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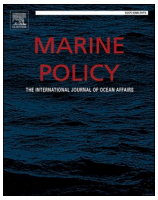

Understanding the ethnobiological importance of mangroves to coastal communities: A case study from Southern and North-western Sri Lanka

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ABSTRACT

Ethnobiological knowledge is an important part of people's capacity to manage, conserve, and improve the governance of mangrove ecosystems. This paper assesses the ethnobiological importance of mangroves to coastal communities adjacent to seven mangrove forests in Southern and North-western Sri Lanka. 197 households were interviewed, and respondents identified various mangrove ecosystem goods and services. Fruit juice produced from *Sonneratia* spp. and salads made with *Acrostichum aureum* L. young leaves constitutes valuable edible products in both regions. *Rhizophora mucronata* Lamk. and *Lumnitzera racemosa* Willd., were employed as alternative sources of fuel. Other uses of mangroves include wood for construction, chemical, and medicinal products. However, the usage extent was significantly higher in the Southern province (87.6%) compared to the North-western province (51%). Five indices were developed to understand the ethnobiological knowledge of respondents (Mangrove Use Index, Perception Index, Regulation Awareness Index, and Knowledge Index, Mangrove Dynamics Index). Except for the Mangrove Use Index, the rest of the indices were significantly different between the provinces. Communities with higher mangrove knowledge showed lesser usage. Respondents had negative attitudes towards the regulations that limit/did not allow the community to enter mangrove forests. Community participation, ethnobiological importance, and perspectives regarding how the community wants to manage mangrove forests should be taken into account to avoid conflicts in the future. Considering local perceptions and translating them into mangrove management regulations can be effective in guiding sustainable mangrove management in Sri Lanka as well as in other countries in the world.

1. Introduction

Mangrove ecosystems are highly biodiverse and productive areas in coastal regions around the tropics and subtropics, and supply goods and services that sustain and improve human livelihoods [29]. Mangrove forest degradation threatens coastal communities by increasing the risks posed by coastal erosion, storm waves, surges, and flooding [16,14,71]. Coastal communities rely on mangrove products for a wide range of ecosystem services, such as construction wood, fuelwood, traditional medicine, aquaculture, and ecotourism [63]. In Sri Lanka, the

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combination of mangrove ecosystem goods and services, as well as revenue-generating and recreational activities offers a range of opportunities that attracts investors in search of economic benefits [70]. Generally, coastal communities around mangroves live below the poverty line with high population densities, and therefore may exploit mangrove resources if there is any possibility to raise their standard of living [43]. However, only a few studies have been carried out on the ethnobiological[1] importance of mangrove ecosystems in Sri Lanka, where the coastal communities are not widely involved in mangrove decision-making processes [22,70]. Furthermore, information on the ethnobiological importance of mangroves is essential for sustainable management practices [70] as it helps delineate whether local communities are overexploiting, moderately using, or not depending on mangroves at all. Studies show that forests managed by dependent communities are more successful than those managed through top-down approaches without the participation of dependent communities [7], since community managed forests have lower levels of disturbance [65]. When managed properly, coastal communities can act as keepers of mangrove forests while using resources sustainably [48].

In Sri Lanka, local communities have used mangrove resources at subsistence levels [38,70,81]. However, the Sri Lankan government has recently pledged to protect all its mangroves by law, and any adverse effects on these coastal communities living below the poverty line remains unclear. Maximum policy reform needed to conserve mangroves in Sri Lanka appears to already be in place ([18] a), but the regulations deny/limit access to communities. These restrictions imposed on local communities regarding mangrove forest use and limitations to decision-making may affect the livelihoods and wellbeing of the communities. This may render the community both helpless and powerless. Local communities may sometimes ignore or deliberately violate mangrove conservation policies to protect their livelihoods. Therefore, it is important to keep in mind that the feasibility, effectiveness, and sustainability of mangrove management depends on how management affects local communities and their livelihoods [40].

Sustainable management of ecosystems should not only focus on protecting biodiversity but also on the socio-economic and cultural interests of the surrounding communities. To make ecosystem management locally impactful and sustainable it should equally improve the well-being and health of human and non-human components of ecosystems [53]. Ethnobiological studies can support the sustainable management of ecosystems as it focuses on the cultural and environmental heritage of an ecosystem that is otherwise invisible or ignored in decision making [34]. Local communities are often marginalized and underrepresented in ecosystem conservation, management, and decision making. Ethnobiological studies provide insights into the interaction of local communities with their environment and the communities' responses to ecosystem management. Studies around the world show that the sustainability of community-based mangrove management institutions is primarily determined by the increasing participation of subsistence-based users in decision-making and resource sharing [21]. Thus, ethnobiological understanding can help safeguard the environmental rights of the communities who are otherwise traditionally excluded from environmental decision-making processes.

Successful mangrove management requires the active participation of coastal communities, and the communities should also benefit in return [2]. By examining the ethnobiological usage of mangroves, we can understand the vulnerabilities of coastal communities and tensions created by "*no entry*" rules as well as how each affects local livelihoods in Sri Lanka. Simply continuing the enforcement of existing mangrove management laws (Fig. 1) and mangrove restoration as part of governmental efforts may not be successful in the long run when ultimately communities choose how to manage and utilize the mangroves close to their villages.

In 2003 the National Environmental Policy and strategies were established where the involvement of local communities in mangrove management was encouraged. In 2006 the National Wetland policy was formulated with the objectives of protecting and conserving wetland ecosystems and preventing illegal utilization. In 2008 through the Marine Pollution Prevention Act, pollution control was emphasized in mangroves. The habitats of three mangroves were protected under the Fauna and Flora Protection Ordinance amendment in 2009. In 2016 mangrove conservation initiatives started to get stronger with "*no entry*" rules. Later in 2018 the Sri Lanka coastal zone and coastal resource management plan was established, and mangrove conservation was further strengthened as part of coastal zone management. In 2020 through the National policy for the conservation and sustainable use of mangrove ecosystems, Sri Lanka became the first country in the world to conserve all of its mangroves by jurisdiction regardless of land tenures [61].

Mangroves in the North-western and Southern provinces of Sri Lanka are threatened by human activities, such as habitat destruction, land use conversion, shrimp farming, and coastal pollution, as well as by natural disasters like the Indian Ocean tsunami [25,47,82]. We hypothesized that coastal communities in our study sites still use mangrove goods and services despite regulations by the Sri Lankan government which deprives coastal communities of accessing mangrove forests. By examining the ethnobiological importance of mangroves to coastal communities in these areas, we aim first to understand the extent of mangrove usage (goods and services) and possible conflicts of interest surrounding management practices and conservation, along with the perception of coastal communities on present and future scenarios. Second, we strive to delineate whether the communities are truly dependent on mangrove resources for their subsistence. The final aim is to contribute to policy reform considering the perspectives of the local communities for sustainable mangrove management, both in Sri Lanka and beyond.

2. Methods

2.1. Description of the study site

Sri Lanka, a tropical island located in the Indian Ocean, covers 65,610 km^2 between latitudes 05°55′ to 09°51′ north and longitudes of 079°42′to 081°53′ east [28]. The coastline spans about 1620 km and hosts scattered patches of mangrove forests totaling an area of 156.7 km^2 [47]. In this study, we considered the ethnobiology of mangroves in the North-western and Southern provinces of Sri Lanka. These provinces were selected as they reflect differing circumstances and are close in proximity. The North-western province supports the largest mangrove forests in Sri Lanka, and these forests are less disturbed than the mangrove forests of the Southern province [47]. Mangroves in the Southern province are primarily threatened by the development of infrastructure and deforestation, whereas the North-western province mangroves are majorly threatened by shrimp farming. Both provinces were affected by the 2004 Indian Ocean tsunami [3,47,70]. The study was conducted in five coastal districts of the North-western and Southern provinces (Fig. 2, Table 1).

2.2. Sampling design and methodology

Ethnobiological surveys (July – August 2020) were carried out using a semi-structured questionnaire (Appendix 1) adapted from previous studies in Galle-Unawatuna in Sri Lanka [70]. 197 household heads living in sixteen villages (Fig. 2) adjacent to mangroves were interviewed in the Southern (n = 97) and North-western (n = 100) provinces. Within each region, communities were selected after an open discussion with researchers from the Department of Botany at University of Ruhuna, who had 25 years of field experience regarding mangrove

[1] Ethnobiology is a field of study that focuses on relationships among people, biota, and environments and can provide insights into the ways that communities interact with the environment [84].

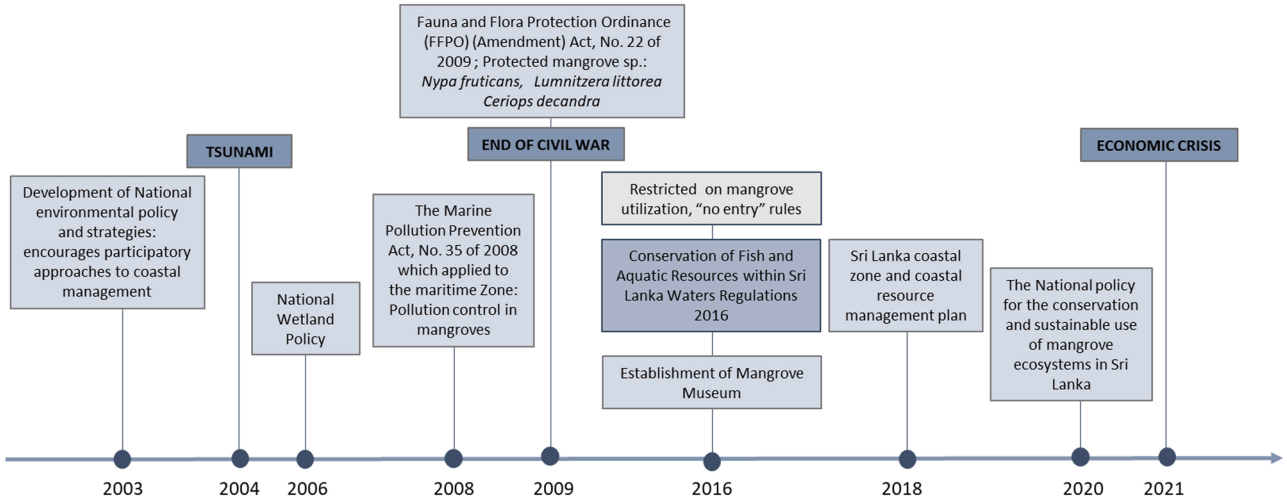

Fig. 1. Mangrove related regulations in Sri Lanka along with notable steps in mangrove conservation and major changes (i.e., Tsunami, Civil war, Economic Crisis).

social-ecological systems in the visited sites, and Google Earth imagery exploration from Maxar technologies. The communities were thereafter validated by preliminary field visits before the survey through transect walks [5] along with the mangrove forests and visual observations of mangrove utilization for one week prior to data collection. During the data collection, the first house was randomly selected within the coastal community adjacent to the mangroves, and thereafter the next houses were systematically chosen at 30 m intervals until the end of mangrove-inhabiting households was reached. Only one person per household was interviewed to avoid the repetition of members within the same household [12]. Each house's geographic coordinates were recorded using simple mapping and GIS tool apps UTM GEO MAP 2.7.7© to avoid redundancy. The sample size represented 1.05% of the total population in Galle district, 1.06% in Hambantota, 0.85% in Matara, and 0.63% in Puttalam [24].

2.3. Data collection

The questionnaire consisted of four sections: (i) socioeconomic and demographic traits, (ii) the main use of mangroves as vegetation and as an ecosystem, (iii) fishery-related activities, and (iv) evolution of mangrove areas and their local importance (Appendix 1). More than 90% in the Southern province and 50% in Puttalam district (North-western province) speak Sinhala while the rest of the sampling sites speak Tamil [73]. Interviews were conducted through direct translation from English to Sinhala, or English to Tamil, and vice-versa by native translators. Furthermore, direct observations on the use of mangrove materials for fencing, roofing, juice making, and food production by the respondents in their day-to-day lives, were collected as complementary information to the interviews.

2.4. Data analysis

The respondents' answers from closed and open-ended questions were compiled and categorized into independent variables (socio-economic and demographic answers) and dependent variables (respondent's answers). Frequency tables were built to understand the relationships among variables, and Pearson's Chi-squared (χ^2) or its corresponding G-Test were used to assess significant differences among variables.

After checking for normality through the Shapiro-Wilk test for the distance to mangroves and frequency of wood collection, the non-parametric Mann-Whitney Wilcoxon test statistic was used to detect their difference between regions. Spearman rank correlation was used to check correlations between continuous variables. For all tests, the statistical significance level was set at alpha $= 0.05$. The Bonferroni method was used to adjust p-values. We focused on multivariate statistics based on variable types and came up with outputs to outline mangrove utilization and socio-economic profile for the Southern and the North-western province respondents. Considering the types of variables, two multivariate analyses were performed: Principal Components Analysis (PCA) and Multiple Correspondence Analysis (MCA). The first was carried out to create a biplot of the association between socioeconomic variables and subjects.

After gathering the respondents' answers, five indices were extracted from the ethnobiological questionnaire and used to analyze the knowledge on mangroves, main uses of mangroves, mangrove dynamics, regulations, and perception (Table 2). These indices were developed to link together similar ethnobiological questions to better understand different categories and to evaluate the relative differences between provinces. The dependency between indices and independent variables (socio-demographic variables) was tested using a χ^2-squared test.

Questions in the same section were equally graded and considered for index building if the value of their absolute load was ≥ 0.3. All PCs with an eigenvalue greater than or equal to one (≥ 1) were considered categories within the same quadrat or close enough imply an association [39]. All data were analyzed with R 4.1.0. software (R [9]).

3. Results

3.1. Socio-demographic and economic profile of the respondents

About 60% of the respondents were male (See Table 3 for other demographic factors). The variable sources of income were strongly correlated with education level, explaining that education drives career choice. Respondents who did not finish their primary level of education were more likely to be engaged in fishing. The average annual income of the respondents was 388,660 ± 224,804 LKR (during the survey 1 EUR = 219.8085 LKR (30th July 2020 as in xe currency converter (www.xe.com)) (Table 3). The main sources of income were trading (26.4% of respondents), and fishing (21.8%). The remainder subsisted through donations, paid jobs, farming, and repairing (construction). Houses were built of wood and mud (50.8%) followed by grey bricks (47.7%).

3.2. Mangrove ethnobiology and utilization

Mangrove-related knowledge was significantly different between regions, based on the respondents' Knowledge Index ($\chi^2 = 7.14$; d.f. $= 2$; $p = 0.02$), where the North-western province scored significantly low. The level of knowledge also varied across mangrove species according to

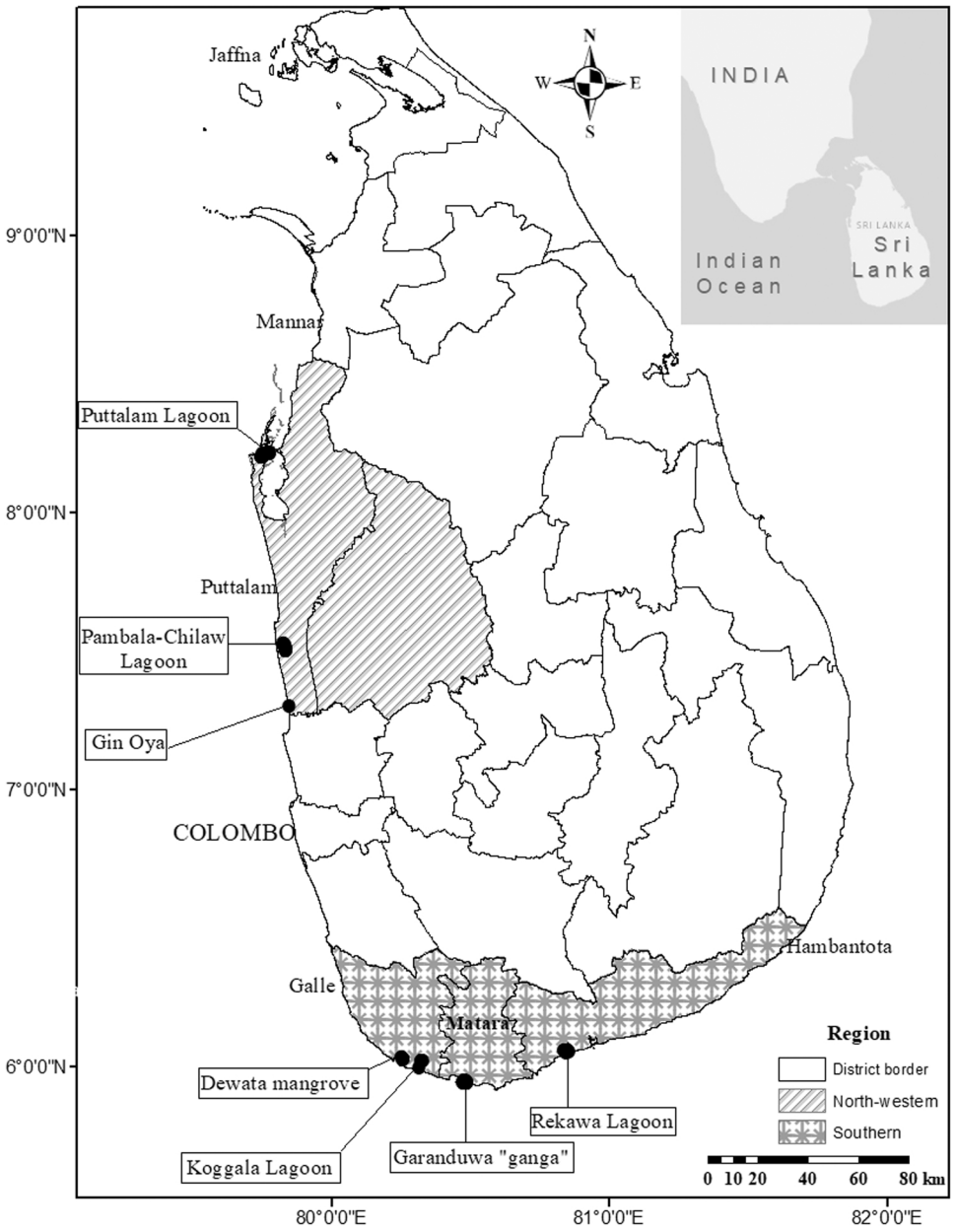

Fig. 2. Map of Sri Lanka showing the sites in the Southern and North-western provinces. Dots represent mangrove inhabiting households interviewed. Names of mangroves forest patches and lagoons are indicated in boxes.

the respondent's region. North-western respondents showed a good knowledge of recognizing mangrove species *Avicennia marina* (Forssk.) Vierh., *Avicennia officinalis* L., *Hibiscus tiliaceus* L., *Rhizophora apiculata* Blume and *Xylocarpus granatum* J. König, and less frequently recognized *Cerbera manghas* L. and *Bruguiera sexangula* (Lour.) Poir.; the reverse was true for Southern respondents ($4.98 < \chi^2 < 32.37$; d.f. = 1; $1.27 \times 10{-}9 < p < 0.025$). The level of knowledge of all other species did not differ between regions.

Mangrove ecosystems in the Southern and North-western provinces provided provisioning and supporting services to the adjacent communities. These supporting and provisioning services were medicines, edible plants, chemicals, firewood, poles for construction, and a favorable environment for fish growth and development. However, the usage extent was significantly higher in the Southern province (87.6%) than the North-western province (51%) ($\chi^2 = 32.98$; d.f. = 3; $p = 3.2 \times 10{-}6$). Moreover, the PCA plot (Fig. 3), indicates that the Southern province respondents were more likely to use mangroves as a source of food, for construction, and firewood than the north-western respondents ($9.78 < \chi^2 < 22.74$; d.f. = 1; $1.84 \times 10{-}6 < p < 0.001$). There was a high probability that respondents who were using mangrove wood for construction were also using it for firewood. Similarly, respondents who used edible plants also reported their medicinal properties. Four religions were practiced in both study sites, but the religious beliefs did not co-relate with the mangrove utilization patterns.

3.2.1. Fuelwood

No signs of degradation, cutting, or clearing were observed during the survey in either province. Even though more than 75% of respondents were using gas for cooking, mangrove and non-mangrove wood was also used as an alternate source of energy. Thirty-six percent of respondents (36%) reported mangrove deadwood collection by any family member for firewood. The collection was significantly higher in Southern province (46.4%) compared to the North-western province (24%) ($\chi^2 = 9.78$; d.f. = 1; $p < 0.001$). None of the other

Table 1
Mangrove villages visited in Southern and North-western provinces.

Province	District	Average Population Density Persons/km^2	Village
Southern Province	Hambantota District	240	Netolpitiya south Rekawa west
	Matara District	641	Garanduwa Thararamba East Thararamba North
	Galle District	658	Kahanda Polhena Attaragoda
North-western Province	Puttalam District	245	Kakkapalliya, Kurinjipitiya South Kurinjipitiya North Nainamadama Galahitiyawa Pambala South Pambala Mandalakudawa

Table 2
Mangrove indices developed from the ethnobiological questionnaire.

Index	Questions combined from the ethnobiological questionnaire
Knowledge Index (KI)	Q13: Definition of the term mangrove Q14: Number of mangrove species known
Mangrove Use Index (MUI)	Q16: Purpose of fuelwood: cooking/heating / other Q25: Mangrove species used for house construction Q33: Mangrove species used as service wood Q34: Mangrove species used for medicinal purposes: species/part/disease Q38: The use of chemical properties from mangrove: species/part/use Q43: Food and drink items from mangrove: species / part / nutritive value / frequency
Mangrove Dynamic Index (MDI)	Q56: Fish increase due to mangrove: yes / no / I don't know Q59: Mangrove Forest change over time and the reason: no / yes (reasons for increase or decrease) Q60: Animal diversities change in the mangrove forest over time: no / yes (reasons and species impacted)
Regulation's Awareness Index (RAI)	Q57: Familiarity with a. Forest regulations b. Fishery regulations
Perception Index (PI)	Q58: The future of mangroves Q 61b: Any other changes in the area over time and reasons: Sea-level and successive changes with respect to i. Mangrove forest ii. Fisheries iii. Agricultural crops iv. The village

independent variables was significantly correlated to this activity and the amount of collected wood did not depend on any factor.

On average, respondents of Southern households traveled 1.16 km, at a frequency of five times per month to collect firewood while North-western households traveled 0.73 km, five times a month, but no significant trends were found regarding the frequency for collection, or the distance traveled between regions. Regardless of the species, deadwood of fifteen woody mangrove species was collected. However, *Rhizohora mucronata* (among 15 woody mangrove species) was the most preferred firewood species in both regions due to its availability and high calorific value as a fuel followed by *Laguncularia racemosa* (L.) C.F. Gaertn.

(Fig. 4). Non-woody species such as *Sonneratia alba* J. Smith, *Sonneratia caseolaris* L., and *Acrostichum aureum*, were reported to provide additional nutritive values for daily consumption and medicines (Fig. 4, Table 4). Only two mangrove associates *Cerbera manghas* and *Hibiscus tiliaceus* L., were mentioned for firewood. In addition to mangrove species and mangrove associates, non-mangrove fuelwood species such as *Cocos nucifera* L., *Azadiracta indica* A. Juss., *Limonia acidissima* L., *Pagiantha dichotoma* (Roxb. ex Wall.) Markgr., and *Artocarpus heterophyllus* Lam. were alternatively used. Other sources of fuel in both regions included gas and electricity (Table 3).

Table 3
Socio-demographic traits of mangrove-fringing communities visited (Southern N = 97 and North-western (N_W) N = 100). Percentages indicate proportions of respondents represented within each region.

Traits	Southern	N_W			
Age	19 – 75	17 – 76	**Main source of income**		
Gender			Employed	14%	24.5%
Male	59.8%	61%	Farmer	6%	1.1%
Female	40.2%	39%	Fishing	25%	18.1%
Existential belief* *			Repairing	16%	14.9%
Buddhist	100%	22%	Trader	26%	26.6%
Catholics	–	66%	None	12%	14.9%
Muslim	–	11%	**Education level**		
Hindu	–	1%	< Primary	9%	7.3%
Ethnicity* *			Primary	59%	46.9%
Sinhala	100%	87%	Secondary	29%	44.8%
Tamil	–	13%	University	2%	1%
Income (×1000) LKR			**House type**		
< 100	2.7%	7%	Grey bricks	46%	49.5%
100 – 500	75.3%	69.60%	Natural stones	1%	1%
500 – 1000	19.2%	21.70%	Wood & mud	52%	49.5%
> 1000	3%	1%	Wood & coconut leaves	1%	–
Source of energy					
Gas* *	77.3%	90%			
Electricity	17.5%	24%			

** Significant difference between regions

3.2.2. Construction and wood services

Mangrove forests used for construction were significantly different between regions, with a higher extent of usage in the Southern province (35%) ($\chi^2 = 11.84$; d.f. = 1; p = 0.001). Mangrove poles were primarily used for roofing (53.4% of construction use), wall frames (22.4%), and fencing (24.1%). Among twelve mangrove species used for general construction, the PCA biplot (Fig. 4) illustrates a preference towards *Rhizophora mucronata* in both regions due to its greater durability, followed by *Laguncularia racemosa.* However, the respondents also used non-mangrove poles for house construction (Fig. 4) such as of *Cocos nucifera, Artocarpus heterophyllus, Tectona grandis* L.f., *Azadirachta indica* A. Juss., and *Alstonia macrophylla* Wall. ex G.Don.

3.2.3. Food, chemical, and medicinal services

Three mangrove species – *Sonneratia alba*, *Sonneratia caseoralis* and *Acrostichum aureum* – constituted alternative sources of food. Southern respondents consumed more of these species, either by drinking *Sonneratia* spp. juice (57.7%) and/or eating *Acrostichum aureum* young leaves (45.3%) compared to North-western respondents (31% and 13%, respectively) ($\chi^2 = 21.4$; d.f. = 1; $p = 1.84 \times 10^{-6}$). Eating mangrove food sources was frequent in respondents with less than 500,000 LKR of annual income ($\chi^2 = 14.1$; d.f. = 4; p = 0.005); this implies that very poor households depend on mangroves, which often form a small but critical part of their subsistence.

For other uses of mangroves, there was no significant trend in their use as medicine or as chemicals (i.e., fish net dye) between regions ($\chi^2 = 1.55$; d.f. = 1; p = 0.21). All respondents reported visiting a physician while seeking medical treatment. However, a few households (< 6%) mentioned use of mangrove plant parts (leaves, buds, flowers, or fruits) for alternative treatment of ailments (Table 4), but no consistent data

Fig. 3. MCA biplot illustrating the existing relationships among variables: socio-geographical variables (existential beliefs and region), mangrove use variables (firewood, construction, food, and medicine), and non-mangrove use variables (other fuel, and other construction materials).

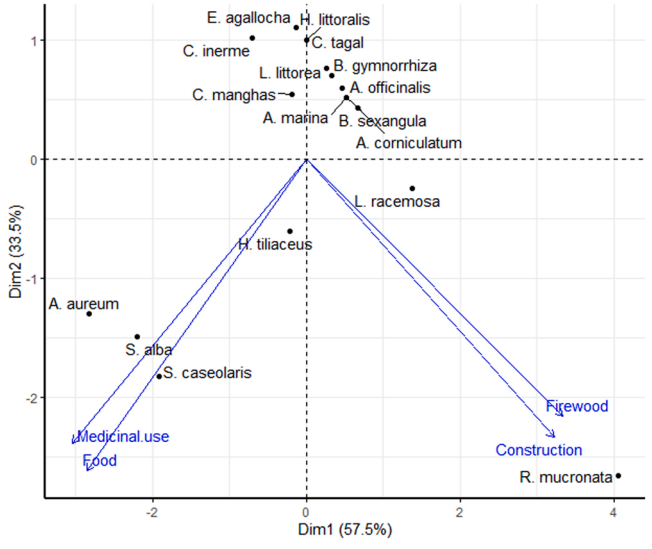

Fig. 4. Biplot of PCA analysis of mangrove species used by respondents in the study site. Each small black point represents the mangrove species used by the respondents. Blue arrows are supplementary variables (use of mangroves) used to build the PCA.

Table 4
Mangroves and mangrove associate species used in traditional Sri Lankan medicine for treatment of diseases as reported in the Northwestern and Southern Provinces of Sri Lanka.

Species	Plant part	Treatment
Acrostichum aureum	Bud	Heart attack
	Leaf	Diabetes
	Bud, leaf	stomach diseases
Sonneratia spp.	Fruit, leaf	Kidney diseases
	Fruit	Gastritis
Cerbera manghas	Fruit	Heart diseases
Clerodendrum inerme	Flower, leaf	Insect and rat bites allergies
Hibiscus tiliaceus	Bark	Bone injury
	Bark	Arthritis

was obtained. Some uses have faded away over time such as the extraction of natural dyes from the bark of *Rhizophora* sp., which was once used to strengthen and stain fishing nets and ropes in the study area.

3.3. Fishery-related activities

Fishing activities was one of the sources of income for 33% and 21.6% of respondents in North-western and Southern provinces respectively. Overall, 75.5% of fishermen fished in lagoons, mangrove creeks, or channels, and 24.4% in the sea. The catch composition contained fish, shrimps or prawns, and crabs with no significant difference between them ($t = 2.48$; d.f. $= 4$; $p = 0.067$). However, fish was the first preference for all fishermen, followed by crabs, shrimps, and prawns. Over the past ten years, 57% of fishermen mentioned an increase of catch and 29.87% pointed to a decrease that resulted from over-exploitation and lagoon pollution. *"Nowadays most of the lagoons and sea areas are heavily polluted. Everything was very clear and beautiful before. We don't see many fish types as we used to see. They may have vanished because of pollution, like we leave our homes and migrate during the war when the situations are not good to live in a place*", a fisherman from the North-western province recalled. Another fisherman from the Southern province stated as "*Now we begin to observe the disappearance of many fish species. It might be because of pollution, overfishing, or other unknown reasons. We also don't know exactly"*. Moreover, 22.81% of fishermen noticed the disappearance of some species for unknown reasons. Species that were mentioned as disappeared were, *Scatophagus argus* (Linnaeus, 1766), *Monodactylus argenteus* (Linnaeus, 1758), *Glossogobius* spp., *Epinephelus malabaricus* (Bloch & Schneider, 1801) , *Loligo duvauceli* (d'Orbigny, 1848) , *Chanos chanos* (Forsskal, 1775) , *Hyporhamphus limbatus* (Valenciennes, 1847), *Sillago sihama* (Forsskal, 1775) ,*Channa* spp., *Gerres oblongus* (Cuvier, 1830), *Rasbora* spp., *Anabas* spp., *Heteropneustes fossilis* (Bloch, 1794), *Caranx* spp., *Oreochromis mossambicus* (Peters, 1852), *Oreochromis niloticus* (Linnaeus1758), *Ambassis gymnocephalus* (Lacepède, 1802), *Etroplus suratensis* (1790).

3.4. Local perceptions on vegetation dynamics and regulations

Around fifty-four percent (54%) of the respondents ranked mangroves as important to their livelihoods. The Mangrove Dynamic Index was used to explain respondents' views about change in mangrove ecosystems over the past ten years and was significantly related to respondents' education level ($\chi^2 = 25.41$; d.f. $= 10$; $p = 0.03$), where respondents with a primary education level were the least likely to mention the increase of mangrove vegetation cover. Fifty percent (50%) of respondents reported an increase in mangrove vegetation cover and shared the same future perception about the gradual expansion of mangroves and change in their floristic composition. The mentioned reasons for the increase were reinforcement of regulations, mangrove restoration projects, self-regeneration, sea-level rise, and education and training. Another 36.5% reported a decrease from illegal cutting,

mangrove-shrimp farming conversion, anthropogenic pressure, and drought, while the rest of the respondents could not answer.

Respondents from different regions and with differing years of residence in the village did not share the same future prediction about mangrove cover. A future increase was predicted in the North-western province ($\chi^2 = 15.68$; d.f. = 2, $p = 0.003$) by native respondents ($\chi^2 = 10.15$; d.f. = 2, $p < 0.04$). Among other changes, faunal diversity change was reported to be significantly higher in the North-western province ($G = 30.36$; d.f. = 2; $p = 2.55 \times 10–7$). 65% of respondents who reported increased faunal diversity mentioned that it was related to increased mangrove forest cover whereas the rest attributed the decrease in faunal diversity to mangrove cover decrease, habitat destruction, and lagoon water pollution. The results also found that familiarity with forestry regulations was significantly higher in the North-western province ($\chi^2 = 17.57$; d.f. = 2; $p = 0.001$).

3.5. Correlation between indices

Indices were used to estimate the overall idea about respondents' answers related to ethnobiology of mangroves under different categories. Our results revealed that there were significant differences between regions in four indices - Mangrove Use Index, Perception Index, Regulation Awareness Index, and Knowledge Index except for Mangrove Dynamic Index (Table 5). According to the Mangrove Use Index "*No use of mangroves*" was significantly reported in North-western by a community with a high level of mangrove knowledge and mangrove related regulations. Moreover, this community (with high levels of mangrove knowledge) predicted a continuous increase in mangrove cover. The existing association between Mangrove Use Index and Knowledge Index ($\chi^2 = 25.99$; d.f. = 6; $p = 0.002$) from MCA indicated that respondents with high knowledge of mangroves were less likely to use mangrove goods (Fig. 5). Respondents who reported an overall decrease in mangroves shared the same perspective about the gradual decrease of mangroves and vice-versa ($\chi^2 = 23.4$; d.f. = 4; $p = 0.001$). The variably high Regulation Awareness Index was close to low Mangrove Use Index ($\chi^2 = 18.7$; d.f. = 6; $p = 0.04$) which again highlighted that people with strong knowledge of forestry and fisheries regulations were less likely to exploit mangroves. The respondents with no regulation awareness tended to use mangroves moderately.

Table 5
Indices' levels of respondents and their significance level between regions and the percentage (%) of respondents in each category. MUI: Mangrove use index, MDI: Mangrove dynamic index, PI: Perception index, RAI: Regulation awareness index, KI: Knowledge index, d.f.: degree of freedom.

Index	North-western (%)	Southern (%)	d.f.	χ^2	p value
MUI			3	32.98	3.23×10^{-7} **
No use	49	12.4			
Low	44	67			
Medium	7	19.6			
High	–	1			
MDI			2	0.44	0.8
Decrease	16	19.6			
Increase	81	77.8			
No change	3	3.1			
PI			2	15.68	0.0003 * *
Decrease	10	30.9			
Increase	75	50.5			
No change	15	18.6			
RAI			2	17.57	0.0001 * *
None	4	13.4			
Medium	96	76.3			
High	–	10.3			
KI			2	7.14	0.02*
Low	22	10.3			
Medium	34	49.5			
High	44	40.2			

* : significant, **: highly significant

4. Discussion

4.1. Mangrove resources and utilization by the coastal communities

Together with trends in coastal development, mangrove usage by local communities in Sri Lanka has often been considered conflictual with existing mangrove management methods [22,47,70,82]. Our study shows that there is a reducing trend in mangrove utilization in both provinces studied. Communities with higher awareness and knowledge of mangrove ecosystems tend to predict positive future change and also observe an increase in mangrove cover. There are claims that coastal communities exploit mangroves and sometimes hinder conservation and restoration initiatives [47,70], neither of which were observed in our study sites. Households interviewed in the Southern and North-western provinces rely on mangrove resources for their subsistence, and there was an overall decrease in mangrove usage in both provinces. These households acknowledge mangroves as an ecosystem that provides food, firewood, poles for construction, habitat for aquatic animals, and sources for medicine and chemicals. However, mangrove species preferences for goods and services are not always related to their abundances. In particular, some very common mangrove species in these regions as reported by [42] (i.e., *A. marina, L. racemosa, E. agallocha, A. aureum, H. tiliaceus*) were not mentioned as the most preferred for day-to-day use. Moreover, Satyanarayana et al. [70] reported that poorer individuals used mangrove products more frequently in Galle Unawatuna in the Southern province. The minimum wage in Sri Lanka is 120,000 LKR per year [59], 75% of the Southern and 65% of the North-western province population fall under the poor category [30].

Mangroves are used for religious, cultural, and ceremonial uses in different parts of the world (i.e., Africa, India). For example, Malaitan villagers place a high value on kastom art (carvings from mangrove wood) in the Solomon Islands [36]. The Baguma community of Nigeria uses *Rhizophora* sp. roots to beat drums to celebrate the annual Masquerade festival [41]. In certain areas in India, Mangrove vegetation is *"worshipped as sacred groves"* and is closely tied with religious beliefs whereas Gods/Goddesses are worshipped as protectors of mangrove forests [57]. Religious and cultural values can play a role in how communities perceive mangroves. But in our survey, we found that there were no religious or cultural practices related to mangroves, yet mangroves were regarded as important ecosystems that need conservation.

4.2. Mangrove Fuelwood

Mangrove wood is used as a source of fuelwood and charcoal across the world, including Sri Lanka [22,70]. Other examples include countries such as Kenya [12,46], India [17,26], Benin [37], Guinea [8], Cameroon, Philippines and Senegal [36]. Communities of North-western and Southern provinces use mangrove firewood for cooking directly, and not charcoal as is common in other parts of the world. Studies further show that the prime reason for mangrove wood collection in the Southern province (Galle-Unawatuna) was due to the dependency on clay-firing kilns for cooking [70]. Even though communities in the Southern province insist that the mangroves are used at subsistence levels, Dayalatha and Ali [22] report that 57.65% of mangrove forest cover has been lost in southern Sri Lanka due to logging. There were no such sites observed in our study, however *R. mucronata* was the most common species in the study sites (Rekawa, Pambala-Chilaw, and Puttalam). It was preferably collected for firewood due to its high calorific value [72] and the hard, dense wood that is rich in tannin. *R. Mucronata* fuelwood usage was reported in many other countries such as Kenya, India, and the Philippines [17,12,74]. The availability of this species was cited as the second reason for its preference. At the same time,

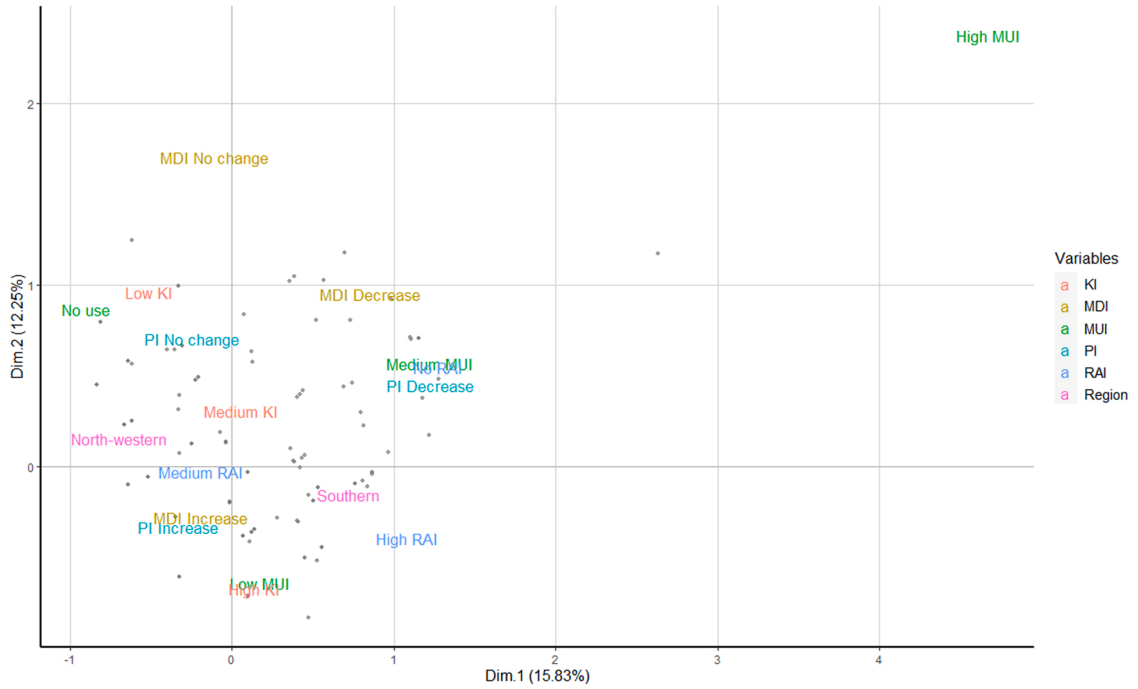

Fig. 5. Biplot presentation from Multiple Correspondence Analysis (MCA) of ethnobiological indices in the study site (n = 197). Small black dots represent respondents who participated in the survey. All variables used to build the MCA are represented in different colors. KI: Knowledge Index, MDI: mangrove Dynamic Index, MUI: mangrove Use Index, PI: Perception Index, and RAI: Regulation Awareness Index.

E. agallocha was not preferred for firewood despite its high abundance and availability in the study areas, as respondents stated that *E. agallocha* produces unpleasant smoke when burned and cracks clay kitchen utensils. The latex produced by *E. agallocha* is also toxic, and can cause blistering of the skin and temporary blindness [6]. Mathiventhan and Jayasingam [52] also emphasized that the toxic latex exudates of *E. agallocha* may be the reason for not being preferred by the coastal communities for firewood. Therefore, it has a high density around mangrove fringing villages in Eastern Sri Lanka.

4.3. Mangroves and construction

Mangrove wood has been used for construction in many countries such as Senegal, west-central Africa, Kenya, South Africa, and India [17,12,33,36,60,78]. Among the many uses of mangroves, provisioning of poles and timber for house construction and fencing homesteads was found to a lesser extent in our study. Mangrove poles are used in Southern Sri Lanka for construction purposes by coastal communities [22,70]. Most respondents (> 60%) use non-mangrove wood for construction. Unlike fuelwood, mangrove construction wood is often visible in construction (such as in fences) and the respondents seem to fear being caught by officers (e.g., Forest Department) for illegal logging while using mangrove wood. Therefore, coastal communities tend to be vigilant about using mangroves in construction. *Rhizophora* sp. is usually the most preferred species because of its dense, hard structure [79] and durability. The overall decrease in mangrove wood usage may be a result of ongoing mangrove restoration projects [47] that enhance community awareness about the importance of mangroves, along with new rules against illegal cutting and poaching (Fig. 4L) by the Sri Lankan government.

4.4. Mangroves and Fishery

Mangrove ecosystems play a crucial role in supporting many fishermen worldwide and providing small-scale fishery opportunities [85]. The fishing sector is one of the major coastal economic activities in Sri Lanka [44]. Mangrove ecosystems are considered to be breeding, spawning, hatching, nursing, and feeding grounds for aquatic species, and are used for fishing activities while providing refuge for many aquatic organisms by reducing predation pressure [4]. In our study, households that rely on a small-scale fishery acknowledged the importance of mangroves as breeding habitats for 20 aquatic species. Studies showed that the continuous reduction of fish catch in the North-western province is a consequence of overexploitation of mangroves, overfishing, and capture of young fish [69]. On the contrary, fishermen from North-western and Southern provinces in our study reported an average increase in fish catch. In reality, a fluctuation in catch occurred and was more related to mangrove destruction and water pollution. The respondents were well aware of illegal fishing, overfishing, and lagoon pollution, as well as the negative effects these have on fish populations. Fisherman of our study suggested that lagoon decontamination, development of fish nursery projects, and mangrove protection would further increase their catch. About 56% of Sri Lankan fisherman use gill nets for fishing which increases incidental bycatch and discard mortalities of numerous marine species [51]. The conservation status of fish species needs to be updated to legally protect threatened species. To protect threatened aquatic species, orders must be given by the responsible ministries to include threatened species in the respective annexes allocated for protected species of the Fauna and Flora Protection Ordinance or the Fisheries and Aquatic Resources Act.

4.5. Mangrove utilization in other provinces in Sri Lanka

Sixty-seven percent of the coastal communities in Sri Lanka are involved in fishery-related activities and live below the poverty line (www.statistics.gov.lk). Studies show that mangroves are used for provisioning and supporting services such as edible plants, construction, and fisheries in coastal areas of Sri Lanka [83]. Mangroves are used at subsistence levels in the Jaffna in the Northern province. But the subsistence level usage seems to have reduced over the past 20 years due to issues related to land tenures such as the acquisition of land to establish security zones. Security zones were established in the Northern province

by the Sri Lankan Government due to two decades of civil war (which ended in 2009). These security zones include fringing mangrove forests that were once used for fisheries by coastal communities [75]. Subsistence level usage in the Northern province was mainly fisheries and firewood [64]. Mangroves are also used for firewood, fisheries, and food in the Eastern province [68]. Mangrove forests in the Eastern province were partly destructed after the 2004 Indian Ocean tsunami [15]. Coastal communities in the Eastern province are in a transitional state and seem have to distanced themselves from coastal ecosystems after the tsunami [32,45]. The north-east of Sri Lanka was heavily affected by the civil war since 1983 and there were continuous mass migrations of native populations to other parts of Sri Lanka and other countries. Mangrove forests adjacent to the sea were traditionally home to native populations ([18]b). Most of the native population migrated from north-east parts of Sri Lanka due to the tsunami in 2004, for political and economic reasons [54,76]. Mangrove ecosystems in the Western province (i.e., Negombo) are mainly used for fisheries and aquaculture, and are threatened by anthropogenic disturbances such as deforestation and pollution [1,66,10].

4.6. Local perception of mangrove dynamics

Ethnobiological studies that include local perceptions on ecosystem change are important for monitoring and assessing the state of ecosystems (e.g., Gnansounou et al., [37]). About half of the respondents reported an increase in mangrove areas over the past decade and expect the increasing trend to continue in the future while the rest observed a decrease in mangrove forest extent. Mangrove vegetation cover increase was similarly reported in Galle-Unawatuna [13,70], Rekawa, Kalametiya, and Kahandamodara [14] in the Southern province. 11.3% of the respondents stated that the mangrove cover increase was observed in abandoned shrimp farms. Moreover, natural colonization of mangroves in silted lagoons was observed in the Southern province. It is known that within stilted lagoons in Sri Lanka, changes in lagoon water bathymetry and salinity resulting from massive soil erosion and improper irrigation plans can change the composition of mangrove species and increase the mangrove forest cover [14,50,49]. This may be one of the reasons for the increased mangrove cover in the Southern province. According to a study by Dayarathne and Kumara [23], small-scale cutting of mangroves was reported around the Rekawa lagoon in the Southern province, which was not observed in our study. The authors highlighted that small-scale cutting could affect the age composition and growing capacity of mangroves and act as a limiting factor for the colonizing capacity in long term [23].

In line with Dahdouh-Guebas et al., [19], Bournazel et al., [3], and Ofori et al., [62] the main reason for mangrove forest decrease in the North-western province was the conversion of mangroves to shrimp farms. However, 90% of shrimp farms were abandoned, left denuded, and have become unproductive landscapes over the years [3]. These landscapes have the potential to be recolonized by mangrove propagules from nearby forests [27]. Furthermore, mangrove plantation/restoration projects show high success rates in the North-western Province. The mangrove plantation projects were 50–100% successful in the North-western province, but only 0–10% successful in the Southern province [47]. According to the indices, communities with high levels of knowledge on mangroves and regulations were less likely to exploit mangroves and perceived an increase in mangrove cover. Increased awareness/knowledge can be thus associated with conservation optimism regarding mangroves around the world in line with Friess et al., [35].

4.7. Mangrove management and coastal communities

Communities on the fringes of mangroves have a strong stake in the sustainable management of mangrove resources. Their role needs to be understood by governmental management plans of mangroves. The introduction of numerous policies regarding mangrove conservation has considerably reduced the communities' access to forests in the study area. According to the Sri Lankan government, damaging, cutting, collecting, or removing mangrove products is not allowed [58]. Specifically, the Fisheries and Aquatic Resources Act (2016) states that *"No person shall engage in removing, cutting or altering mangrove ecosystems grown in the coastal belt or in any area adjacent to the Sri Lankan Waters"* [31]. *"No entry"* rules may have forced the coastal communities to stay away from these forests, which reduces utility. But local knowledge, observations, and sustainable use of mangroves are essential components of mangrove management. Moreover, considerations should be given to the *"no entry"* rules as *"continuity in the production of basic goods is never unimportant"* [20]. Restrictions by the government seem to be well understood and applied in the visited sites. The presence of signboards regarding forest conservation reflects the governmental effort to enforce *"no entry"* rules in the study area (Fig. 4L). But the communities residing near mangroves live below the poverty line and still use these forests for subsistence. A buffer zone or area of mangrove forest closer to villages can be allocated to local communities for utilization. When considering the healthy mangrove ecosystems, the socio-economic setting of the coastal community should equally be healthy and resilient [11]. The worsening energy crisis in Sri Lanka along with the recent fuel demand [77], and the recent continued unresolved explosion of gas cylinders in Sri Lankan households in late 2021 [67] may push communities to increasingly return to encroachment.

4.8. Mangrove conservation priorities

There are still unclear land tenures regarding the ownership of mangroves in Sri Lanka including our study sites. The ownership of mangroves and management rights needs to be adequately supported by the responsible authorities. Efforts must be taken by the government to consult with relevant stakeholders at the village levels to ensure agreements on land tenure and ethnobiological usage before the implementation of mangrove conservation initiatives and enforcement of mangrove management regulations. We did not find sufficient reference to the mangrove ethnobiological importance within mangrove legislations in Sri Lanka. Melana et al., [55] state that *"people first and sustainable mangrove forest management will follow"*. To sustainably manage mangroves, we suggest that mangrove management policies in Sri Lanka be truly community oriented. Policies can be made more flexible and responsive to the needs of the community and incorporate ethnobiological importance so that the local ecological knowledge be preserved and provide long-term benefits to the communities. For this purpose, all stakeholders and communities should be consulted at the early stages of policy development to ensure that marginalized coastal communities have their say about the importance of mangroves to their livelihoods, subsistence, and well-being to responsible authorities. Sustainable mangrove management is not possible without the support of adjacent communities and the policies need to support the communities to continue their livelihoods while sustainably utilizing mangrove goods and services. The practicality of conservation policies needs to be reassessed in Sri Lanka. Even though the importance of mangroves is well understood, coastal communities in Sri Lanka are afraid to restore mangroves on their own, for fear that the government will claim the mangroves in later stages. Such ambiguities need to be cleared by the government to increase community-based mangrove management.

We further suggest that the input from communities regarding mangrove management be channeled through to the village councils (who are closely associated with the communities) followed by the district and provincial councils and can be discussed in stakeholder meetings where all departments will be involved. Decisions taken during these meetings can later be adopted by the responsible ministries during policy adaptation/formulation. Furthermore, the Forest Department is responsible for managing all forest ecosystems in Sri Lanka including the mangroves. According to the Ministry of Forestry and Environment, one

of the serious threats to wet zone forests is the encroachment by communities living in the peripheral areas. To address this issue regarding encroachments, the Forest Department of Sri Lanka has been trying to come up with participatory approaches for forest management involving the local communities over the past 25 years. According to this department, this can be achieved with technical guidance from entities such as the International Union for Conservation of Nature (IUCN), and other national and international organizations. Through participatory forest management buffer zones (established in between the mangrove forests and the adjacent villages) can be established where the communities can be encouraged for sustainable, subsistence-level utilization of mangroves [56]. Such buffer zones are not yet established in the mangrove forests studied.

4.9. Limitations of the study

Only communities with voluntary participation were approached in our study. Since there were *"no entry"* rules, some communities denied participating in the survey while using mangroves. The other limitations were limited access due to COVID-19 distancing measures, periodic lockdown, and travel ban among districts. The sample may be non-representative because the respondents were disproportionately distributed throughout mangrove forests and urban areas. Some of the fishermen could not participate in the survey because of changing time schedules.

4.10. Knowledge gaps and future recommendations

This study can be coupled with a remote sensing-based survey to observe the past changes of mangrove forests and to check the community's perception of change. The recent fuel crisis in Sri Lanka and gas cooker explosions have already created fear among communities. Together, these might alter the local need to focus more on mangrove fuelwood, which might result in different perceptions within our study community that uses mangroves as an alternate fuel source. More participatory methods (Delphi, Q, Social Network Analysis) can be used to fully disentangle the mangrove ethnobiology and stakeholder involvement, and to understand the stakeholder point of view regarding coastal communities and mangrove utilization.

5. Conclusion

Our findings indicate that the mangrove-adjacent communities in the North-western and Southern provinces of Sri Lanka use mangrove goods and services at subsistence levels. The ethnobiological importance and knowledge regarding mangroves appears to be diminishing over the past ten years. However, communities with higher levels of mangrove knowledge and regulations show optimism regarding the future of mangroves and are reducing their usage. Regulating and cultural services provided by mangroves were hardly cited by respondents. As the government expected, the mangrove cover seems to be increasing, but the ban on communities entering mangroves needs to be reassessed, and communities must also be involved in decision-making processes. Mangrove-related awareness needs to help communities sustainably manage these ecosystems and serve as its guardians, rather than fully ban entry to the forests – a practice that may not be sustainable in the long run. Local communities should not be separated from mangroves, nor should the ethnobiological connection they had with these ecosystems for many generations be abandoned. The conclusions of this study can be adapted when synthesizing community-based mangrove management projects both in Sri Lanka and beyond.

CRediT authorship contribution statement

T.W.G.F. Mafaziya Nijamdeen: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Funding acquisition. **Ngendahimana Ephrem**: Methodology, Formal analysis, Investigation, Writing – original draft, Funding acquisition. **Jean Hugé**: Writing – review & editing, Supervision. **Kodikara Arachchilage Sunanda Kodikara**: Writing – review & editing, Supervision. **Farid Dahdouh-Guebas**: Conceptualization, Writing – review & editing, Supervision.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105391.

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