sustainable, underscoring the need for knowledge-driven, context-specific, and long-term restoration strategies.

5 Conclusion

Mangrove loss and degradation is a worldwide phenomenon. Its global manifestation is made visible and studied with the help of modelling and remote sensing (Giri et al. 2011; Friess et al. 2019; Bryan-Brown et al. 2020). Much needed are local studies, such as the present study, which delivered a more nuanced understanding of mangrove degradation and fragmentation in a local social-ecological system. This knowledge is relevant for global mangrove conservation efforts because it suggests the need to conserve degraded mangrove SES in a variety of other contexts as well.

The SES framework used in this study of Batan reflects a broader academic shift toward understanding mangrove ecosystems as interconnected human-nature systems (Dahdouh-Guebas et al. 2021, 2022; Come et al. 2023). In the case study of Batan, results were framed as elements, including mangrove biodiversity, local livelihoods, resource use, perceptions of environmental change, and coastal management, which serve as entry points for understanding how ecosystem dynamics and human activities are interrelated. The holistic approach of linking elements is important for managing ecosystems like mangroves, where changes in one element (e.g., mangrove loss) can trigger cascading effects on others (e.g., biodiversity, fisheries and livelihoods).

Our study found that local people are aware of the importance of mangrove forests and sustainably harvest local resources. These natural resources are perceived by many to be threatened by multiple sources. In Batan, there has been rapid development of fishponds, the use of mangrove resources, overfishing and gleaning, which directly and indirectly impact the mangroves and have been linked to a decline in SSF-based livelihoods (Altamirano et al. 2010; Altamirano and Kurokura 2010; Kamiyama et al. 2015; del Norte Campos et al. 2023). Also, our study shows that MEK can be used in data-poor systems to reveal local dependence on natural resources and assist in setting priorities for management.

The study demonstrates that the remnant mangrove forests in Batan, Aklan, continue to support important biodiversity and ecosystem services despite extensive mangrove loss and ongoing degradation pressures from multiple threats. Importantly, these remaining mangroves constitute one of the last known habitats of *Camptostemon philippinensis*, an endangered mangrove species, underscoring the high conservation value of Batan's mangrove ecosystem. At the same time, many of the diverse fishing activities associated with the mangrove social–ecological system of Batan remain challenged by land cover and land-use change, as well as local impacts of climate change (FAO 2023a, 2023b, 2024).

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
J.S. led the conceptualization, methodology, investigation, formal analysis, visualization, and writing – original draft. R.P. assisted as a translator during the investigation, contributed to resources, and writing – review and editing. R.S. contributed to writing – review and editing. All authors reviewed and approved the final manuscript.

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