Valuation of Ecosystem Services by Local Communities Around Matang Mangrove Forest Reserve, Malaysia

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Abstract: Matang Mangrove Forest Reserve (MMFR) on the west coast of Peninsular Malaysia is one of the longest managed mangrove forests for sustainable charcoal and pole production. To understand the interactions between nearby communities and the mangrove ecosystem, a systematic sampling of the houses for questionnaire-based interviews was conducted, and the data were analyzed through multiple correspondence analysis and group comparison tests. In general, Malay communities have higher mangrove-related knowledge and utilization levels than Chinese communities. Out of 124 respondents, 31% use mangroves as fuel, 44% for construction material, 13% for medicine, and 2% for food, drinks, or animal feed. Although personal collection is limited, there is a heavy reliance on mangrove charcoal and poles purchased from the market. While being a major (wood) production forest, the mangrove reserve is also an important fishing ground for 56% of the respondents, where trawler encroachment and the use of illegal fishing gear are common problems. Respondents observed sea level rise, sedimentation, and pollution in the area; depopulation

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is a prominent problem for some Chinese communities. Our findings show that coastal mangrove fishing communities are facing new environmental and social challenges; thus, supportive policies should be in place to ensure their livelihood and wellbeing.

Keywords: Mangrove ecosystem, Ecosystem services, Resource utilization patterns, Ethnobiology, Fisheries, Multiple correspondence analysis

Abstrak: Hutan Simpan Bakau Matang (MMFR) di utara pantai barat Semenanjung Malaysia merupakan salah satu hutan bakau yang paling lama diuruskan untuk pengeluaran arang dan cerucuk secara mampan. Kajian ini bertujuan untuk memahami interaksi etnobotani dan etnoekologi komuniti tempatan dengan ekosistem bakau. Temu bual secara bersemuka telah dijalankan menggunakan soal selidik dengan persampelan sistematik isi rumah. Topik soal selidik meliputi pengetahuan dan pengumpulan sumber berkaitan bakau, corak penggunaan produk bakau, perikanan, dan perubahan yang dialami. Daripada 124 responden, 31% menggunakan bakau sebagai bahan api, 44% untuk pembinaan, 13% untuk ubat dan 2% untuk makanan, minuman atau makanan haiwan, termasukkebergantungan tinggi kepada arang dan cerucuk yang dibeli. Ekosistem bakau merupakan kawasan penangkapan ikan yang penting bagi 56% daripada keseluruhan responden, di mana amalan penangkapan ikan secara haram turut berleluasa. Analisis Koresponden Berbilang dan ujian perbandingan kumpulan telah dilaksanakan dan didapati masyarakat Melayu mempunyai tahap pengetahuan dan penggunaan yang lebih tinggi berbanding masyarakat Cina. Responden telah menyaksikan kenaikan aras laut, pemendapan, dan pencemaran di kawasan tersebut. Pengurangan populasi juga merupakan masalah yang ketara, khususnya bagi masyarakat Cina. Penemuan kami menunjukkan bahawa komuniti nelayan menghadapi pelbagai cabaran sosial dan alam sekitar yang baharu, justeru sokongan dasar serta kempen kesedaran harus dilaksanakan bagi membantu komuniti ini dalam menghadapi fasa peralihan.

摘要: 马当红树林保护区 (MMFR) 位于马来西亚半岛西海岸，是可持续木炭和木材生产管理时间最长的红树林之一。在民族植物学和生态学层面，本研究旨在了解附近社区及其与红树林生态系统的关系。通过系统抽样和问卷，我们对家庭进行了面对面访谈。问卷主题涵盖红树林相关知识和采集、红树林相关产品的使用、渔业，和环境社会的变化。 在 124 份答复中，31% 使用红树林作为燃料，44% 用于建筑，13% 用于医药，2% 用于食品、饮料或动物饲料。社区对购买的木炭和木材有较强的依赖性。红树林生态系统是 56% 受访者的重要渔场，常见非法捕鱼行为。数据分析采用了多重对应分析和分组比较检验。总体而言，马来社区的红树林相关知识和利用水平高于华人社区。受访者观察到该地区海平面上升、泥沙沉积和污染问题；对华人社区而言，人口减少也是一个突出问题。我们的研究结果表明，沿海红树林渔业社区正面临新的社会和环境挑战，因此应制定相关政策来帮助这些社区转型。

Introduction

Mangroves are plants that grow at the land-sea interface in tropical, subtropical, and warm temperate climates. Some are non-woody (e.g., *Nypa* palm) or herbaceous (e.g., *Acrostichum* and *Acanthus*), but most mangroves are woody trees and shrubs. Mangroves and their associated organisms make up the mangrove forest community—referred to as the "mangal"—and

together with abiotic factors, they form the mangrove ecosystem (Dahdouh-Guebas et al. 2021). The mangrove ecosystem is known for its ability to protect coastal areas by buffering wave action (Dahdouh-Guebas et al. 2005; Horstman et al. 2014), especially in the face of extreme weather events and sea level rise (Primavera et al. 2019; Vo et al. 2012), which have been identified as priority research topics for the future (Dahdouh-Guebas et al. 2022). Mangrove ecosystems also play a significant role in mitigating climate change with their high carbon sequestration potential and belowground carbon storage (Cooray et al. 2024; Rovai et al. 2018; Wolswijk et al. 2022).

The mangrove ecosystem is crucial in hosting a unique assemblage of species, supported by a wide range of fish, shellfish, and invertebrates (Dahdouh-Guebas et al. 2021; Yates et al. 2014). It provides important goods and services, often constituting the basis of local livelihood (Walters et al. 2008). Mangrove forests are important sources of fisheries (Zu Ermgassen et al. 2021, 2025), consumable plants, medicinal herbs (Bandaranayake 2002), construction materials, and fuel (Ariffin and Nik Mustafa 2013; Mukherjee et al. 2014).

However, mangrove cover has been declining worldwide (Bunting et al. 2022), and Southeast Asia is one of the hotspots experiencing sustained anthropogenic intervention (Goldberg et al. 2020). The continuous decline of mangroves highlights the urgent need for sustainable management and conservation. Local communities can share important ecological and ethnobotanical knowledge, participate in resource management, and contribute to research and monitoring of the mangrove ecosystem (Grimm et al. 2024; Hugé et al. 2016, 2023; Walters et al. 2008). Ethnobiological studies are crucial for understanding the interaction between people and nature, and the socio-ecological data helps to make policy decisions for more sustainable resource utilization (Albuquerque et al. 2024).

The present study is focused on Matang Mangrove Forest Reserve (MMFR), where the use of mangroves for commercial charcoal and pole production has been well documented (Ariffin and Nik Mustafa 2013; Chen et al. 2024; Satyanarayana et al. 2021). However, little is known about resource utilization patterns by local fishing communities. There are abundant ethnobiological studies from other mangrove areas in Malaysia (Abdullah et al. 2021; Ruslan et al. 2022) and around the world (Alimbon and Manseguiao 2021; Dahdouh-Guebas et al. 2000, 2006; Dupont et al. 2025; Hamza et al. 2024; Kovacs 1999; Kusmana 2018; Mafaziya Nijamdeen et al. 2023; Nfotabong-Atheull et al. 2009, 2011), but no such research has been conducted for Matang Mangrove Forest Reserve. This study, therefore, is the first ethnobiological survey in the world's longest-managed mangrove forest. The objectives of this study are (i) to identify relations and patterns in resource use and fishery activities by local communities in the mangrove ecosystem and (ii) to understand general opinions and perceived socio-ecological changes in the area.

Methods

Study Area

Matang Mangrove Forest Reserve (04°15′–05°01′ N; 100°02′–100°45′ E), located in the state of Perak with a warm, humid climate, is the largest and oldest mangrove forest reserve on the west coast of Peninsular Malaysia (Ariffin and Nik Mustafa 2013) (Fig. 1). In an area of 40 km^2, the reserve hosts true and associated mangrove plant species, notably *Acanthus* (Acanthaceae), *Acrostichum* (Pteridaceae), *Avicennia* (Acanthaceae), *Bruguiera* (Rhizophoraceae), *Ceriops* (Rhizophoraceae), *Derris* (Fabaceae), *Excoecaria* (Euphorbiaceae), *Heritiera* (Malvaceae), *Intsia* (Fabaceae), *Lumnitzera* (Combretaceae), *Nypa* (Arecaceae), *Rhizophora* (Rhizophoraceae), *Scyphiphora* (Rubiaceae), *Sonneratia* (Lythraceae), and *Xylocarpus* (Meliaceae) (Ariffin and Nik Mustafa 2013).

Matang Mangrove Forest Reserve is one of the longest managed mangrove forests with a well-established documentation since 1902 (Chen et al. 2024; Wolswijk et al. 2022). The forest reserve is composed of protective, productive, restrictive productive, and unproductive forest zones; the productive and restrictive productive zones are mostly with *Rhizophora mucronata* Lamk. and *Rhizophora apiculata* Bl., managed via a 30-year rotation cycle (Ariffin and Nik Mustafa 2013). Each rotation cycle starts with natural regeneration and planting, followed by thinnings (15- and 20-year-old stands) for poles and clear-felling (at the age of 30-year-old stands) for charcoal production (Satyanarayana et al. 2021). Although

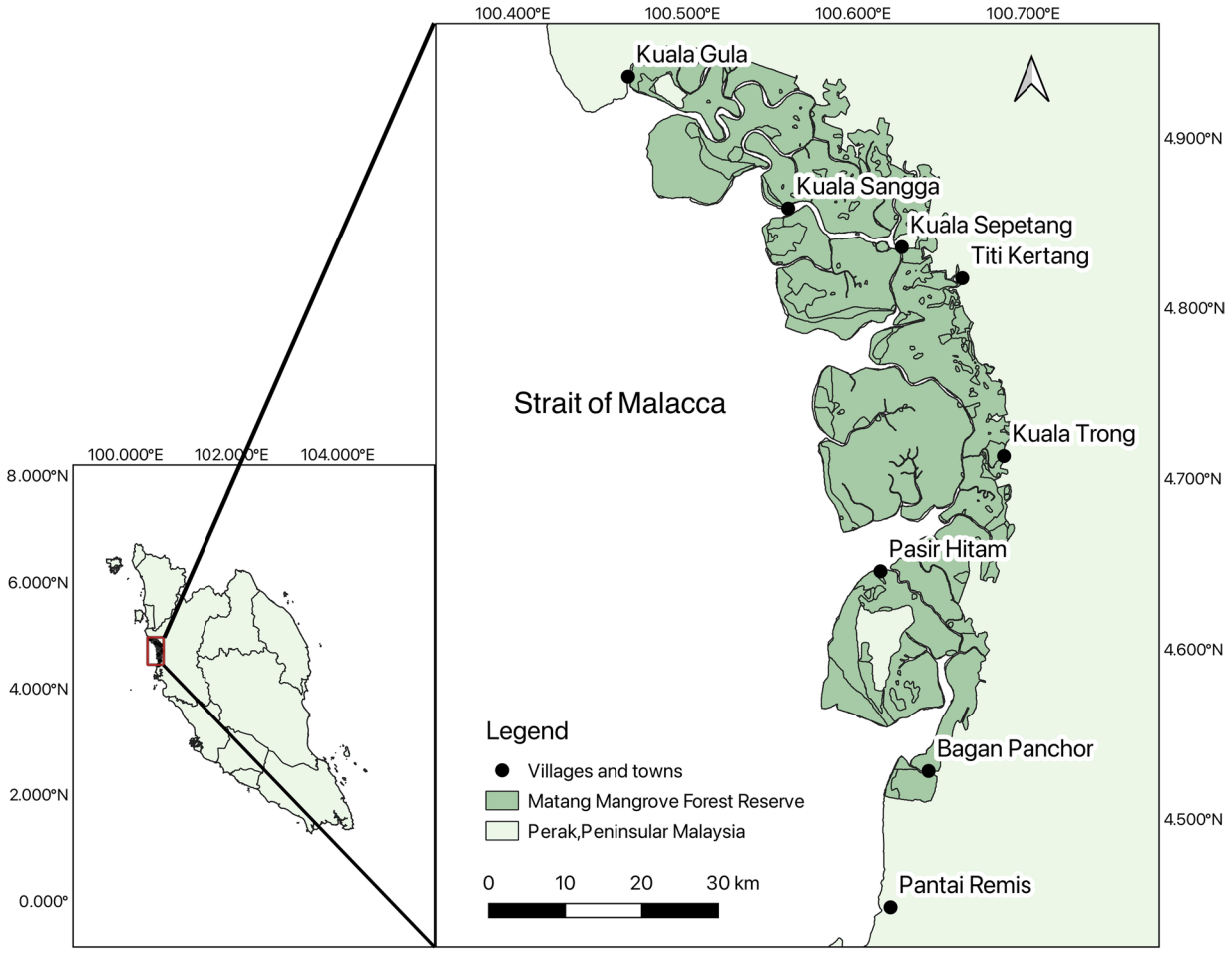

Fig. 1. Location of the study site Matang Mangrove Forest Reserve (MMFR) in Malaysia (left) and location of the eight fishing villages/towns where face-to-face questionnaire-based interviews were conducted (right). Shapefile obtained from Lucas et al. (2020)

management at Matang Mangrove Forest Reserve aims at harvesting forest resources sustainably, whether it is truly sustainable or not remains a subject of debate (Goessens et al. 2014; Hugé et al. 2016; Romañach et al. 2018).

According to the Matang Mangrove Forest Reserve management plan for 2010–2019 (Ariffin and Nik Mustafa 2013), besides producing more than 52,284 Mg of charcoal and 957,600 pieces of poles per year, the forest reserve has been contributing to 88,887 Mg of fish and prawn catch, together with a big support to the industries of seafood processing. Other mangrove-related activities include cockle culture, fish cage culture, and ecotourism.

Local livelihoods are dependent on forestry, fisheries, agriculture, and relevant processing industries (Ariffin and Nik Mustafa 2013). Besides Malay people, there are also Chinese communities at Matang, formed by descendants of immigrants from Southern China to British Malaya 100 to 150 years ago. While Chinese and Malay communities coexist in the same villages next to each other, they live in separate areas due to their cultural and religious differences and typically gather around different mangrove creeks. The Malay communities are Muslims who believe that dogs and pigs are impure animals; but the Chinese communities are mostly Buddhists or Taoists who keep dogs as pets and do not avoid eating pork. Malay people speak Malay; the Chinese communities speak Mandarin and the dialect of their region of origin, usually Teochew, and many also speak Malay.

To conduct interviews, eight fishing villages and towns, namely Kuala Gula/瓜拉牛拉 (~400 households), Kuala Sangga/老港 (~10 households), Titi Kertang/峇登 (~150 households), Kuala Trong/瓜拉自农 (~40 households), Pasir Hitam/大直弄渔村 (~30 households), Bagan Panchor/双礼佛 (~200 households), Pantai Remis/班台 (~3000 households), and Kuala Sepetang/十八丁/拄港 (~400 households), were chosen to represent the area (Fig. 1). Residents have free access to enter the productive zones for fishery resources, but to enter the protective zones, a permit from the forestry department is required.

Data Collection and Analyses

Data were collected using questionnaires (Electronic Supplementary Material, ESM A) in August 2023. According to the village heads, Indian communities were less than 1% of the total population, and they were not encountered during this study.

Systematic sampling was used for household visits. In larger villages, every 10th house was visited going upstream along the mangrove creek; in the case of no response, the next house was visited. For small villages, all houses were visited (Kuala Sangga, Pasir Hitam, and Kuala Trong). At least ten questionnaires were obtained for each site except for Titi Kertang, where only four questionnaires were collected due to low house occupancy. Direct observation of fishing gear, types of catch, and types of fishing activity was conducted at jetties and fish markets.

The standardized questionnaire has been used in other mangrove ecosystems elsewhere (Dahdouh-Guebas et al. 2000, 2006; Nfotabong-Atheull et al. 2011). It covers socio-demographic traits, economic situation such as annual income, personal collection of mangroves, knowledge about mangroves, mangrove product utilization, fishing activities, perception about ongoing changes, and impacts of the COVID-19 pandemic (Electronic Supplementary Material, ESM A). Respondents were asked to identify mangrove plants nearby if they reported knowing about certain species. Since mangroves are a relatively species-poor community and there is little confusion about species identification, no specimen was collected, and the comprehensive taxonomic keys published by Tomlinson (2016) were used to confirm mangrove identification. An additional section addressing the impact of the pandemic (Asante et al. 2023) was included, as it has been reported to potentially have had an influence on research (Vandebroek et al. 2020; Dahdouh-Guebas and Vandebroek 2021).

The permission to conduct this research was issued by the Forestry Department of Perak, Malaysia. Interviews were conducted following the ISE Code of Ethics (2006). The research objectives of the research and the interview process of the interview were explained clearly to the participants. An informed consent was solicited from each participant while explaining that the interview was anonymous, voluntary, without compensation, and for the purpose of academic research. Before conducting the interviews, Chinese and Malay community leaders in Kuala Sepetang were consulted and explained the aim and

objectives of this study. Each household was visited in a quiet and polite manner, avoiding Islamic prayer times and after fishing activities. Mandarin Chinese (native language of the first author, Ms. Arya Ying Yue) was used to communicate with the Chinese community, whereas the Malay community was consulted through a local language interpreter. Efforts were taken to ensure that the interview process did not cause any inconvenience to respondents by informing them of the estimated duration when obtaining their consent. After daily fishing activity, it was relatively easy to interview fishermen at jetties and coffee shops, and each interview lasted 20 to 40 min depending on the level of details provided by the respondent. After the interview, the respondents were thanked, and contact numbers were exchanged upon request if they showed interest in learning about the outcome of the research (Vandebroek et al., 2025). No female fishers were encountered; women were mostly at home doing chores or shucking clams for sale. Therefore, the word "fishermen" was used for the rest of the paper.

Multiple correspondence analysis (MCA) was conducted in R (version 4.2.2) using packages *FactoMineR* and *factoextra*, which is fit for analyzing categorical survey results and has no distributional assumptions (Higuera-Mendieta et al. 2016). The input categorical variables are gender, age class, education, ethnicity, religion ("Muslim," "Taoist," "Buddhist," and "None"), family status, profession ("fishery," "logging and charcoal-related," "retail," "construction," "other," and "no job"), collection, and main uses of mangrove resources ("Fuel," "Construction," "Food," "Medicine," and "Mangrove_fishing"). Supplementary quantitative variables used are annual income, average catch for fishermen, number of people in one household, and the number of mangrove species known. Age and education are treated as ordinal data and other variables nominal. A non-parametric Mann–Whitney test was conducted on the number of species known by ethnicity. Pearson chi-squared test and Fisher's exact test were used to understand relationships between different variables. In this paper, Fisher's exact test was used when the total sample size is less than 20 or value in any cell is less than 5, because Fisher's exact test is suitable for small sample sizes. Otherwise, a chi-squared test was used. *p*-values have been adjusted using the Holm method for multiple testing correction.

Results

Demography

Malay and Chinese communities were found living near mangrove creeks. In total, 124 valid questionnaires were collected, 78 from Chinese communities and 46 from Malay communities; 74% are male and 65% are native to their villages, with 60% working in the fishery industry. Most respondents received either primary school (42%) or secondary school (36%) education. The average household size was 5.1 ($\pm$ 2.9 std. dev.) people, with an average annual personal income of MYR 31,746 ($\pm$ 22,845 Std. Dev.) (1 MYR $\approx$ 0.22 USD, as of August 2023). An overview of villages is presented in Table 1 to show data heterogeneity.

The multiple correspondence analysis biplot shows a visualization of key variables (Fig. 2). Despite the first two dimensions explaining only 21.5% of the total variance, the graph still provides an informative overview. For example, Malay communities (shown as the green cluster) seem to know more species of mangroves and are more likely to collect mangroves and use them as medicine (Fig. 2). The scree plot, squared cosine of variables, and contributions of variables to axes are presented in Electronic Supplementary Material, ESM B.

Mangrove Knowledge and Collection

Mangroves are referred to as "bakau" in Malay and "红树" ([hóng shù], meaning "red tree") in Mandarin Chinese. Most people (59%) did not know any mangrove species; 28% knew *Rhizophora mucronata* and *Rhizophora apiculata*; the 13% that could name or describe other species (Electronic Supplementary Material, ESM C) are the ones working in mangroves, such as propagule collectors (hired by the forestry department for replanting), charcoal workers, logging workers, or ecotourism guides. A Mann–Whitney test shows that Malay people knew more mangrove species compared to Chinese people (confidence level = 0.95, two-tailed, $W = 648.5$, p-value = 8.812e − 12, $n = 124$), although neither group comes close to the degree of mangrove richness (Fig. 3).

Table 1. Overview of the eight villages and towns near Matang Mangrove Forest Reserve where the research was conducted with estimation of the population size, number of interviews, connectivity, house occupancy, and other observations

Village name	Estimated number of Malay and Chinese households	Number of people interviewed	Connectivity	House occupancy	Observations
Kuala Gula	370 (70 Malay, 300 Chinese)	4 Malay, 14 Chinese	By road	Normal	Shrimp processing and export; one abandoned shrimp farm in adjacent mangrove forest
Kuala Sangga	10 (40 houses but only 10 houses occupied; all Chinese)	10 Chinese	By boat	Low	Primary school closed in 2022 due to lack of students
Kuala Sepetang	670 (270 Malay, 400 Chinese)	15 Malay, 18 Chinese	By road	Normal	Ecotourism in Matang Mangrove Forest Eco Park and mangrove creeks; charcoal kilns
Titi Kertang	150 (mostly Chinese, < 10 Malay households)	1 Malay, 3 Chinese	By road	Low	Jetties only used by logging workers
Kuala Trong	40 (36 Malay, 4 Chinese)	12 Malay, 5 Chinese	By road	Low	Charcoal kilns; Malay people from nearby towns and cities come to Kuala Trong jetties during high tides for shrimps, crabs, and snails
Pasir Hitam	30 (all Chinese)	1 Malay (police officer), 9 Chinese	By boat	Low	Primary school had 8 students in 2023
Bagan Panchor	300 (50 Malay, 250 Chinese)	6 Malay, 9 Chinese	By road	Normal	Large-scale commercial fishing; small-scale fishing mostly done by Malay fishermen near the mangroves
Pantai Remis	2000 (composition unknown)	7 Malay, 10 Chinese	By road	Normal	Large-scale commercial fishing; small-scale fishing mostly done by Malay fishermen near the mangroves

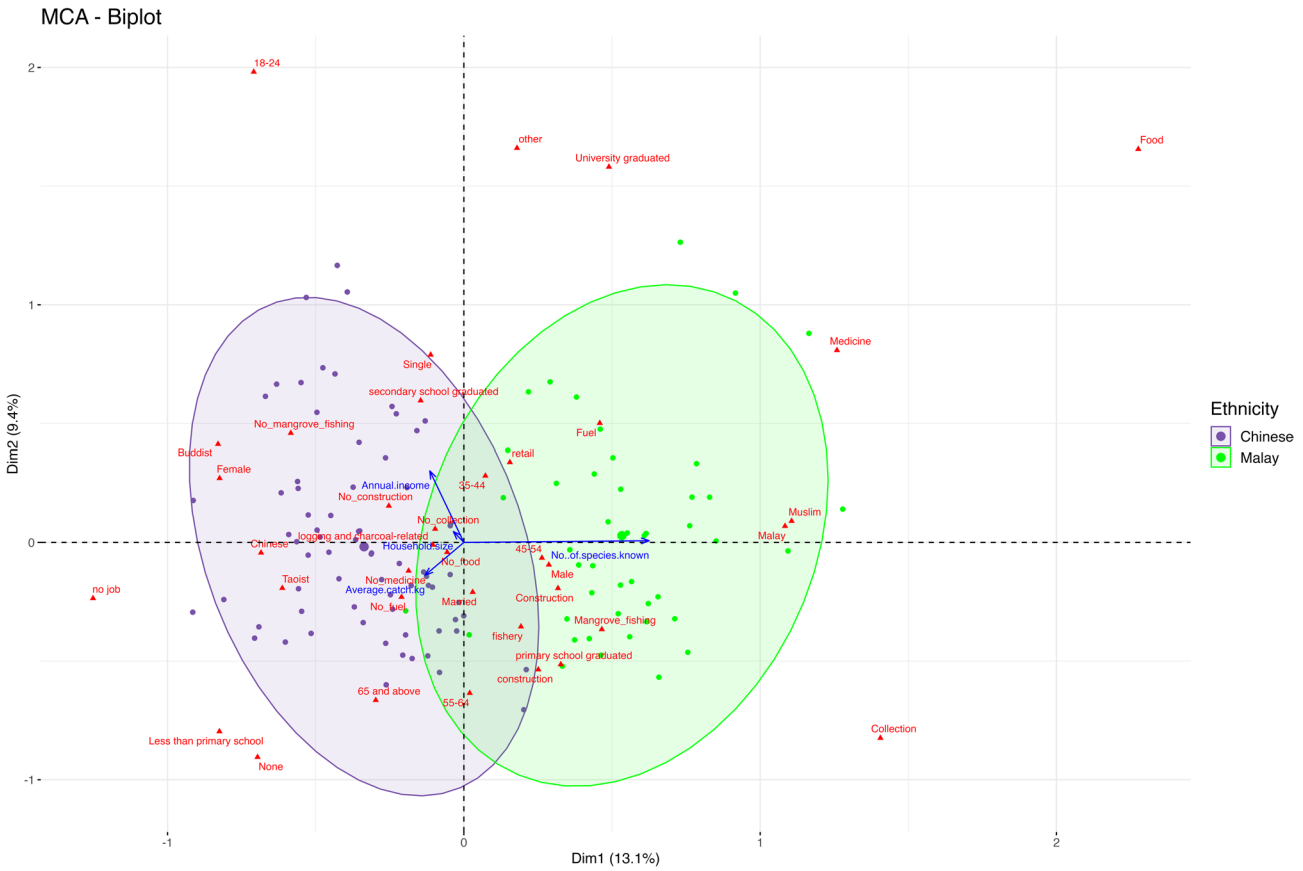

Fig. 2. Multiple correspondence analysis (MCA) biplot showing questionnaire results, $n = 124$. Individuals are colored by ethnicity. Active variables (categorical variables used to generate the graph axes) are printed in red, and supplementary quantitative variables are added to the graph in blue. Although the first two dimensions explain only 21.5% of the total variance, the graph clearly presents a distinction between Chinese and Malay communities in demographic traits and mangrove utilization patterns

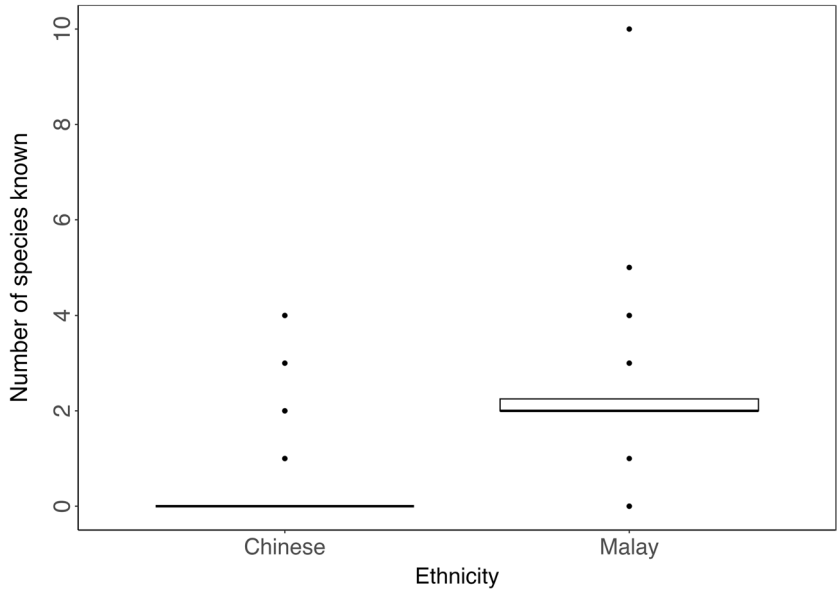

Fig. 3. Boxplot showing the number of mangrove species known by ethnicity at Matang Mangrove Forest Reserve, $n = 124$

Only eight respondents (7%) confirmed that they personally collect mangrove wood. It is mostly used as firewood or to tie boats at the pier. Other uses of self-collected poles include tying shrimp nets, making clam rakes, and marking the boundaries of cockle farms. If large quantities or larger sizes are needed, poles are purchased from licensed sellers.

Mangrove Wood Product Utilization

The usage of mangroves for medicinal purposes and as food, drinks, or animal feed is low, but for construction and firewood, it was high (Fig. 4). Pearson chi-squared tests and Fisher's exact tests (d.f. = 1, confidence level = 0.95, two-tailed, $n = 124$) show that Malay

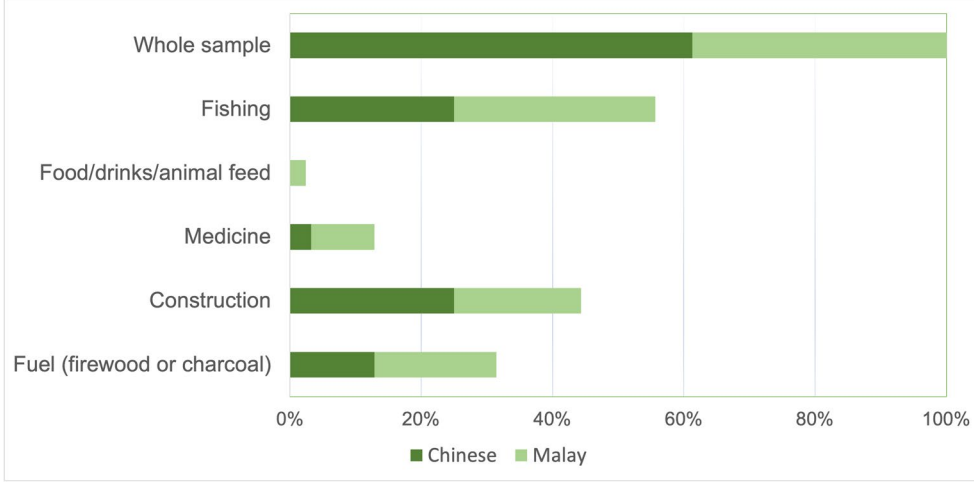

Fig. 4. Main uses of mangrove resources by ethnicity at Matang Mangrove Forest Reserve, $n = 124$

communities have higher utilization levels for fuel (X-squared = 8.64, p-value = 0.0099), medicine (odds ratio = 5.91, p-value = 0.0085), and fishing (X-squared = 16.04, p-value = 0.00031) than Chinese communities.

Propane gas cylinders are used as the main cooking source, but 27% of respondents still use mangrove charcoal at least occasionally during festivals and celebrations. For the 34 people that still use charcoal, half named *Rhizophora apiculata* and *Rhizophora mucronata* as the species used for making charcoal, and *Rhizophora apiculata* was identified by ten people as the best species due to its thin bark, large size, and longer burning time with less smoke. Only four households in Kuala Trong use charcoal exclusively for all cooking activities, receiving charcoal from nearby charcoal kilns. High calorific value, little or no smoke, and availability are the top reasons for using mangrove charcoal; 94% of charcoal users said they would not replace it with other fuels for specific cooking purposes.

Mangrove poles are important piling material. Forty percent of respondents use mangrove wood for piling, and half of them said they would not replace it with other materials. Poles can be connected to reach greater depths to support heavier houses with more stories (Fig. 5A). Meanwhile, piling blocks made from concrete and steel as an alternative are gaining popularity. *Rhizophora apiculata* and *Rhizophora mucronata* are the most used for piling due to their availability and durability in muddy soil.

Mangroves are rarely used as food or animal feed. Only two people consume *Sonneratia caseolaris* L. fruits that are commonly known as the mangrove apple, and one feeds cows with shoots from *Rhizophora mucronata* and *Rhizophora apiculata.* Only 16 respondents (13%) reported medicinal or chemical uses of mangroves (Table 2 and Fig. 5B), and one said mangrove-related cures are more effective than visiting a general physician.

Fisheries

Out of the 124 respondents, 88 people (71%) fish on a regular basis. For small-scale fishermen, average catch per fishing activity is 25.2 (± 17.4 std. dev.) kg. Fishes, shrimps, crabs, clams, cockles, and snails are harvested (Electronic Supplementary Material, ESM D) through a variety of fishing methods (Table 3) (Fig. 5C–H).

Some fishermen have resorted to illegal fishing gear such as the "dragon cage" to increase catch, while others condemn this behavior for depleting fishery resources. Trawlers' encroachment is also a common problem: according to Malaysian law, they can only operate at least 5 nautical miles away from the shore, but many boats do not go that far to save fuel cost, thus it is harder for less-equipped fishermen with smaller boats to get satisfactory catches.

Opinions and Perceptions of Change

Ecosystem Services and Mangrove Management

Many ecosystem services were mentioned without prompting, including coastal protection against tsunamis (13%, $n = 124$), the nursery function for marine organisms (6%, $n = 124$), and air quality improvement (6%, $n = 124$).

Kuala Sepetang is the major site for mangrove ecotourism. Popular tourist programs include sunset river cruise, eagle feeding, firefly viewing, and visits to Matang eco-educational center with a mangrove boardwalk (Fig. 5I). When interviewed, 74% held a positive attitude due to increased seafood sales and employment opportunities, and 26% complained about traffic and price inflation ($n = 35$). The mangrove boardwalk is also an important recreational site for Matang residents.

Regarding the Matang Mangrove Forest Reserve management policies, 49% are satisfied with the current management, while 51% express concerns about illegal cutting and overharvesting due to increased construction activities ($n = 59$). Some people mentioned that there had been more monkeys (20%) and fewer wild boars (20%), birds (11%), and snakes (13%), while 50% said there had been no change in biodiversity ($n = 46$).

Sea Level Rise, Sedimentation, and Pollution

Sea level rise was observed by 49 respondents (40%, $n = 124$), and during high tides, water can easily get into their houses. Roads and platforms have been raised with cement, and many houses are undergoing renovation to be lifted entirely

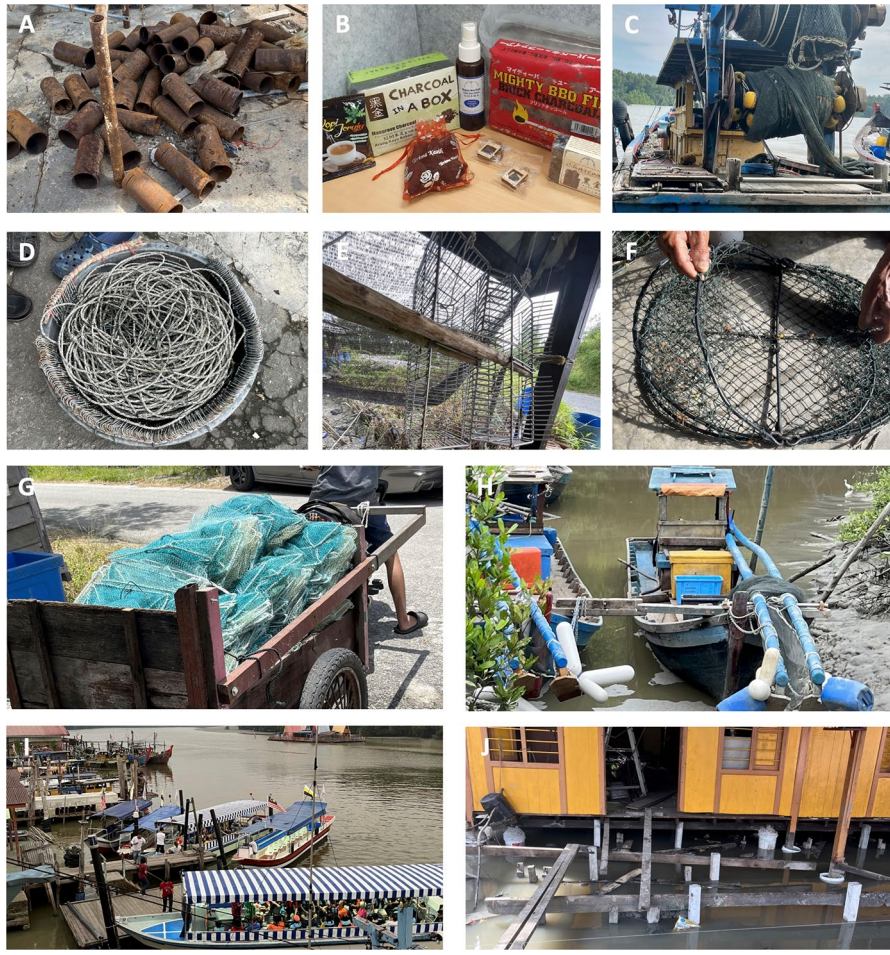

Fig. 5. Photographs illustrating ethnobiological relationships and mangrove resource utilization at Matang Mangrove Forest Reserve. **A** Connectors between mangrove poles for stronger piling to support heavier buildings. **B** Mangrove goods for sale at the charcoal factory: Acanthus coffee and different Rhizophora charcoal products incl. indoor deodorant and dehumidifier, wood vinegar, charcoal bricks, charcoal fragments in a thank-you bag, key hangers with charcoal fragments, and handmade charcoal soap (with wood vinegar). **C** "Pukat rimau," "pukat apollo," or "拖网," a trawler. **D** "Rawai ikan sembilang," a long line with hooks on the edge of the basin. **E** "Tangguk kerrang" or "蛤耙," clam rakes with a mangrove pole as handle. **F** Crab cages commonly used to catch crabs in the mangroves. **G** "Bubu naga" or "蜈蚣笼," illegal long cages with small mesh size, usually left in mangrove creeks overnight. **H** "Pukat rawa" or "推网," illegal push nets that catch shrimps and fish by a forward pushing movement driven by the boat. **I** Tourist boats in Kuala Sepetang. **J** Houses being elevated entirely due to increasing water level during high tide

(Fig. 5J). Twenty-six people (20%, $n = 124$) were affected by sedimentation, since the creeks are often not deep enough during low tides for fishermen to drive their boats out. Pollution is another problem reported by 14 respondents (11%, $n = 124$), with chemical pollution from nearby factories, shrimp farms, and fish farms. There was also a lack of an effective garbage collection system for households; many people in Kuala Sepetang throw their trash into the water because the garbage collection point is too far.

Fisher's exact tests of each reported problem by village were conducted, and Holm-adjusted p-values are 0.13, 0.49, and 0.28 for sea level

Table 2. Medicinal use of mangroves at Matang Mangrove Forest Reserve mentioned by local residents, including the species, parts used, processing, and purpose

Species	Parts used	Processing	Purpose
Acanthus ilicifolius L	Leaves	Boiling with water	External use for pain and itchiness
		-	*Acanthus* coffee
Rhizophora apiculata Bl. and *Rhizophora mucronata* Lamk	Shoots and fruits	Boiling with water	For drinking; helps with diabetes, stomach ache, and high blood pressure
	Charcoal	Boiling with water	For drinking; helps with sore throat
		-	Deodorant and dehumidifier (whole pieces); fertilizer (whole pieces or ash); charcoal soap used for deep cleansing and skin detoxification; charcoal head "kepala arang" used as decoration and air filter at home
	Wood vinegar	Condensed from charcoal kilns as a by-product	External use for itchiness, fungal infection, scabies, and small cuts; improves hair, skin, and nail health; used as mosquito repellent

rise, sedimentation, and pollution, respectively (d.f. = 7, confidence level = 0.95, two-tailed, $n = 124$). Thus, these problems do not seem to be confined to certain villages.

The Impact of the COVID-19 Pandemic

The COVID-19 pandemic has led to a decrease in available quantity and increased the price of seafood, charcoal, and poles (Table 4).

Out of 88 responses, 59% reported a decrease in fishing frequency during the pandemic (6% more frequent, 35% no change). While the number of people observing decreases in production and increases in price was highly significant, only few were able to provide a percentage change. Those that did reported price increases as high as 30%, which is considerable. Government regulations and disruptions in boat fuel supply contributed to the reduction. Fishing boats operated by single fishermen operated as usual; only bigger boats that required more than one person were not allowed to embark for fishing. Charcoal kilns were not allowed to burn during the pandemic, and there was a demand surge that drove the price up after charcoal kiln operation was restored.

Depopulation or Modernization

Villages and towns near Matang Mangrove Forest Reserve are experiencing rapid transitions. The younger generation has migrated to bigger cities like Taiping and Kuala Lumpur, with 16% respondents ($n = 124$) worrying that their villages are disappearing. Depopulation is a more prominent problem for Chinese communities than for Malay communities (Fisher's exact test, d.f. = 1, confidence level = 0.95, two-tailed, $n = 124$, odds ratio = 0.065, $p = 0.0004$). The most obvious population loss was observed in isolated Chinese villages, Pasir Hitam and Kuala Sangga. These villages are now occupied by seniors, with their children only visiting during holidays. Meanwhile, Kuala Gula, Kuala Sepetang, Bagan Panchor, and Pantai Remis have a more vibrant economy with large-scale fishing, seafood trading, and eco-tourism, and people generally no longer depend on mangrove-related wood products or mangrove creek fishing.

Discussion

Low Species Knowledge and Little Direct Collection

Malay communities have relatively better knowledge on mangrove species than Chinese communities, which is possibly due to stronger dependence on mangrove resources and generational knowledge accumulation. *Rhizophora mucronata* and *Rhizophora apiculata* form the

Table 3. Description and operation patterns of fishing methods by small-scale fishermen

Method	Description	Operation	Is it legal?
Fishing rod	-	Varies	Yes
"Bubu Gerogoi"	Made from *Nypa* leaves for shrimps	Half an hour each time; 5–6 times per day	Yes
"Rawai Ikan Sembilang"	200-m fish line with 250 hooks for *Plotosus canius* Hamilton	Varies; many leave it for 8 h in mangrove creeks	Yes
"Bubu Ikan Sembilang"	A cylindrical wooden cage for gray eel-catfish, *Plotosus canius*	More than 100 cages used in mangrove creeks (10 at each place)	Yes
"Bubu Ketam/螃蟹笼 [páng xiè lóng]"	Crab cage	Some only use a few while others deposit 70–80 cages at the same time	Yes
"Tangguk kerang/蛤耙"	Clam rake: 70–80 cm long and 20–30 cm in depth and width	Varies	Yes
"木排网 [mù pái wǎng]"	"Nets with standing wood": 4-m nets tied to anchored mangrove poles forming a line of 10 to 20 nets for shrimps	3 h during high tide (10 days per month); only used in Kuala Gula and Kuala Sangga	Yes
Cast net	Mesh size varies from 38 to 150 mm	Varies, usually 5 a.m. to 11 a.m., 5–6 days per week	Yes
"Pukat rawa/推网 [tuī wǎng]"	"Push net": nets tied to two poles, pushed forward by the boat	At night, or "until the police comes"	No
"Pukat rimau/pukat apollo/拖网 [tuō wǎng]")	Trawler or "Drag net": dragged by one to two boats; mesh size varies from 38 to 150 mm	3 a.m. to 3 p.m., 6 days per week; operation needs to be at least 5 nautical miles away and is prohibited on Sundays; license required	Yes
"Bubu naga/蜈蚣笼 [wú gōng lóng]"	"Dragon cage": 7–8 m long, 10–30 cages used together; mesh size can be less than 10 mm	Left in mangroves creeks overnight; common in Pasir Hitam, Bagan Panchor, and Pantai Remis	No

Some fishing methods are illegal

Table 4. Observed changes in quantities available and in prices for mangrove charcoal, poles, and seafood since the beginning of the COVID-19 pandemic at Matang Mangrove Forest Reserve

	Increased (%)	Decreased (%)	Number of responses
Quantity: charcoal	6.4	93.6	47
Quantity: poles	4.8	95.2	42
Quantity: seafood	1.2	98.8	82
Price: charcoal	98.1	1.9	52
Price: poles	97.6	2.4	42
Price: seafood	93.5	6.5	77

Responses are less than 124 because not all respondents answered these questions

monocultures in *productive* forest zones (Ariffin and Nik Mustafa 2013; Lucas et al. 2020) and are thus known to a higher number of people. The majority of the other 25 mangrove species are found in the protective forest zones, where a permit is required to enter (Ariffin and Nik Mustafa 2013), but are only known to a minority of people. Restricted access to *protective zones* greatly reduces the likelihood of encountering species other than *Rhizophora mucronata* and *Rhizophora apiculata*. The lack of direct involvement in forest resources collection has contributed to limited knowledge about mangroves; reduced livelihood dependency and increased variety of job opportunities are further weakening the local communities' connection with mangroves, which in the long term might result in a loss of Traditional Ecological Knowledge (TEK) like other mangrove communities around the world (Dahdouh-Guebas et al. 2006; Grimm et al. 2024; Nfotabong-Atheull et al. 2011).

Little personal collection for mangrove wood (7%) can be a result of government regulation and easy access to high-quality charcoal and poles from the market. This is similar to low collection levels in mangrove communities in the Philippines, where "illegal cutting of mangroves" is also prohibited by the government (Alimbon and Manseguiao 2021; Quevedo et al. 2020). At Matang, regular patrols ensure that all loggers have appropriate licenses. One respondent said they would "steal" the mangroves when the forest rangers are not around and that only thin poles are collected due to the lack of proper tools. The residents cutting one or two mangrove trees for their personal use is commonly witnessed (pers. comm. with local Forestry Department personnel).

Wood Product Utilization via Government-Regulated Markets

In Matang Mangrove Forest Reserve, charcoal and pole industry replaced firewood industry in the 1990 s (Chen et al. 2024). *Rhizophora* is valued as the best option for fuel and construction material (Ariffin and Nik Mustafa 2013; Satyanarayana et al. 2021), similar to other mangrove communities elsewhere (Arumugam et al. 2021; Dahdouh-Guebas et al. 2000; Walters et al. 2008). Matang Mangrove Forest Reserve, managed for the purpose of sustainable silviculture, thus has prioritized *Rhizophora* for harvesting and replanting, leading to the formation of monocultures in productive zones. With the collection, processing, and distribution carried out by commercial entities under government regulation, the direct indigenous connection between mangroves and resource users has been reduced. Therefore, the management contributes to a more efficient, rigid, and universal utilization pattern by both Malay and Chinese communities, for which a regulated market plays an essential role.

Chinese people use charcoal for roasted duck, stew, soup, and new year cakes for Chinese New Year and other festivals, whereas Malay people use it for satay, rice, and barbeque, or for cooking during Eid al-Fitr (End of Ramadan). Charcoal-cooked food is believed to have better smell and taste, which explains why people are unwilling to use other fuels for replacement (Satyanarayana et al. 2021).

According to a manager of a logging company, poles are used across coastal Malaysia as piling material for construction, and demand often exceeds supply. Community usage has been reduced as the wood is no longer freely attainable. Alternative materials for piling are freshwater woods or a layer of standing glass bottles. However, concrete with steel has gained more popularity as it is more long-lasting and can provide better support, but this option is more expensive.

Shift Away from Mangrove Fisheries

There has been a general shift away from small-scale fishery around Matang Mangrove Forest Reserve, with more people upscaling to commercial fishing or converting to aquaculture. Six respondents mentioned without prompting that more people shift from traditional fishing to cage/pond aquaculture for a higher and more stable income and that seafood from aquaculture is becoming more dominant on the market. It is likely that fishing resources within and around Matang Mangrove Forest Reserve are declining, similar to research findings in other mangrove habitats (Carrasquilla-Henao et al. 2019; Dahdouh-Guebas et al. 2006; Fabinyi et al. 2022;

Nfotabong-Atheull et al. 2011) and that in turn, LEK and TEK about artisanal fisheries may be eroded over time. Illegal fishing practices in response to reduced catch and livelihood pressures are likely to worsen the problem, posing a challenge to sustainability (Wong and Yong 2020).

For reduced catches, solutions suggested by local fishermen include increasing law enforcement effort against illegal fishing practices, setting up artificial refuge structures called "tukuns" (boxes with grids and holes), setting up marine reserves, introducing seasonal fishing closures, releasing juveniles and females, and controlling upstream pollution. Given the importance of mangrove ecosystems to small-scale fishery, the prevalence of overfishing, and the poor enforcement of management structures (Zu Ermgassen et al. 2020), it is recommended to investigate the fishing intensity of the area and to conduct ecological monitoring on available fishery resources (Hugé et al. 2016; Mahmud et al. 2015; Martínez-Espinosa et al. 2020).

COVID-19 Impacts on Local Markets and Livelihoods

Most respondents noted increases in price and decreases in market availability for seafood, charcoal, and poles. One respondent noted that seafood from aquaculture filled the gap in the market when fishing activity was reduced during the COVID-19 fishing ban. Given the dependency on fishery, reduced fishing activities must have caused negative impacts on the livelihood of the local communities (Vandebroek et al. 2020). According to the respondents, the government fishing ban lasted 2 months or longer, but it is possible that the duration and enforcement of the ban varied between different villages. Although people who operated boats alone were not affected by the ban, they could still be affected by the reduced frequency of fuel delivery by truck. Boat owners of bigger boats and especially workers hired on these boats could have been severely affected. Therefore, it is recommended that community livelihoods should be taken into consideration before any extreme or long-term fishing restrictions are implemented.

Environmental and Social Changes

The Indian Ocean Tsunami in 2004 was mentioned frequently with strong conviction that mangroves provided essential protection (cf. Dahdouh-Guebas et al. 2005; Danielsen et al. 2005). It is important to note that mangrove coastal protection has become part of the social collective memory in the Southeast Asian region, although the amount of protection is still debatable, as most literature is based on observational studies and models (Chang et al. 2006; Marois and Mitsch 2015; Teh et al. 2009). Respondents' supportive attitude towards sustainable mangrove management and ecotourism is in line with other research findings in Malaysia (Abdullah et al. 2021; Martínez-Espinosa et al. 2020).

Sea level rise, sedimentation, trash dumping, and chemical pollution are other environmental concerns. Sedimentation also led to difficulty in boat navigation in other mangrove ecosystems such as Senegal (Arumugam et al. 2021). Given Malaysia's vulnerability to sea level rise (Ehsan et al. 2019) and the prevalence of pollution in coastal Southeast Asia (Cochard 2017; Sandilyan and Kathiresan 2014; Wolswijk et al. 2020), it is crucial to investigate the current conditions and propose solutions to avoid further damage.

With increased connectivity and labor mobility, communities around Matang Mangrove Forest Reserve are undergoing rapid transition. Some are developing a booming commercial fishing industry with foreign workers; small villages with limited opportunities experience rapid depopulation, where households have been relocated to bigger towns, or seniors are left behind as empty nesters. Therefore, relocation and foreign worker influx may have become prominent social issues in these communities.

Specific investigations and actions are recommended to improve the current situation at Matang Mangrove Forest Reserve:

- Conducting long-term studies with repeated surveying efforts to understand socio-economic changes, transitions, and TEK loss (Faridah-Hanum et al. 2019)
- Investigating the types and effects of pollution at Matang Mangrove Forest Reserve (Hugé et al. 2023; Wolswijk et al. 2020)

- Conducting fish stock assessments and understanding current fishing intensities,
- Applying temporary fishing closures to allow for population recovery
- Ensuring stricter law enforcement on trawlers and the use of illegal fishing gear

Conclusion

The communities within and adjacent to Matang Mangrove Forest Reserve in general have a limited knowledge level about mangrove species and limited personal collection of mangrove plants. There still is, however, a high reliance on purchased mangrove poles for piling and on purchased charcoal for cooking certain foods, which are collected by government-registered companies and are available in the local market. Local fisheries depend heavily on mangrove creeks and surrounding coastal areas. Silviculture management in Matang Mangrove Forest Reserve inevitably separates mangroves from the local communities by commercializing harvesting activities and restricting access to species-rich protective *zones*, which in turn weakens the interaction between mangroves and the people living among them. However, if the management is sustainable and *Rhizophora* monocultures can persist and thrive, they will continue to supply wood products through markets and at the same time continue to support local fisheries and protect the coast of Malaysia.

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Author Contributions

Arya Ying Yue: methodology, formal analysis, data curation, investigation, writing—original draft preparation, writing—review and editing, visualization, project administration. Behara Satyanarayana: conceptualization, methodology, resources, writing—review and editing, supervision, project administration. Nur Hannah AbdRahim: resources, writing—review and editing. AhmadAldrieAmir: conceptualization, writing—review and editing, supervision. JeanHugé: conceptualization, methodology, writing—review and editing, supervision. Farid Dahdouh-Guebas: conceptualization, methodology, resources, data curation, writing—review and editing, supervision, project administration, funding acquisition.

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Data Availability

Data are available from Systems Ecology and Resource Management Research Unit on reasonable request.

Declarations

Ethics Approval The research was reported to and approved by the Forestry Department of Perak, Malaysia. Interviews were conducted following the ISE Code of Ethics (2006). The objectives of the research and the process of the interview were explained clearly to participants. An informed consent was solicited from each participant while explaining that the interview was anonymous, voluntary, without compensation, and for the purpose of academic research.

Competing Interests The authors declare no competing interests.

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