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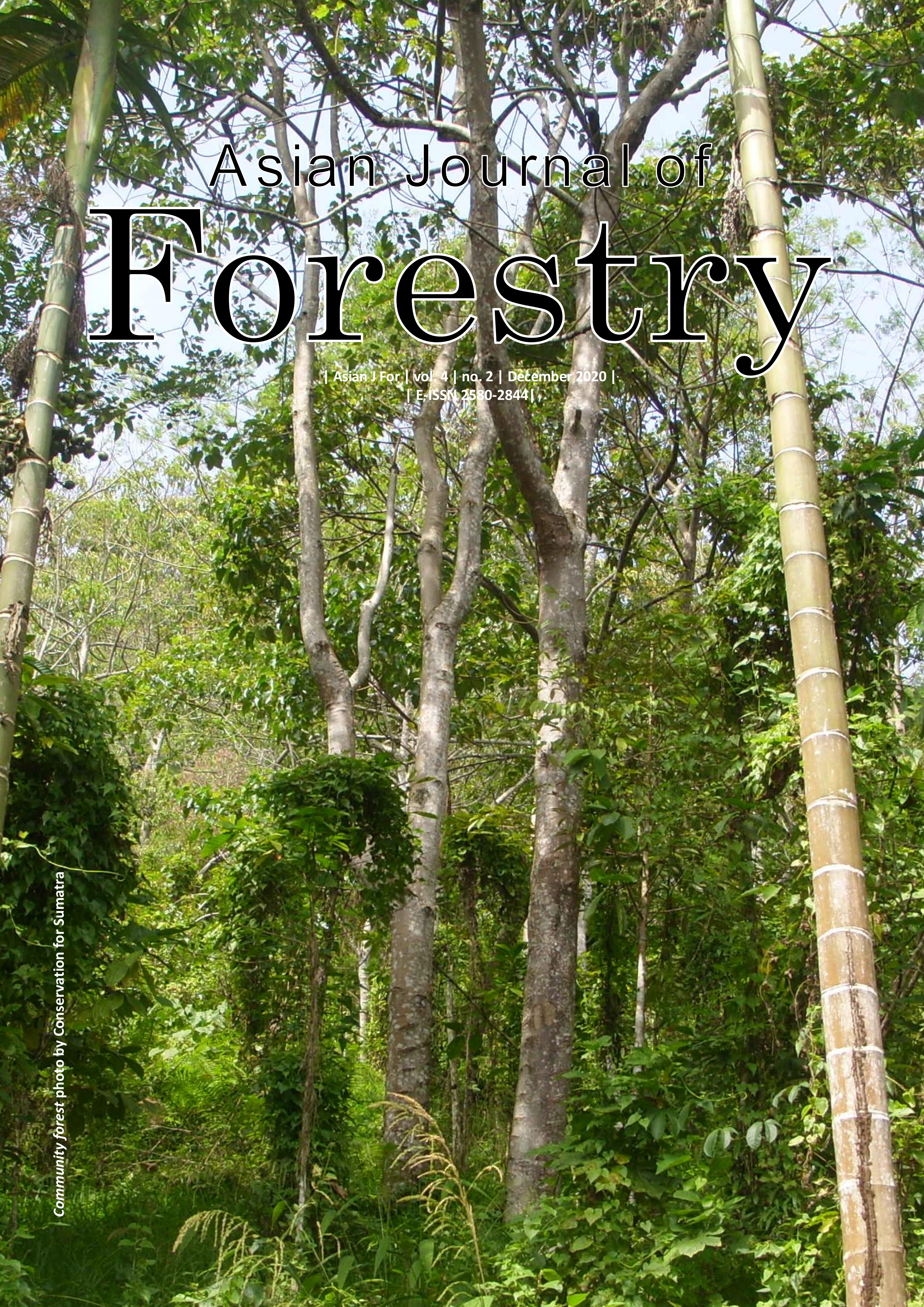

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Chapter in book:

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Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th Annual Symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.) Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

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New Forest Code effects on smallholder's intention to trade non-timber forest products

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Abstract. *Brites AD. 2020. New Forest Code effects on smallholder's intention to trade non-timber forest products. Asian J For 21: 41-45.* The Brazilian new Forest Code (NFC) allows the sustainable economic use of one of its main mechanisms for native vegetation protection: the Legal Reserves. This study aimed to investigate smallholders' intention to trade non-timber forest products (NTFPs) collected from the Legal Reserve areas. Data were collected through 350 in-person surveys in two municipalities from Bahia, Brazil. Outcomes showed that more than half of the respondents do not intend to trade NTFPs from their Legal Reserve areas. The lack of knowledge about the process to obtain government permission for the economic use of these areas was the main reason gave of their reluctance. Further, higher household incomes showed a negative correlation with the intention. Incentives from public or private policies and dissemination about the steps needed to obtain permission for Legal Reserve's sustainable use are needed for engaging smallholders in NTFPs trade. With these incentives, it would be possible to increase the NFC potential for adding economic value to the protected native vegetation and for linking conservation with the economic development of rural areas inhabitants. Thus, these outcomes add up to previous findings of the benefits of NTFPs trade, and in terms of practice and policy, they can help in the development of environmental policies that incentivize the NTFPs trade, contributing to increase landholders' incomes and to the NFC compliance.

Keywords: Environmental legislation, governance, legal reserve, native vegetation, New Forest Act

INTRODUCTION

Increasing rates of deforestation, land degradation and landscape fragmentation worldwide put conservation strategies on the spot of environmental policy discussions (Alencar et al. 2015, Keshtkar and Voigt, 2016). Public protected areas are therefore promoted as the counterforce to mitigate the detrimental effects of deforestation and land fragmentation to protect biodiversity and ecosystem services (Stolton et al. 2015). However, their existences are not adequate to avoid the great negative impacts of deforestation and land fragmentation, requiring complimentary options including the establishment of privately protected areas (Holmes 2013). Patches of native vegetation inside private lands may increase the connectivity among large, and frequently distant from each other, public protected areas, contributing to overall landscape conservation (Tambosi et al. 2013).

However, conservation policies inside private areas can restrict its use for economic activities, such as agricultural of livestock production, resulting in low acceptance by landholders (Stickler et al. 2013). Thus, strategies that combine conservation with economic development are the best option to promote a win-win scenario and maximize compliance, for example through the trade of non-timber forest products (NTFP). The commercial trade of NTFPs, such as fruits and seeds, from native vegetation patches, is acknowledged for its potential for adding value to standing forests (Shanley et al. 2015). The rationale of this strategy rests on the fact that harvesting NTFPs is already a long-practiced activity to rural inhabitants worldwide, who use NTFPs for subsistence and as a source of cash income through trading them in their natural form or being processed (Shanley et al. 2015). Moreover, NTFPs harvesting values the maintenance of natural ecosystems whose resources people rely on, and is less harmful to the environment than other activities that involve forest conversion, such as agriculture and cattle breeding (Vodouhe et al. 2016).

In Brazil, where more than 50% of the remaining native vegetation occurs inside private farms (Sparovek et al. 2015), the new Forest Code from 2012 (Brasil 2012) is the primary law that regulates the use and protection of these areas. Since Brazilian native vegetation remnants sustain essential ecosystem services, such as carbon sequestration and climate regulation (Zarin et al. 2016), and conserve 10 to 20% of the world's biodiversity (Giulietti et al. 2005), the new Forest Code has great importance in global environmental protection. Two of the main mechanisms for protecting native vegetation through the new Forest Code are the Areas of Permanent Preservation (mostly riparian vegetation) and Legal Reserves. The Legal Reserve is a portion of the farm that must keep a native vegetation coverage. The percentage varies from 20% to 80%, depending on the biome where the farm is located. To comply with the law, landholders who do not meet these percentages can opt to restore or regenerate native vegetation inside their property, or to compensate it in another land. The Legal Reserve area allows the sustainable management and economic exploitation of natural resources as long as the activity has a management plan approved by government environmental institutions (Brasil 2012).

The new Forest Code also sets different rules for the Legal Reserve of small farms. Smallholders are excepted to the need to restore or regenerate native vegetation to meet the Legal Reserve percentage of the new Forest Code. Thus, the Legal Reserve from small farms should be equal to the amount of native vegetation existing on July 26, 2008. Besides, the smallholders have the right of a simplified process for the approval of management plans for the sustainable use and economic exploitation of their Legal Reserves (Brasil 2012).

Another novelty brought by the new Forest Code is the “Rural Environmental Registry” (Portuguese acronym: CAR). CAR is a nationwide compulsory self-declared digital registry in which rural landholders must map and provide georeferenced data about the property boundaries, Areas of Permanent Preservation and Legal Reserves. By linking the landholder to the land use within a specific property, the registration allows to compile and systematize information and makes it easier to monitor the new Forest Code implementation (Gibbs et al. 2015).

Considering the Legal Reserve mechanism, we can argue that exploiting NTFPs from such areas can be a great opportunity for reconciliation native vegetation preservation with economic gains. Here, the relation between the smallholder Legal Reserve requirements and their intention to trade NTFPs from such areas was explored. The main reasons for trading NTFP from Legal Reserves and the main barriers to doing so were also analyzed. The initial hypothesis was that the acknowledgment of the area destined to Legal Reserve through the CAR registration would increase smallholders’ intention to trade NTFPs of these areas. The outcomes of this study can help in the development of environmental policies that incentivize the trade of NTFPs, contributing to increasing their incomes and to the new Forest Code compliance.

MATERIALS AND METHODS

Study period and area

Data were collected through face-to-face surveys from March to May 2017 across two municipalities (São Desidério and Riachão das Neves) in the west of Bahia State, Brazil. São Desidério has a total area of 15,157 km^2 and approximately 33,000 inhabitants (IBGE 2019). The municipality is located about 27 km from Barreiras, the main town from Bahia west region. It has a tradition of trading crafts, household utensils, tools, and other objects made from "buriti" straw, an NTFP from a palm tree (*Mauritia flexuosa* L.f.) (Melo 2006). Its economy is mainly based on agriculture, especially soy and sugarcane production. Riachão das Neves has a total area of 5,840 km^2 and approximately 22,000 inhabitants. The municipality is located about 54 km from Barreiras. Tourism and agriculture are the main economic activities of the region (IBGE 2019).

Data collection procedure

An initial sample of 500 farmers that had already done their CAR was randomly selected. The selection was made among farmers that had already done their CAR registration with the support of a local firm (Ambientagro) contracted by the State government to assist smallholders with the CAR process. According to the Brazilian legislation, smallholders are farmers with properties up to four fiscal modules (Brasil 1993). The fiscal module varies across municipalities and depends on the minimum amount of land required for primary economic activities in the region. In both municipalities surveyed the fiscal module equals to 65 ha, thus farms up to 260 ha are considered as small proprieties.

Of the 500 selected farmers, 115 were not located at the farm and 23 refused to participate, giving a total of 362 completed surveys. To keep farmers anonymity and, thus, obtain more straightforward answers, their names or any other type of personal identification were not recorded in the survey sheets. Survey questions were made to gather if the farmer was aware of the total area of native vegetation that must be kept as Legal Reserve (i), aware of the possibilities of using the Legal Reserve area (ii), already trade NTFPs from the native vegetation assigned as the Legal Reserve area (iii), intended to start trading NTFPs from the Legal Reserve Area (iv), and reasons for opting or not for trading NTFPs from the Legal Reserve Area (v). In addition, smallholders’ individual or household characteristics such as age, gender, education level, income, agricultural production, were also collected by the survey.

Data analysis

Descriptive statistics were used to: describe the sample (a), show the reported intention to trade NTFPs from the Legal Reserve areas (b), and show reported reasons for trading it or not (c). Then an exploratory model was constructed to investigate which factors best explain intention to trade NTFPs from Legal Reserve areas.

The dependent variable from the model was the intention to trade which indicates smallholders´ intention to start trading NTFPs from their Legal Reserve area and was based on their answers along a 5-point ordinal scale. The explanatory variables were total household income, total farm area and travel time from the farm to the nearest market. Control variables were gender, age, and education of the farm owner.

Due to the categoric nature of the dependent variable (intention to trade), an ordered logit regression model was used. Explanatory variables were included in the regression models in their standardized form to enable direct comparison of effect magnitudes from variables estimated in different scales (Zuur et al. 2009). The variables were standardized by subtracting their mean and dividing by two times their standard deviation. Variables thus have a mean of zero and take ± 0.5 standard deviation values, allowing a direct comparison between regression coefficients (Gelman 2008).

RESULTS AND DISCUSSION

Sample characteristics

On average, farmers' owners were men above 40 years old and with more than 5 years of formal education (Table 1). Households' total income ranged from 1,874.00 to 7,496.00 Brazilian Reais. Farms had, on average, a total of 34.3 ha and were located, on average, from a 15 minutes car ride from the nearest market.

Legal reserve and intention to trade NTFPs

Only 3% of respondents were not aware of the farm area that they must set as Legal Reserve and 6% did not know that the Legal Reserve allows the sustainable commercial use of natural resources (N=362). A small percentage of the respondents already traded some type of NTFPs existent in their propriety (16%; N=362).

A total of 293 respondents knew their Legal Reserve area but do not trade NTFP from these areas. From these, 67.9% (n=293) showed a negative intention to trade NTFPs from their Legal Reserve in the future, i.e. do not intend or probably do not intend to trade. While 21.8% showed a positive intention and 10.2% did not know (Figure 1).

The most cited reason for intending to trade NTFPs was to obtain an extra income (58,.5%), followed by doing a traditional household activity (28.7%). Only a few smallholders answered that it would represent their main income (5.3%) or that they would do it for nature conservation purposes (7.4%) (Figure 2).

The most cited reason for not intending to trade NTFPs was the lack of knowledge about the process to obtain permission to use the Legal Reserve area (66.1%), followed by the belief that it would not be an economically valuable activity (13.4%). About 9% of the respondents stated that there would not be a market for the NTFPs (9.4%) or that do not have enough knowledge about NTFPs to explore it (9.1%).

The reported intention to trade NTFPs from the Legal Reserve area was negatively correlated to the household total income (Table 2). Thus, smallholders from households with higher incomes are less likely to show a positive answer towards the intention to trade NTFPs from their Legal Reserves in the future.

Thus, contradicting the study initial hypothesis, more than half of smallholders who know their Legal Reserve area showed a negative intention towards trading NTFPs. The lack of knowledge about how to proceed to obtain the government permission for sustainable use if their Legal Reserve area was the main reason given by them to justify the disinterest in the activity. Further, higher incomes were associated with the lowest interest in such activity.

Table 2. Outcomes from the ordered logit regression of the association between intention to trade NTFP and explanatory variables

Variable	Intention to trade
Income	-0.793 (1.65)**
Farm area	-0.007 (0.023)
Travel time	-0.352 (0.231)
Gender	0.165 (0.175)
Age	0.004 (0.010)
Education	0.020 (0.034)

Notes: a: Robust standard errors; * p< 0.10; ** p < 0.05; *** p < 0.01

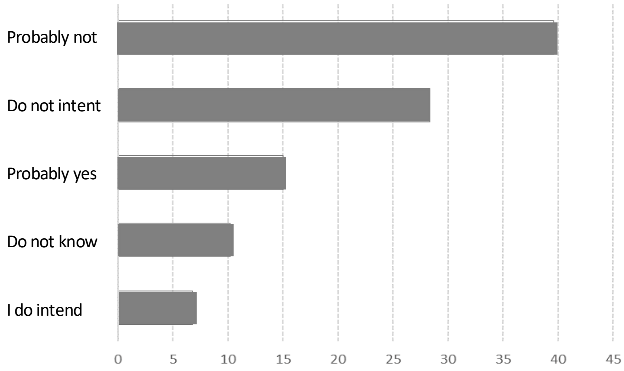

Figure 1. Smallholders' intention to trade NTFPs from their Legal Reserve areas (n=293)

Table 1. Descriptive statistics of the variables included in the model

Variables	Definition/values	N	Central tendency	SD
Dependent				
Intention to trade	Ordinal scale from 1= do not intend to 5= intend	362	Me^a=2.32	1.53
Explanatory				
Income	Household total income in minimum wage (from 1 to 10)	362	Me=4.32	3.87
Farm area	Farm total area (x 10 ha)	362	Me=3.43	1.02
Travel time	Travel time to the next market (min)	362	Me=15.58	4.67
Control				
Gender	Man=1; Woman=0 of the farm owner	362	Mo^b=1 (75%)	[c] n.a
Age	Age in years of the farm owner	362	Me=48.73	13.2
Education	Number of years of formal education of the farm owner	362	Me=8.8	5.7

Notes: [a] Me: mean; [b] Mo: mode and percentage in parentheses; [c]n.a: not applicable

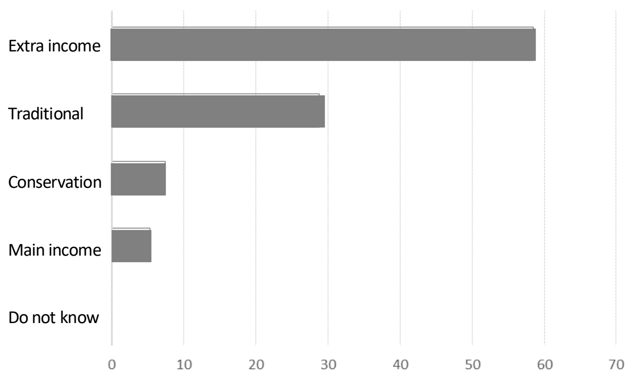

Figure 2. Reasons given by smallholders to trade NTFPs from their Legal Reserve areas (n=94)

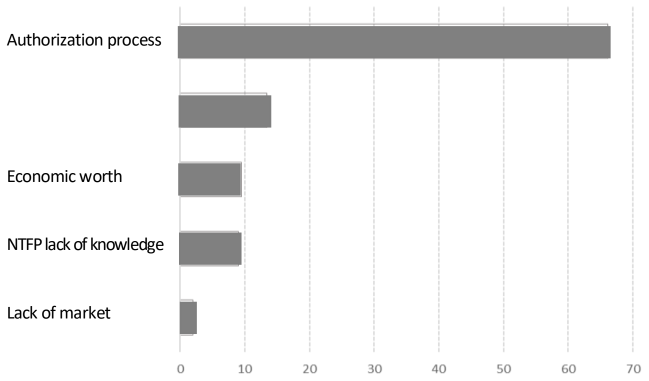

Figure 3. Reasons gave by smallholders to do not trade NTFPs from their Legal Reserve areas (n=199)

Although trading NTFPs is a strategy recognized by its potential to value standing forests (Shanley et al. 2015), it seems that it does not fit in the study context. One of the main claims of farmers during the process of the new Forest Code revision was that the previous law did not allow the country economic growth since the land use was very restricted (Brancalion et al. 2016). Thus, strategies to increase the protected land capacity of generating income would be expected to be welcomed by landholders. The fact that NTFPs income represents, in general, a small number of households' total gains and is a strategy used mainly by traditional communities or in places of high levels of poverty (Kusters 2006, Rizek and Morsello 2012), could explain the low interest observed. The decrease in interest according to the income increase, also seems to corroborate with this explanation.

In this case, strategies to add value to NTFPs could lead to an increase in farmers' intention to engage in its trade. Policies promoting incentives or financial support for the trade (Tewari, 1998), increasing the NTFP value trading processed products rather than in raw materials (Prasad et al. 1999) and promoting green market initiatives (Shanley and Laird 2006), could help in this sense. In addition, strategies to familiarize smallholders with the process of obtaining government permission allowing the economic use of the Legal Reserve could also improve their intention to trade NTFP. Promoting on the ground activities to explain these procedures, or hiring firms to help smallholders in this process, in a similar way to what was done for CAR registration, could improve farmers' willingness to trade NTFPs and consequently, improve their protected vegetation economic value.

Future studies could focus on which one, or which set, of incentives would work better to improve farmers' intention to trade NTFP from their Legal Reserve area. Once the most promising strategies are accessed public and private policies could be designed to incentive such trade increasing the new Forest Code capacity of adding value to protected vegetation.

In conclusion, since the Brazilian new Forest Code allows the sustainable economic use of Legal Reserves, the trade of NTFPs from these areas of protected vegetation could represent an opportunity for linking nature conservation and economic gains. However, outcomes from this study showed that smallholders do not intend to do so. Thus, incentives from public and private policies are needed to engage farmers in NTFPs trade. Further, to better explain the steps needed to obtain permission to trade and to facilitate the process to do it could also increase the probability of engagement. Once these barriers are overcome, the trade of NTFPs can be a strategy to enhance the new Forest Code potential of valuing the native vegetation remnants.

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Morphological variation of plantain squirrel *Callosciurus notatus* (Boddaert, 1785) (Rodentia: Sciuridae) populations in West Sumatra, Indonesia

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Abstract. *Tjong DH, Sari RM, Roesma DI. 2020. Morphological variation of plantain squirrel* Callosciurus notatus *(Boddaert, 1785) (Rodentia: Sciuridae) populations in West Sumatra, Indonesia. Asian J For 21: 54-60.* Plantain squirrel (*Callosciurus notatus* (Boddaert, 1785)) is unique in terms of morphological and geographical variations, making this species is divided into three sub-species so far. A study about the morphological variation of plantain squirrel among four populations in West Sumatra was conducted. As many as 38 specimens of *C. notatus* were collected from Padang, Lubuk Basung, Sangir, and Baso using a survey and direct collection method. The morphometric measurement was conducted in the Laboratory of Genetic and Biomolecular, Department of Biology, Faculty of Mathematics and Natural Sciences, Andalas University. Morphological measurement data based on 21 external characters and 35 skull characters were analyzed by the Kruskal Wallis test, Principal Component Analysis (PCA), and Unweighted Pair Group Method Arithmetic Average (UPGMA). The result showed that there was morphological variation in ten body characters and nine skull characters. Body and tail length characters that had a relatively longer length ratio were found in Baso population. Character lengths of ears and extremities (ulna and digiti length) which relatively had a longer ratio were found in the Sangir population. Skull morphological characters that showed significant differences were generally found in Baso populations having longer ratio values than other populations. The results of this study suggest that it is necessary to do further research to determine what environmental factors specifically influence certain morphological characters.

Keywords: Bukit Barisan Mountain Range, *Callosciurus notatus*, morphological variation, squirrel

INTRODUCTION

Callosciurus notatus (Boddaert, 1785) is one of the squirrel species that belong to the subfamily of Sciurinae in the family of Sciuridae (Nowak, 1999). One characteristic that distinguishes this squirrel from other species within the same genus is its habitat which is in the plantations area (Payne et al. 2000). This species is usually found in plantations or secondary forests, particularly living and breeding in monoculture plantations (Francis 2008). *C. notatus* is a diurnal animal that is active during the day (Saiful and Nordin, 2004).

Callosciurus notatus is geographically distributed in Southeast Asia, including Thailand, Malaysia, Singapore, Sumatra, Java, Borneo, and several smaller surrounding islands (Tamura and Yong 1993). There are two subspecies of this squirrel in Sumatra (i.e., *C. notatus vittatus* and *C. notatus tapanulius*) and one subspecies each in Java and Kalimantan, namely *C. notatus notatus* and *C. notatus dulitensis*, respectively (Martoyo et al. 2002).

Callosciurus notatus has an average 175-223 mm in body length, 160-210 mm tail length, 42-52 mm hind food length, and 150-280 g body weight (Payne et al. 2000). The specific fur color of this species is brownish agouti on the upper parts and reddish-orange on the underparts that alter from very pale to fairly dark or sometimes with a gray wash. *C. notatus* has distinctive stripes on its flanks with the buff and black line (Francis 2008).

Morphometric studies of intra-specific or inter-specific variations by quantitative analysis are valuable for detecting patterns of geographic variations and delimiting intra-specific or inter-specific evolutionary units (Li et al., 2012). For example, Hale and Luz (2003) revealed that there were morphological changes in British red squirrel (*Sciurus vulgaris*) as a result of introduced species and changes in landscape management. Endo et al. (2004) observed the geographical variations of skull characters among *Callosciurus caniceps* populations in Thailand and found that the northern population had a larger skull size than the southern population in the continental mainland.

The wide distribution of this species is presumably followed by morphological variation among populations, including the population in West Sumatra. West Sumatra is a region in Sumatra Island crossed by Bukit Barisan mountain range that stretches from north to south of the island with the highest peak of 3.805 m asl. Anwar et al. (1984) stated that the Bukit Barisan mountain range was formed during the early Paleocene (60 million years ago). The geographical factor variations between the east and the west area sorely affected the ecological condition of each region.

Callosciurus notatus was found in lowland up to 1,500 m asl (Duckworth et al. 2008). The existence of Bukit Barisan mountain range might act as geographical barrier separating *C. notatus* populations between the western and eastern areas. Reece et al. (2011) stated that geographic separation could make the gene pool divergence that interrupts gene flow among the separated populations. Based on such theory, this study aimed to analyze the morphological variations of *C. notatus* from four locations separated by the Bukit Barisan mountain range in West Sumatra.

MATERIALS AND METHODS

Squirrels were collected from four locations in West Sumatra, Indonesia, i.e.: Padang (9888602 S, 654200 E), Lubuk Basung (9971522 S, 605335 E), Sangir (9827689 S, 749274 E) and Baso (9969295 S, 665103 E) (Figure. 1). Squirrels were captured by using small mammal traps that were placed on the tree branches during the day. Jackfruit, coconut, peanut butter, and rambutan were used as baits. We recorded the age (sub-adult or adult) and the sex of each squirrel captured. A total of 38 specimens (20 males and 18 females) were collected and used for morphological analyses. The number of specimens collected from each location was: Padang (4 males and 3 females), Lubuk Basung (10 males and 7 females), Sangir (3 males and 4 females), and Baso (3 males and 4 females). The specimens consisted of 30 adults and 8 subadults. Specimens were deposited at the Museum Zoologi Universitas Andalas (MZUA).

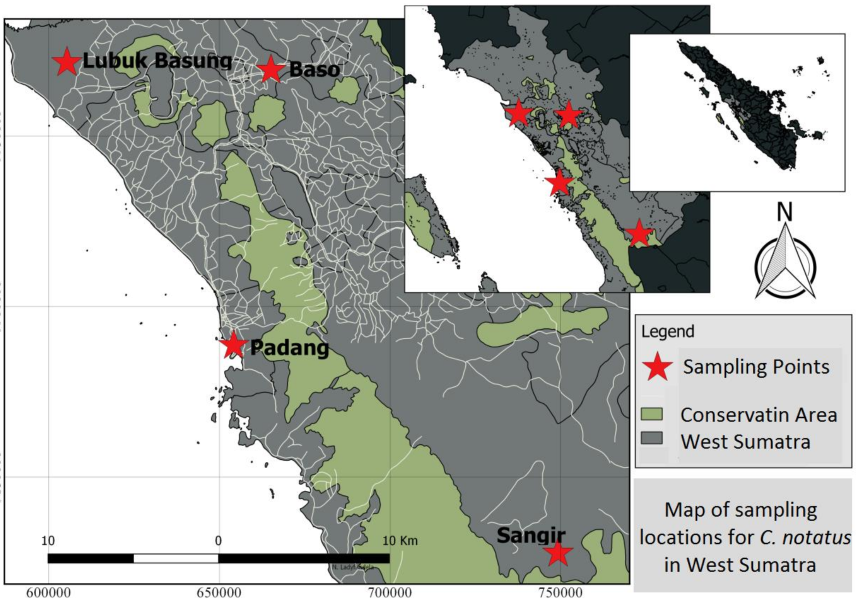


Figure 1. Map of sampling locations for *Callosciurus notatus* in West Sumatra, Indonesia. Padang and Lubuk Basung represented the western region of Bukit Barisan mountain range, while Baso and Sangir were located in the eastern region.

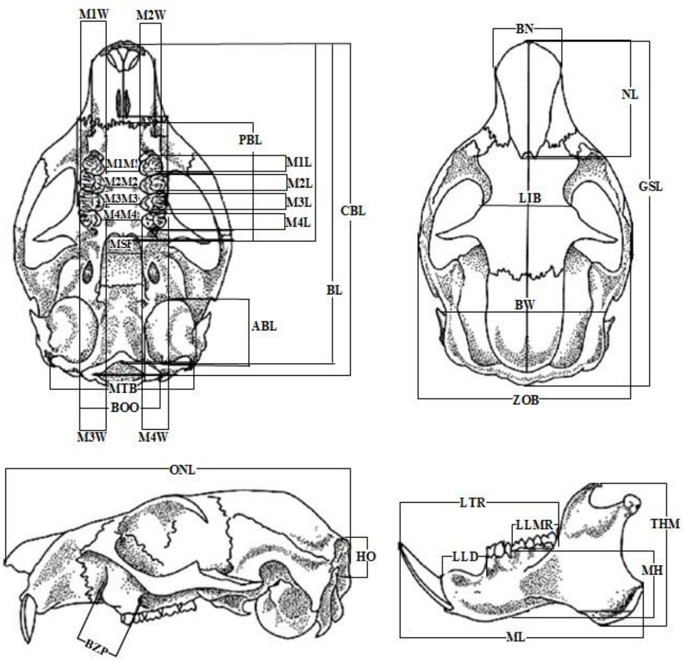


Figure 2. Skull characters measured in this study (sketch modified from Li et al. 2012)

Procedures

There were 56 measured characters; i.e. 21 external characters and 35 skull characters. The external characters were measured following Francis (2008) with addition of 17 characters. External characters measurements consisted of head and body length (HB), tail length (T), ear length (E), eye length (EL), interorbital distance (IOD), nose high (NH), nose width (NW), internarial space (IN), ulna length (UL), fore palm length (FP), first finger of forefoot length (1FFL), second finger of forefoot length (2FFL), third finger of forefoot length (3FFL), fourth finger of forefoot length (4FFL), tibia length (TL), hindfoot length (HF), first finger of hindfoot length (1FHL), second finger of hindfoot length (2FHL), third finger of hindfoot length (3FHL), fourth finger of hindfoot length (4FHL) and fifth finger of hindfoot length (5FHL).

Skull characters were measured following Martoyo et al. (2002), Song, Fa-Hong and Xue-Fei (2012), and consisted of maximum length of skull (GLS), nasal length (NL), nasal breadth (BN), zygomatic breadth (ZOB), length of first upper molar (M1L), width of first upper molar (M1W), distance between first upper molar (M1M1), length of second upper molar (M2L), width of second upper molar (M2W), distance between second upper molar (M2M2), length of third upper molar (M3L), width of third upper molar (M3W), distance between third upper molar (M3M3), length of fourth upper molar (M4L), width of fourth upper molar (M4W), distance between fourth upper molar (M4M4), palatal length (PL), length of palatal bridge (PBL), basal length (BL), condylobasal length (CBL), auditory bulla length (ABL), breadth of occipital condyles (BOO), mastoid breadth (MTB), least interorbital breadth (LIB), braincase width (BW), mesopterygoid fossa breadth (MSF), occipito-nasal length (ONL), breadth of zygomatic plate (BZP), height of occipital (HO), mandible length (ML), height of mandible (THM), length of lower diastema (LLD), length of lower molar row (LLMR), length of lower tooth row (LTR), and mandibular height (MH). The diagrammatic description of skull characters is presented in Figure 2.

Data analysis

The measurement data were divided by head and body length (external measurements) and the maximum length of the skull (skull measurements) to a standardized character size of all specimens. Morphological variations among the population were analyzed using the Kruskal-Wallis test at a significance level of 5% using SPSS Ver. 17 software. MVSP 3.1 was used to analyze Principal Component Analyses (PCA) and Cluster Analysis.

RESULTS AND DISCUSSION

Characters comparison among four populations showed significant differences among them in 10 external characters and nine cranial characters (Table 1). Kruskal-Wallis test showed that ten external characters were significantly different among populations. Those characters were head and body length (HB), tail length(T), ear length (E), nose high (NH), nose width (NW), ulna length (UL), first finger of forefoot length (1FFL), second finger of forefoot length (2FFL), third finger of forefoot length (3FFL) and fourth finger of forefoot length (4FFL). Characters on the finger are more differentiated than other characters. The fingers are one part of the squirrel body used to climb. Based on the measurement results, the finger sizes of Sangir population were generally longer than those of Lubuk Basung and Baso populations. The differences were likely affected by the adaptation of *C. notatus* in Sangir that lived in an area large arbor plant as well as being near to the secondary forest whereas *C. notatus* populations founded in Lubuk Basung and Baso were located at the plantation area with palm trees and cacao.

Li et al. (2012) stated that the phenotype divergence may have regard to the geographical distribution and living conditions, and can serve as a reflection of the adaptation form of the different ecological niches. Hansson and Henttonen (1988) reported that the populations of the same species in different habitats could indicate variations due to the influence of extrinsic factors. One factor that may have significant influence is food. Pizzimenti (1980) stated that there is a relation between diet habits and morphology.

The skull characters that showed variation on the four *C. notatus* populations were the maximum length of the skull (GLS), basal length (BL), condylobasal length (CBL), and mastoid breadth (MTB). These characters affect or are affected by the size of the brain. While the other skull characters with differentiation such as nasal length (NL), length of first upper molar (M1L), mandible length (ML), the height of mandible (THM) and length of lower diastema (LLD) may be more dominated by the type of food. Velhagen and Roth (1997) suggest that the arboreal squirrel usually shows the most substantial mechanical advantage on incisors used to eat fruits and nuts. Hayashida et al. (2007) argued that skull variations of *Callosciurus caniceps* are influenced by geographical differences.

Based on the analysis of 21 external characters and 35 skull characters, we obtained the Euclidean distance representing relationships based on the similarity of morphological characters among populations (Table 3). According to the Euclidean distances, *C. notatus* populations that have the most similarities were between Padang and Lubuk Basung population, while populations that have the least morphological similarities were between Lubuk Basung and Sangir populations. Based on those values we can infer that geographical distance relatively reflected the relationship distance among populations. Padang population is closer geographically to Lubuk Basung population, while the geographical distance between Lubuk Basung and Sangir is the furthest compared to the other sampling locations.

Table 1. Comparison of *Callosciurus notatus* external characters from four populations in West Sumatra, Indonesia by Kruskal-Wallis test that showed significant results.

Characters	Population				Kruskall-Wallis Test
	Padang N=6	Lubuk Basung N=16	Sangir N=7	Baso N=7	
HB	185.0±9.8	191.1±7.5	183.7±8.9	196.9±3.8	H=10.372
	171.0-195.0	177.0-203.0	172.0-198.0	192.0-203.0	p=0.016
T	183.0±5.9	182.4±9.1	192.7±7.5	204.9±12.9	H=14.311
	174.0-190.0	165.0-195.0	185.0-203.0	183.0-225.0	p=0.003
E	18.2±1.2	17.7±1.2	18.6±0.9	18.1±1.3	H=10.105
	17.0-20.0	14.5-20.0	17.0-20.0	16.0-20.0	p=0.018
NH	7.5±0.8	6.2±0.6	6.6±0.7	6.2±0.6	H=14.237
	6.6-8.3	5.3-7.2	5.7-7.4	5.6-7.5	p=0.003
NW	8.4±0.3	7.9±0.7	7.6±0.9	7.8±0.4	H=8.784
	8.0-8.7	7.0-9.4	6.5-8.8	7.5-8.6	p=0.032
UL	38.3±2.3	37.6±2.0	38.6±2.3	39.6±1.6	H=11.942
	36.0-41.0	34.0-41.0	34.5-42.0	37.0-41.0	p=0.008
1FFL	10.8±0.7	11.1±0.6	11.9±0.6	11.1±0.9	H=9.572
	10.0-12.0	10.0-12.0	11.0-12.5	10.0-13.0	p=0.023
2FFL	14.3±2.3	14.1±0.7	15.0±0.6	14.1±0.1	H=9.696
	12.5-19.0	13.0-15.0	14.0-15.5	12.5-15.5	p=0.021
3FFL	15.5±2.2	15.1±0.7	15.8±0.4	15.3±0.6	H=10.314
	14.0-20.0	14.0-16.5	15.0-16.0	14.5-16.0	p=0.016
4FFL	11.7±0.5	11.7±0.9	12.2±1.0	11.8±0.5	H=8.989
	11.0-12.5	10.5-13.5	11.0-13.5	11.0-12.5	p=0.029

Note: The mean, standard deviation, maximum, minimum measurement in millimeters. (p significance ≤0.05; N: numbers of specimens)

Table 2. Comparison of *Callosciurus notatus* skull characters from four populations in West Sumatra, Indonesia by Kruskall-Wallis test that showed significant results

Characters	Population				Kruskal-Wallis Test
	Padang N=7	Lubuk Basung N=17	Sangir N=7	Baso N=7	
GSL	49.4±1.7	49.4±1.2	50.1±1.4	50.9±1.2	H=7.908
	46.8-52.1	47.4-51.5	48.3-52.6	48.4-51.7	p=0.048
NL	14.9±1.0	15.1±0.7	14.3±0.6	15.0±0.5	H=14.862
	13.2-16.3	13.9-16.0	13.2-15.3	14.1-15.4	p=0.002
M1L	2.0±0.1	2.0±0.1	1.9±0.1	1.9±0.1	H=9.001
	1.9-2.1	1.8-2.1	1.8-2.1	1.8-2.0	p=0.029
BL	41.9±1.6	41.9±1.2	42.3±1.2	43.7±0.9	H=9.119
	39.1-44.2	39.9-43.7	41.0-44.4	42.1-44.7	p=0.028
CBL	44.8±1.7	44.8±1.1	45.2±1.3	46.7±1.0	H=10.709
	42.0-47.4	42.5-46.4	43.5-47.5	44.5-47.6	p=0.013
MTB	20.9±0.4	20.8±0.6	21.5±0.6	22.1±0.3	H=13.725
	20.2-21.4	19.6-21.7	20.4-22.6	21.7-22.7	p=0.003
ML	32.1±1.2	32.2±1.0	32.0±0.9	33.3±0.4	H=9.545
	29.9-34.0	30.3-33.6	30.6-33.3	32.3-33.6	p=0.023
THM	15.5±0.9	15.1±0.9	15.9±1.0	16.7±0.7	H=9.165
	14.3-16.5	13.7-16.8	15.1-18.0	15.8-17.6	p=0.027
LLD	6.5±0.4	6.8±0.3	7.0±0.5	7.5±0.2	H=16.354
	5.8-7.1	6.3-7.6	6.4-7.6	7.2-7.8	p=0.001

Note: The mean, standard deviation, maximum, minimum measurement in millimeters. (p significance ≤0.05; N: numbers of specimens)

Table 3. The Euclidean distance of *Callosciurus notatus*

Population	Padang	Lubuk Basung	Sangir	Baso
Padang	-			
Lubuk Basung	**8,754**	-		
Sangir	10,787	**11,234**	-	
Baso	10,900	10,461	11,160	-

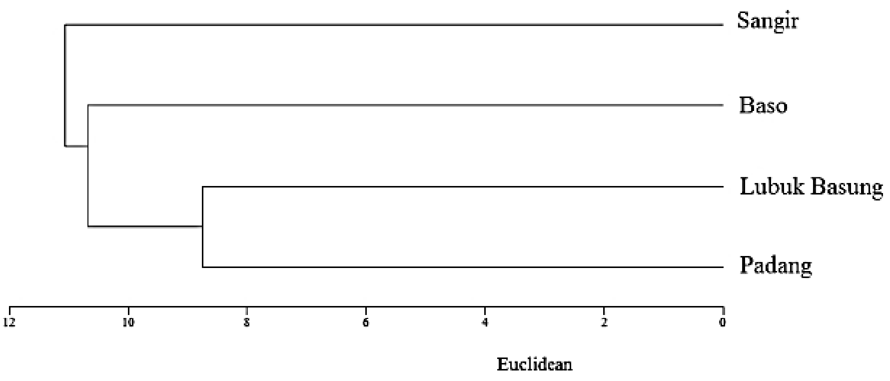
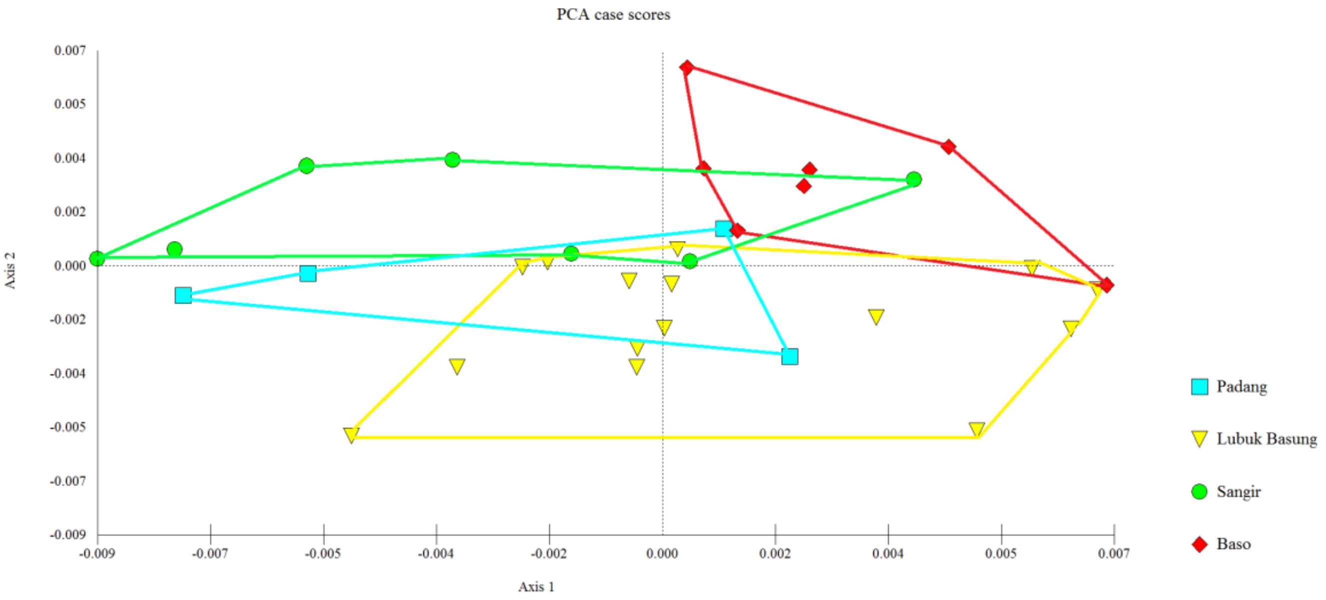
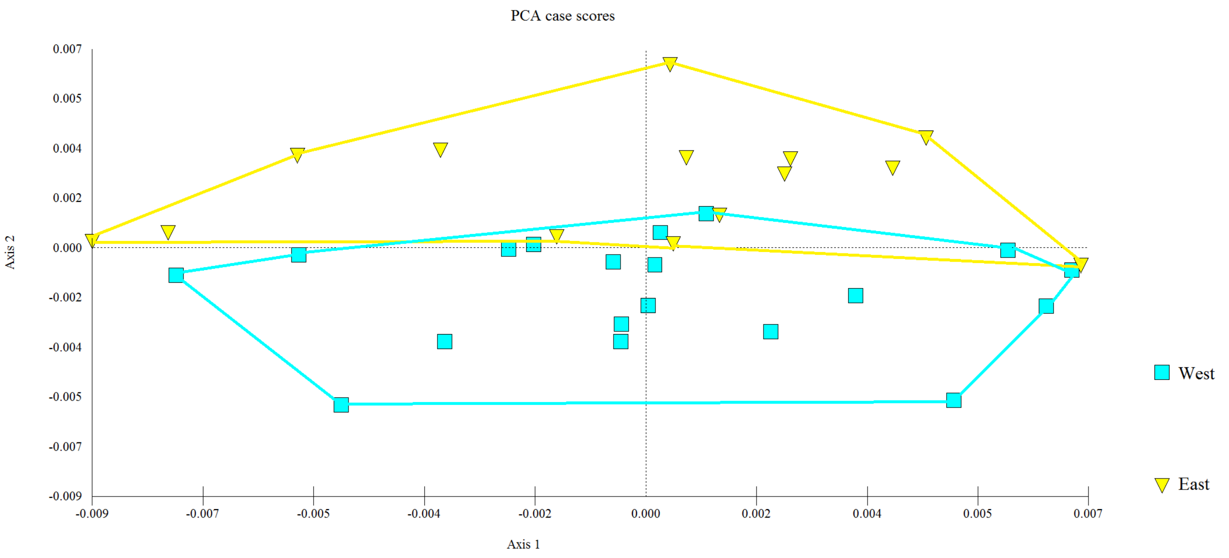


Figure 3. UPGMA phenogram based on morphological characters of *Callosciurus notatus*



A



B

Figure 4. The plot of principal component 1 (PC1) versus principal component 2 (PC2) for the Principal Component analysis of *Callosciurus notatus* group. (A) Based on population group (B) Based on the east and west part of Bukit Barisan mountains range.

Analysis of UPGMA (Unweighted Pair Group Method Arithmetic Average) showed an overview of phenetics relationships among *C. notatus* populations (Figure 3). The phenogram (Figure 3) shows that the morphological similarities between populations were relatively related to the geographical distance and geographical location of the sampling sites that were separated by Bukit Barisan mountain range. Map of sampling location (Figure 1) illustrates that Padang is closer geographically to Lubuk Basung. Both locations are also located on the western side of Bukit Barisan. However, *C. notatus* population from Baso and Sangir tend to have higher Euclidean distances although both locations are on the east side of Bukit Barisan. It is also reinforced by the phenogram which does not show the same cluster between Sangir and Baso. Even *C. notatus* from Baso has more similarities to Lubuk Basung population that is closer geographically in distance than to Sangir population. Sangir population tends to have more similarities with Padang population that is also closer in geographical distance.

In addition to the geographical distance, the populations of *C. notatus* that were found in similar environmental conditions also showed similarities in morphological characters. Sangir and Padang populations, which are both located in the areas of the fields and adjacent to the secondary forest comparatively had more similarities than Baso, and Lubuk Basung population had. While Baso and Lubuk Basung populations, which are both located on the vast plantations areas, had similarities too. Therefore, the presence of Bukit Barisan mountain range does not entirely affect the similarity or differentiation of morphological characters among populations of *C. notatus* in West Sumatra. There are other factors such as geographical distance and environmental conditions, like available food resources and habitat vegetation, which probably influence the similarity of morphological characters among populations in West Sumatra.

The natural barrier of geographical distance is related to gene flow from separated populations. Andrews (2010) stated that gene flow, genetic drift, and natural selection do not act in isolation in the fragmented habitat. The obstruction of gene flow will result in genetic homogeneity within a metapopulation, promoting the population divergence, and, if continuously, can end up to speciation. Moncried (2015) reported that morphological differentiation in fox squirrels and gray squirrels had been influenced by the lower Mississippi River valley that had been preventing gene flow of these species.

Kramm, Marki, and Glime (1975) reported that morphological characters between populations of red squirrels (*Tamiasciurus hudsonicus*) in the area of Lake Superior were also influenced by geographical position. The closer geographical distance, the more similarities of morphological characters it had. Barrett and Schluter (2008) stated that the dynamics and different results of adaptation were affected by the variation source. The variations that occur are very related to how the population can respond to environmental change.

The PCA analysis showed the distribution of individuals from each population based on morphology, which is the loading or deciding factor. The ordination of plots (Figure 4) has shown that there are two groupings of *C. notatus* samples that describe the distribution of populations in the west and east side of Bukit Barisan. Character variation in populations of *C. notatus* in the parts of east and west possibly caused by the difference in environmental conditions that are the result of the formation of the Bukit Barisan since millions of years ago.

Anwar et al. (1984) report that Sumatra that was divided into two sides by the Bukit Barisan has a different ecological condition. The factors such as geomorphology, vegetation, climate, rainfall, and soil variation between the west and east area have impacted the ecology in both separated sites. Colombijn (2005) stated that the Bukit Barisan has two unequal parts that form the narrow coast and the wider half of hills in the west part and alluvial lowland in the opposite part.

Yu (2002) reported that the morphological and genetic differentiation among some populations of flying squirrels (e.g. Eupetaurus, Eoglaucomys, Hylopetes, and Petaurista) occur in line with the geographical variations along the Trans-Himalaya mountain chain that caused the climate change during the Pleistocene, and also became occurrence of physical barriers to migration. Research by Endo et al. (2003) on the skull variations of *Dremomys rufigenis* in three geographical locations consisting of Peninsular Malaysia, Viet Nam, Laos and Thailand showed variations affected by the existence of the Isthmus of Kra as a geographical barrier.

In conclusion, variation of morphological characters of *C. notatus* in several populations in West Sumatra was found in ten external characters and nine skull characters from a total of 56 characters measured. Body and tail length characters that had a relatively longer length ratio were found in Baso population. Character lengths of ears and extremities (ulna and digiti length) which relatively had a longer ratio were found in the Sangir population. Skull morphological characters that showed significant differences were generally found in Baso populations having longer ratio values than other populations. Based on the results of this study it is hoped that further study will be carried out to determine what environmental factors specifically influence certain morphological characters.

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Thermal properties of wooden-based flask made from tropical hardwood species, *Tectona grandis* and *Albizia saman*

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Abstract. *Ogunsanwo OY, Onakpoma I, Korede M. 2020. Thermal properties of wooden-based flask made from tropical hardwood species,* Tectona grandis *and* Albizia saman. *Asian J For 4: 61-64.* Most materials used for production of conventional thermos flask (i.e., metals and plastics) are not environmentally friendly with particular concerns that are not biodegradable. Alternative materials for thermos flask might use woods, particularly wood wastes to achieve both waste management and environmentally friendly materials This study was therefore conducted to investigate the thermal properties of wooden thermos flask (WTF) using tropical hardwood species with a view to promoting the use of greener technology. Offcuts of *Tectona grandis* and *Albizia saman* were used to produce 12 WTF with two thicknesses (11 mm and 12 mm) and a height of 26.67 cm using bamboo as inner lining. The data of heat loss and heat gain by the wooden flasks and conventional flask were collected using a 2×2 factorial experimental in a completely randomized design. Data were analyzed using ANOVA at p=0.05. The highest heat loss (64.00ºC) after 12 hours was observed in *T. grandis* WTF with 11 mm and 12 mm while *A. saman* thermos flask with 12 mm thickness had the least heat loss (62.00ºC). Metallic flask lost only about 30.00 ºC of its heat content after 12 hours. The highest heat gain (28ºC) after 12 hours was observed in *T. grandis* WTF with 11mm and 12mm while *A. saman* WTF with 11 mm thickness had the least heat gain (25.67ºC). Heat gained by WTF was 28.00ºC and 25.83ºC for *T. grandis* and *A. saman*, respectively, after 12 hours while heat gain by the metallic flask after 12 hours was 18.00ºC. Species and thickness did not significantly affect heat loss and gain of thermos flask. Significant difference was, however, observed between the heat lost and gained by WTF and metallic flask. Wooden thermos flask still retained heat and prevented loss to a certain degree but with technological improvement would perform better.

Keywords: *Albizia saman*, heat gain, heat loss, *Tectona grandis,* thermos flask

INTRODUCTION

Over the years, various materials have been used as thermal insulators based on their thermal insulation properties, availability, cost, density and environmental friendliness. Hence, materials with low thermal conductivity, low cost to produce, available in large quantities and comparable with existing industrial insulators are of global interest. Commonly used materials as thermal insulators include calcium silicate, mineral fiber, fiberglass, polyurethane, polystyrene, plastic foam, etc. Natural products and industrial wastes, such as cotton wool, clay, sawdust, rice husk among others, which exhibit low thermal conductivity values are also useful as solar device materials. The utilization of industrial wastes around the world is largely driven by serious environmental degradation caused by industrial activities and the need to conserve energy and resources (Sumrerng and Prinya 2010). Therefore, various research efforts had been focused to develop locally available materials with suitable structural and energy-conserving properties.

Common materials (i.e., metals and plastics) used for production of conventional thermos flasks are not environmentally friendly (Palm 2018). Plastic pollution arises from both terrestrial and marine sources which is of particular concern in developing countries that lack proper waste management policies (Thevenon and James 2014; Hayden et al. 2012). In 2012, 165 million tons of plastic polluted the ocean (Reddy et al. 2014). Very few plastics discarded in Nigeria are recycled, much of it ends up in landfills, which may take up to one thousand years to decompose, leaching potentially toxic substances into the soil and water (UN Environment 2018). Also, Iron (Fe) and aluminum (Al) can alter the biodegradation of dissolved organic matter (DOM) by forming strong complexes with carboxylic and phenolic groups which are abundant in dissolved organic matter (Xiao et al. 2016).

Wood waste management is important towards achieving sustainable development in the forestry sub-sector (Marinela 2009). A major problem with the use of wood is the generation of non-utilized wood wastes, such as offcuts, bark, crooked logs, slabs, etc. For example, less than two-third of the harvested tree during logging operation are taken from the forest, and less than 40% of the wood brought from the forest are being converted to lumber in the industry (Ogunwusi 2014). This situation leads to the unsustainable utilization of wood which is a setback to the sustainable management of the forest and forest industries. The management of wastes resulting from wood processing activities creates a lot of environmental challenges (Ogunbode et al. 2013). The prominent waste disposal methods in Nigeria are burning, dumping, recycling and composting with the predominant wood waste management is open incineration, leading to release of greenhouse gases and also air pollution. It is therefore important that ways of recycling these waste are sustainably managed.

The use of wood waste at the industrial level has led to the innovation of wood utilization as floor tiles, wall tiles, ceiling boards and laminated wood products (flower vase, trays, lamp holders, etc.) (Ogunsanwo 2001). This could also be extended to other products as thermos flask. This study was therefore conducted to investigate the thermal properties of wooden thermos flasks using tropical hardwood species and comparing the insulating properties of metallic thermos flasks.

MATERIALS AND METHODS

Wood materials

Offcuts of *Tectona grandis* and *Albizia saman* were obtained from the Department of Forest Production and Products, University of Ibadan, Ibadan, Oyo State, Nigeria. The wood was then taken to the wood workshop at the university for further processing into thermos flask.

Design of thermos flask

Twelve thermos flasks with two thicknesses (11 mm and 12 mm) and a height of 26.67 cm were produced using bamboo as an inner lining.

Production of thermos flask

Processing of the wood

The offcuts were processed into cants using the wood mizer machine and further sawn into rectangular blocks of 14 inches each using a saw. The rectangular blocks were converted to a cylindrical shape then partitioned into base and top (cap). The inner and outer parts of each section were turned and sanded.

Preparation of bamboo

The bamboo was cut into sections, ensuring that they were cut a little below the nodes to have a closed-end cylinder. It was steamed using the autoclave at 100°C to stabilize it. The inner and outer parts were sanded to ensure that the bamboo fits into the already prepared wood. It was then coated with kerosene as a form of preservation.

Gluing and finishing

Adhesive was applied to the outside of the bamboo and inside of the carved wood. The bamboo was then placed into the carved wood. Heavy rectangular blocks were then placed on the flask to ensure proper alignment and proper drying of the wood and bamboo. The wooden thermos flask was allowed to dry for three days. An electric sanding machine was used to smoothen the flask and then it was sprayed with paint.

Data collection

The heat loss and heat gain by the wooden flasks and conventional flask were collected using a thermometer which was inserted into the cap of the flasks through a hole drilled in it, the hole was covered at intervals to prevent heat loss and heat gain from the opening, data was collected every two hours for twelve hours.

Heat loss experiment

Hot water of 1000 mL at 100°C was poured into the flask. The heat loss by the wooden flasks and metallic flask were collected using a thermometer which was inserted into the cap of the flasks through a hole drilled in it, the hole was covered with cotton wool to prevent heat loss through the opening. The temperature was measured and recorded every two hours for twelve hours

Heat gain experiment

Iced water of 1000 mL at 0°C was poured into the flask. The heat gain by the wooden flasks and metallic flask were collected using a thermometer which was inserted into the cap of the flasks through a hole drilled in it, the hole was covered with cotton wool to prevent heat gain through the opening. The temperature was measured and recorded every two hours for twelve hours for calculation of heat gain.

Experimental design and data analysis

The study design was a 2×2 factorial experimental design in a completely randomized design with thickness (11mm and 12 mm) and species (*T. grandis* and *A. saman*) as factors. Data were analyzed using ANOVA at p=0.05.

RESULTS AND DISCUSSION

Heat loss

Table 1 shows the mean heat loss of *T. grandis* and *A. saman* wooden thermos flask (Figure 1) with varying thicknesses. The highest heat loss (64.00ºC) after 12 hours was observed in *T. grandis* wooden thermos flask with 11mm and 12mm while *A. saman* thermos flask with 12mm thickness had the least heat loss (62.00ºC). There was a sharp drop in wooden flask temperatures for both wood species for the first two hours while the temperature stabled after 10 hours of filling. The heat loss is reduced with time at varying intervals. Species and thickness did not significantly affect heat gain of thermos flask as shown in the table.

In Table 2, it was observed that the heat loss was greater in both wooden flasks when compared with that of a metallic flask. Metallic flask lost only about 30.00 ºC of its heat content while *T. grandis* and *A. saman* lost 64.00ºC and 62.17ºC of its heat content after 12 hours which were doubles that lost by metallic flask. Also, significant difference was also observed between the wooden flasks and metallic flask.

Heat gain

Table 3 shows the mean heat gain of *T. grandis* and *A. saman* wooden thermos flask with varying thicknesses. The highest heat gain (28ºC) after 12 hours was observed in *T. grandis* wooden thermos flask with 11 mm and 12 mm while *A. saman* thermos flask with 11 mm thickness had the least heat gain (25.67ºC). The temperature of water in the wooden thermos flask was observed to be stable after

10 hours of filling. The heat loss is reduced with time at varying intervals. Species and thickness did not significantly affect heat gain of thermos flask as also represented in the table

The heat was gained faster in the wooden flasks than that of a metallic flask. Heat gained by wooden flask was 28.00ºC and 25.83ºC for *T. grandis* and *A. saman*, respectively after 12 hours, while heat gain by the metallic flask after 12 hours was 18.00ºC (Table 4). Significant difference was also observed between the heat gained by wooden flasks and metallic flasks.

Discussion

The highest heat gain and loss in wooden flask was obtained from the first two hours and the lowest mean value was obtained from the last two hours for both thicknesses, meaning that the wooden flask lost heat at a fast rate for the first two hours. This could be due to the absence of a lagging material such as cotton wool or silver panel commonly used in metallic flask that helps to trap heat in the flask, thus reducing heat loss and gain by the flask. The loss of energy is in line with the second law of thermodynamics which states that "in all energy exchanges if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state". Also, the temperature for the last two hours was constant which is also in line with Newton's Law of cooling which states that the rate of change in the temperature of an object is proportional to the difference between its own temperature and the ambient temperature. This, therefore, infers that the temperature was constant due to the fact that the temperature of the water, flask, and its surroundings were at an equilibrium temperature.

Figure 1. Wooden thermos flask

Table 1. Mean values of heat loss of *Tectona grandis* and *Albizia saman* with varying thicknesses

Time	Species	*Tectona grandis*		*Albizia saman*	
	Thickness	11mm	12mm	11mm	12mm
Initial		100.00	100.00	100.00	100.00
2 hours		76.33±0.44	76.00±0.44	85.00±0.44	85±0.44
4 hours		62.00±0.69	61.33±0.69	69.33±0.69	69.00±0.69
6 hours		51.33±0.60	52.00±0.60	60.00±0.60	59.00±0.60
8 hours		40.67±0.60	41.00±0.60	50.00±0.60	50.00±0.60
10 hours		36.00±0.17	36.00±0.17	40.33±0.17	40.33±0.17
12 hours		36.00±0.17	36.00±0.17	37.67±0.17	38.00±0.17
Heat loss		64.00	64.00	62.33	62.00

Table 2. Heat loss of *Tectona grandis* and *Albizia saman* and metallic flask

	Initial (°C)	2 hrs (°C)	4 hrs (°C)	6 hrs (°C)	8 hrs (°C)	10 hrs (°C)	12 hrs (°C)	Heat loss
T. grandis	100	76.17	62	51.69	40.83	36	36	64.00[a]
A. saman	100	85	69.17	59.5	50	40.17	37.83	62.17[a]
Metallic flask	100	98	95	86	80	76	70	30.00[b]

Table 3. Mean values for heat gain of *Albizia saman* and *Tectona grandis* at varying thicknesses

Time	Species	*Tectona grandis*		*Albizia saman*	
	Thickness	11 mm	12 mm	11 mm	12 mm
Initial		0.00	0.00	0.00	0.00
2 hours		12.00±0.00	12.67±1.15	7.68±0.58	7.33±1.15
4 hours		20.00±0.00	20.00±0.00	15.67±0.58	15.67±0.58
6 hours		24.00±0.00	24.00±0.00	19.67±0.58	20.00±0.00
8 hours		26.33±0.58	26.00±0.00	24.67±1.15	24.67±1.15
10 hours		28.00±0.00	28.00±0.00	26.33±0.58	24.67±1.15
12 hours		28.00±0.00	28.00±0.00	25.67±0.58	26.00±0.00

Table 4. Heat gain of *Tectona grandis, Albizia saman* and metallic flask

	Initial (°C)	2 hrs (°C)	4 hrs (°C)	6 hrs (°C)	8 hrs (°C)	10 hrs (°C)	12 hrs (°C)	Heat gain
T. grandis	0	12.33	20	24	26.17	28	28	28.00[a]
A. saman	0	7.5	15.67	19.83	24.67	26.17	25.83	25.83[a]
Metallic flask	0	3	6	9	12	14	18	18.00[b]

Studies have shown that the thermal conductivity of wood is low within the range of 0.1-0.8 $Wm^{-1}K^{-1}$ (Samuel et al. 2012) with teak having a thermal conductivity of 0.139 $Wm^{-1}K^{-1}$ (Mohapatra et al. 2014). When compared to materials used to make the metallic flask, this means that the high heat loss and gain could not have been as a result of wood having higher thermal conductivity than this material but due to increased conduction, convection and radiation in the wooden thermos flask. Oluyamo and Bello, (2014) reported sawdust also exhibits low thermal conductivity (0.045199-0.147759 $Wm^{-1}K^{-1}$) that is comparable with materials used as insulator in industrial solar flat plate collectors in lagging of refrigerator, incubator, cooler, food flask, etc. as well as exhibiting high thermal resistivity value which could serve as potential sources of heat resistant in device applications.

In conclusion, this study has shown that wood residues such as offcuts can be used to produce thermos flask. The result of this research shows variation in the heat loss and gain of *A. saman* and *T. grandis* of varying thicknesses and species with time. Also, this study shows that heat gain and loss in wooden thermos flask were faster than conventional flask after 12 hours which may be as a result of the absence of lagging materials in between the wood which would have helped to prevent heat gain and loss by conduction, convection, and radiation. However, wooden thermos flask still retained heat and prevented loss to a certain degree. Further research should be carried out on how to improve the wooden thermos flask with respect to heat loss and gain so as to be used as substitute for the plastic and metallic flask.

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Bringing back the Chakaria Sundarbans mangrove forest of South-east Bangladesh through sustainable management approach

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Abstract. *Dutta S, Hossain MK. 2020. Bringing back the Chakaria Sundarbans mangrove forest of Southeast Bangladesh through sustainable management approach. Asian J For 4: 65-76.* The oldest mangrove forest of Indian sub-continent namely Chakaria Sundarbans (CS) is currently in a critical situation. Destructive anthropogenic and natural impacts coupled with shrimp farming and excessive grazing have caused severe damage to this oldest mangrove ecosystem. A study was carried out based on the extensive literature survey and tried to explore the overall situation and conservation practices for CS of Bangladesh. This paper analyzed, reviewed, and identified the impacts of natural and man-made effects on CS mangroves. Finally, we recommended the sustainable management approach (SMA) including policy and participation of the local people for bringing back this potential natural mangrove forest resource of CS along with rich forest diversity.

Keywords: Bangladesh, Chakaria Sundarbans, mangrove, shrimp farming, sustainable forest management

INTRODUCTION

Mangroves are an association of halophytic plants growing in brackish to saline tidal waters, and this vegetation type is quite different from upland forests in terms of composition, structure, function, and diversity (Kauffman and Donato 2012; Mitsch and Gosselink 2007). Mangrove forests are affected by climatic factors, such as temperature and moisture, and distributed latitudinally within the tropics and subtropics reaching their maximum development between 25°N to 25°S (Uddin et al. 2014). Spalding et al. (1997) estimated mangrove ecosystems covered 18 million hectares worldwide, while FAO (2003; 2007) estimated 15.2 million hectares of mangroves to exist worldwide distributed in 100 countries. Uddin et al. (2014) reported that the most extensive mangrove area is found in Asia, followed by Africa, and North and Central America. Five countries (Indonesia, Australia, Brazil, Nigeria, and Mexico) together are account for 48% of the total global mangroves (FAO 2007). In Asia and Southeast Asia, the greatest concentration (41.5%) of the world’s mangroves exists (Primavera 2000).

Mangrove ecosystems are the most threatened and rapidly disappearing natural environments worldwide (Valiela et al. 2001). In many areas of the world, mangrove forests are degraded and their area is substantially reduced relative to their historic range (FAO 2007; Spalding et al. 2014). Due to aquaculture expansion and over-exploitation for its timber, approximately 30-50% of global mangrove forests have been lost over 50 years (Donato 2011). Mangrove ecosystems cover only 0.7% of tropical forest area, and such forests account for 10% of carbon emission from deforestation (Donato 2011). Research conducted by Njisuh and Ajonina (2011) predicted that around 25% of developing countries’ mangrove forests will be lost by 2025. The mangroves of Asia are experiencing faster, long-term, and large-scale clearances due to agricultural and aquacultural activities, and also confront severe policy challenges to their protection, production and maintenance (Richards and Friess 2016). Bangladesh, a developing country in South Asia, contributes about 4% of the world mangrove forest and is placed at the sixth position in terms of area coverage (Hossain 2015a).

Bangladesh, located in the northeastern part of South Asia with geographical coverage of 14.76 million ha, is exceptionally endowed with a wide variety of flora and fauna due to its unique geophysical location (Dutta et al. 2014), and possesses a rich biological heritage of flowering plants, algae, fungi, ferns, mammals, birds, reptiles, amphibians, insects, microbes, and fishes (Dutta et al. 2015; Hossain 2015b). It has the largest delta on the earth situated at the 24˚N to 90˚E, passing about 700 rivers and 8,046 km of inland waterways. The total forest area of Bangladesh is 2.57 million ha, which is 17.72% of the total land area of Bangladesh (Hossain 2015b). Mangrove forest is considered one of the main forest types in Bangladesh which provides a large number of products and ecosystem services, and supports a very diverse flora and fauna (Das and Siddiqi 1985). Both natural and planted mangrove forests of Bangladesh are well developed in the Sundarbans on the Ganges-Brahmaputra delta, but very poorly developed in the Chakaria Sundarbans (CS) on the Matamuhury delta (Siddiqi 2001).

The mangrove forests of Bangladesh are divided into three forest zones according to their location. First one is the Sundarbans, the largest single tract of mangrove forest ecosystem in the world. It is situated in the south-western part of Bangladesh having an area of 600,386 ha, of which 4111,230 ha is forest area and 189,156 ha of water bodies like rivers, channels, and creeks (Iftekhar and Saenger 2008; SRDI 1999). The second one is the Chakaria Sundarbans (CS); the most excruciating case appears to be the total destruction, once the pristine forest, and the second-largest mangrove forest of Bangladesh. The CS in Cox's Bazar was originally 8510 ha (Hossain et al. 2004). And the third one is the coastal mangrove plantations, which started during the mid-sixties (NFTRA 2007). The CS is located in the eastern part of Bangladesh whereas the Sundarban mangrove is in the extreme south-western part of Bangladesh (Choudhury et al. 1990; Siddiqi 2001).

As the oldest mangrove forests of the Indian sub-continent, the Chakaria Sundarbans mangroves are widely distributed in the south-eastern part of Bangladesh including Chattogram District and Cox's Bazar coastal zone (Siddiqi 2001). Due to shrimp farming, over-extraction of wood and non-wood resources, population pressure, deforestation, settlement, urbanization and unscientific management practices, mangrove forests in CS are continuously depleted (Alam et al. 2014; Siddiqi 2001). In this regard, sustainable forest management is an effective approach to achieve the management goals without undue undesirable impacts on the environment. This study analyzed and reviewed the changes in area, floral composition, and forest reserves in CS over time. It compiled and clearly stated the influence of shrimp firming and anthropogenic disturbances on the oldest mangrove in Bangladesh. This paper also evaluated the impacts of several actions on the degradation of CS and recommended probable mitigation measures through sustainable management approach (SMA).

MATERIALS AND METHODS

Distribution of Chakaria Sundarbans (CS) in south-east Bangladesh

The CS lies in the district of Cox’s Bazar and occupies the central part of the Matamuhury delta (Siddiqi 2001). The Cox's Bazar coastal zone and CS have been important since prehistoric times for the abundance of natural resources. In the past, the area of the CS was about 18,200 ha (Cowan 1926). On 19th December 1903, the government formed the CS range (8510 ha) and announced it as a reserve mangrove forest (7490 ha) and a protected forest (1020 ha) (Cowan 1926; Hossain et al. 2001). In the early 20th century, one of the major areas of this forest was cleared for settlement, salt pan, and agricultural use under the British colonial role (Figure 1). Over the last century, local people and outsiders or settlers have been haphazardly utilizing the natural resources, resulting in complete destruction of CS (Hossain et al. 2001). Now this area is no longer belonging to mangrove swamp (Alam et al. 2014; Siddiqi 2001). The general description of the CS was presented in Table 1.

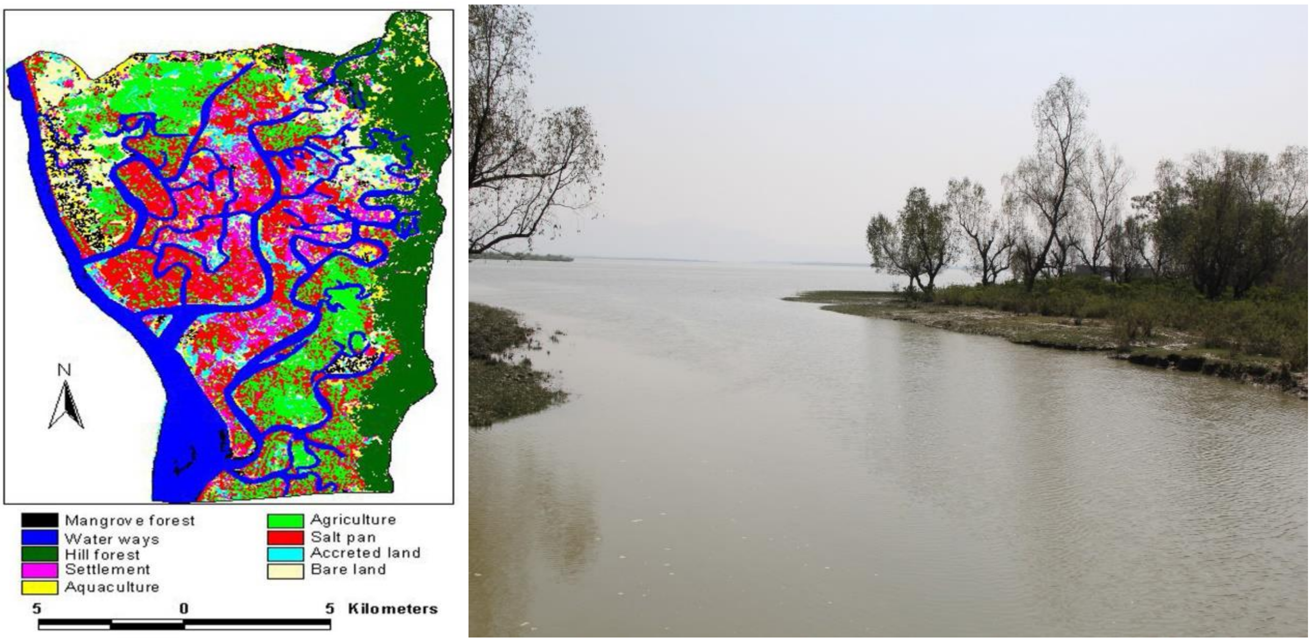

Figure 1. Landsat image (2012) showing the land use patterns (*left*) and a forest patch (*right*) of Chakaria Sundarbans in south-east Bangladesh

Table 1. Geographical and environmental information of the mangroves of Chakaria Sundarbans

Parameters	Data	Source
Latitudes	21º36′to 21º45′ North	Alam et al. 2014, Hossain et al. 2001, Siddiqi et al. 1994
Longitudes	91º58′to 92º05′ East	
Mean annual temperature (Maximum)	32°C	
Mean annual temperature (Minimum)	20°C	
Average annual rainfall	3,500 mm	
Water salinity	23ppt to 34ppt	
pH range	< 4.5	Anon 1973, Richards and Hassan 1988
Soil type	Acid sulfate soils	

Collection and compilation of data

The present review was carried out based on secondary information. The methodology of this review consisted of collection of data/information from different sources, consulting associated consultants and researchers, and data analysis. The authors consulted different books, journals, and research reports related to CS mangrove forests according to the objectives of the present study. Then, the authors examined collections of secondary data, and analyzed the literature extensively.

For more justification, information on CS mangroves was compiled through personal communication, and informal interview from renowned researchers/experts in the field of forestry, ecology, mangrove ecosystems, and environmental science. Further, we analyzed several reports from Governmental and non-governmental organizations to evaluate the socio-economic and environmental conditions of local communities in the CS mangrove areas. The impacts of several underlying actions on the disappearance of CS mangroves were also assessed, and designed a sustainable management approach (SMA) to rehabilitate the CS mangrove ecosystems.

SWOT analysis

A SWOT analysis was carried out to assess the opportunities and available strengths to bring back the forest resources of CS mangroves. SWOT analysis is logical thinking applied to optimize strengths and opportunities, minimize external threats, transform weaknesses to strengths, and summarize key management issues (Hong and Chan 2010; Saaty 1987). SWOT is a recognized and effective analysis technique to be used in compiling, synthesis, and analysis of information for Forestry development (FAO 1989). We conducted SWOT analysis through an extensive literature survey developed by Hong and Chan (2010). We identified several external and internal factors systematically to formulate an efficient strategy for bringing back the CS mangroves as proposed by Murtini et al. (2018). Top strengths, weaknesses, opportunities, and threats of CS mangrove restoration were identified systematically through SWOT analysis and enlisted in an organized list. Finally, we expressed the major findings in a simple two-by-two grid.

RESULTS AND DISCUSSIONS

Disturbances to biological diversity

Due to the lack of appropriate guidelines for natural resource utilization and conservation, land use conflicts occur and sometimes the coastal zone is turned into an area of major conflicts, and ultimately resulting in land degradation in CS. Chaffey et al. (1985); Das and Siddiqi (1985); Hossain et al. (2001); IUCN (2000) reported that the excessive use of natural resources accelerated the deforestation and destroyed the plant and animal diversity of that swamp.

A trace of deterioration of the forest vegetation in CS was first noticed in the nineteen sixties (Chowdhury 1967). Destructive deforestation by clear-cutting of mangrove vegetation of CS was first noticed to be widespread on the aerial photographs of 1981 taken by SPARRSO (Choudhury et al. 1990). There are several factors responsible for the degradation of mangrove forests, viz. overexploitation, excessive collection of non-wood products, overgrazing, encroachments, urbanization, diversion of freshwater flows, over fishing and land conversion for aquaculture, agriculture, mining, salt extraction, and shrimp firming (Alongi 2002; Siddiqi 2001; Valiela et al. 2001). After stereoscopic examination of the aerial photographs, it was found that about 2,104 ha of forest cover had been completely opened for shrimp farming (Choudhury and Ahmed 1994). Deforestation of CS greatly affected the socio-economics of more than 90% of the local community (Hossain et al. 2001). On the other hand, the rapid expansion of shrimp farming has drastically reduced the stock of indigenous fish varieties and destroyed mangrove flora and fauna (Jahan and Ancev 2014). CS mangrove forest was the home of tigers, deer, wild cats, wild boars, foxes, etc. These all animals are now rarely seen in the CS due to the disappearance of the mangrove forests (Rahman 2015).

Cowan (1926) recorded 53 plant species belonging to 42 genera and 22 families from the CS mangroves. Almost seven decades later, Siddiqi et al. (1994) reported a very poor species diversity (18 plant species belonging to 18 genera and 14 families) and abundance of species in CS. Recent reviews on the status of plant diversity of CS showed a very poor condition of the forest flora (Alam et al. 2014; Iftekhar and Islam 2004). Iftekhar and Islam (2004) reported that the most important plant species of CS were Sundri (*Heritiera fomes*), Gewa (*Excoecaria* *agallocha*), Kankra (*Bruguiera gymnorrhiza*), Hargoza (*Acanthus ilicifolius*), and Ananta kata (*Dalbergia spinosa*). According to the report of Alam et al. (2014), the notable feature of CS mangrove area was the total absence of Goalpata (*Nypa fruticans*). The present review revealed that the floral diversity of CS was reduced over time (Figure 2).

Imbalance in coastal ecology

The shrimp activities in the coastal zone of Bangladesh upgrade the lifestyle and obviously increase the income level of many poor coastal people with increasing environmental degradation (Barua and Chakraborty 2011). Shrimp farming is expected to continue to play an important role in ensuring food security and poverty alleviation for the coastal poor communities (Barua and Chakraborty 2011; Siddiqi 2001). Thia-Eng et al. (1989) reported that coastal aquaculture, particularly shrimp aquaculture, is an important coastal industry in Bangladesh. But, this industry highly destroys coastal communities and ecosystems by mangrove destruction, loss of fishery communities and biodiversity, pollution of land and water, loss of employment activity, and even violation of human rights (Barua and Chakraborty 2011; Salequzzaman 2001; Yeh 2002).

In coastal Bangladesh, shrimp farming is the most destructive form of resource utilization, which contributed tremendously to mangrove ecology destruction with a corresponding loss of biological resources (Islam and Wahab 2005; Islam et al. 2019). During the last two decades, coastal ecosystem of Bangladesh has experienced notable degradation due to shrimp farming (Sohel and Ullah 2012). Research findings of Barua and Rahman (2020) indicated that unplanned growth of shrimp culture in coastal areas of CS has a serious effect on alteration of coastal ecology. Unplanned shrimp farming has multifarious impacts in terms of salinity increase on soil, adverse effects on population health, destroying biodiversity and ecosystems, environmental changes, and imbalance in sustainability (Barua and Rahman 2020; Rashid 2019). Vast area of tidal land previously used for cultivation in CS has been changed into shrimp farms. Due to shrimp farming, marine pollution has reached a level that could create an unmanageable situation in near future (Islam 2003). Inundation of arable lands by saline water to cultivate shrimp has become a common occurrence in CS. A large number of people both male and female including children are getting increasingly engaged in fry collection. Islam (2003) clearly stated that most of the commercially important fish stocks are either overexploited or under threat in CS. Our review clearly demonstrated that shrimp farming and aquaculture have caused serious ecological imbalances in coastal ecology of CS.

Similarly, unplanned expansion of salt production led to destruction of forest ecosystem and already reduced the 70% forest area. During the last few decades, CS has extensively been used for salt production and almost 38,328 people are professionally dependent on this sector (Hossain et al. 2017). Hence, CS mangroves have been declining sharply and their long-term survival is at great risk (Duke et al. 2007).

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Impact of shrimp farming

Shrimp farming is a growing sector in Bangladesh because of its suitable agro-climatic conditions, adequate water resources, cheap labor force, interest of international donor agencies, and the involvement of multinational corporations (Paul and Vogl 2011). Shrimp farming is profitable and highly traded export-oriented industry for the last few decades because of its export earning potentials (Islam 2003; Siddiqi 2001). It not only provides immediate economic benefits, contributing to poverty reduction and food security, but also generates employment from shrimp fry collectors to exporters (Paul and Vogl 2011). Therefore, this farming is often encouraged by government agencies. Since the 1950s, two of the most important transformations in land use along the coastal region of southeast Bangladesh have been the growth of solar evaporative salt production and the introduction of export shrimp culture (Pokrant and Peter 2005). From the late 1970s, the government of Bangladesh encouraged the conversion of reserved mangrove forests of the CS to shrimp ponds (Siddiqi 2001). In the late 1970s, commercial shrimp farming began in coastal Bangladesh, which then represents the second-largest export sector after garments in the nation (Ishtiaque and Chhetri 2016). Bangladesh's shrimp industry has been rapidly expanding since the early 1980s and is now a major source of export earnings (Ahmed 2004; Barua and Chakraborty 2011). Government of Bangladesh, several businesses, and international aid agencies supported the monoculture of shrimp production integrated into global trading networks at the expense of local resource extraction activities including forestry (Pokrant 2014). Such rapid expansion of shrimp activities threatens the natural mangrove ecosystems, particularly across the vulnerable coastal regions of CS (Ishtiaque and Chhetri 2016). As a result, the area of CS that became the most vulnerable to climate change has lost its natural protector (Khan 2009).

The entire 8,500 ha of the mangroves of CS have been replaced by shrimp ponds (Table 2) (Siddiqi 2001). High rate of economic return in shrimp farming is constantly inducing the farmers to convert more and more forest land into shrimp farms. This has resulted in over-exploitation of shrimp juveniles from the wild, leading to ecological imbalance and change in forest pattern, increasing conflict, leasing of land of small farmers, depriving them of their rights to own land, and other socio-economic and environmental consequences (Rahman and Hossain 2015). In Bangladesh, shrimp farming has devastating effects on the most carbon-rich mangrove forests (Ahmed et al. 2017). Mangrove forest areas of CS were reduced over time with the development of shrimp farming (Figure 3).

Table 2. Changes in land use in Chakaria Sundarbans (in ha) over time

Land use	Area (in ha) with year			
	1974	**1984**	**1994**	**2012**
Mangrove forest	6127	3048	123	170
Agriculture	7847	6556	2832	1582
Salt pan	432	1484	4363	5078
Shrimp culture	0	3456	4601	5583
Water bodies	3096	2484	2463	3308
Accreted land	1180	1254	1949	2113
Bare land	136	421	1350	1680
Reserve (hill) forest	2650	2677	2625	2646
Settlement	422	510	602	712
Total area	21890	21890	21890	21890

(Source: Rahman and Hossain 2015; Siddiqi 2001)

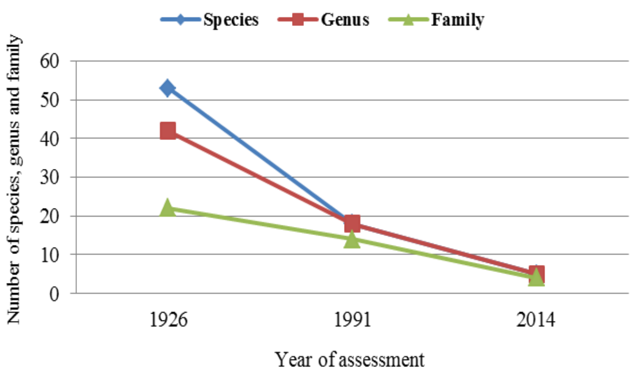

Figure 2. Disappearance of floral diversity in Chakaria Sundarbans over time

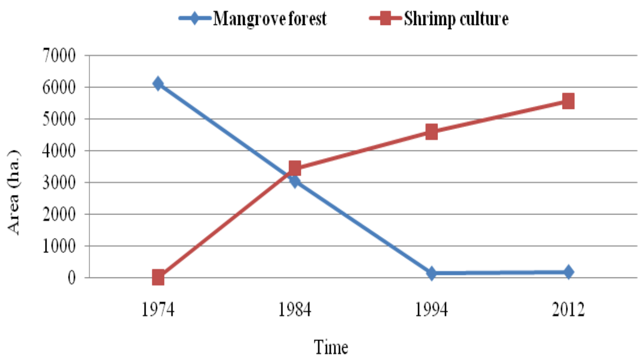

Figure 3. Degradation of natural resources against expansion of shrimp culture in Chakaria Sundarbans mangroves with time

Impacts of aquaculture on mangrove environment

Coastal aquaculture is a century-old practice in Bangladesh (Barua and Chakraborty 2011). Destruction of mangroves is of great consequence because shrimp farms are constructed by clearing mangroves. This also results in shrinking of grazing land and destruction of inland forests. Horizontal expansion of traditional extensive shrimp farming reduces grazing land and affects the fruit-bearing trees like mango, rose apple, betel nut, and coconut due to prolong retention of saline water. Production of crops and green vegetables has alarmingly fallen down due to increased salinity. Hossain et al. (2001) reported 5 major causes for mangrove forest destruction, and showed 9 direct and 4 indirect effects from these destruction related issues. Some ecological consequences of mangrove destruction are higher level of soil salinity, loss of agricultural lands, decline in biological diversity, increased risk of flooding and natural disasters, etc. (Pokrant 2014).

Although coastal shrimp farming is an important industry in Bangladesh (Sen 2010), but it is not sustainable due to its impacts on the local socio-economic, environmental, ecological and cultural environment of coastal Bangladesh on a long-term basis (Barua and Chakraborty 2011). Aquaculture and shrimp farming have been connected with environmental degradation, enhanced social and economic differences, and also involved in violation of human rights (Barua and Rahman 2020).

Shrimp growers indiscriminately cut the embankments at several points and also open the sluice gates frequently for intrusion of saline water inside the embankment, causing harm to the standing crops. However, minimum salinity is not detrimental to land fertility, but it becomes hazardous when it exceeds the minimum level (Rahman and Hossain 2015). The salinity level in the coastal lands has presently increased manifolds than the minimum level. The farmers should cultivate shrimps in scientific manner to obtain higher production and at the same time protect environment. Unavailability of hatchery-produced shrimp on the one hand and expansion of shrimp culture in the coastal area increased pressure on the collection of wild shrimp fry (Siddiqi 2001; Rashid 2019). Local women gain financial benefit from shrimp fry collection, which has reduced fish diversity and increased salinity in the CS mangroves (Chaudhury 2008).

In the present study, we reviewed the potential environmental impacts of several actions on the degradation of CS and recommend probable mitigation measures (Table 3). Mangrove restoration by the REDD+ program also has the potential to conserve mangroves for resilience to climate change. However, institutional support is needed to implement the proposed adaptation strategies (Ahmed et al. 2017).

Findings from SWOT analysis

Human population growth, coastal embankment, upstream withdrawal of river and canal water, brackish water shrimp farming, salt production, use of agro-chemicals, industrial activities, commercial activities, over-exploitation of mangrove flora, etc. are responsible for the degradation of both resources and production environments of mangrove ecosystems, specifically for CS (Miah et al. 2010). After reviewing several literature (e.g., Alam et al. 2014; Barua and Rahman 2020; Siddiqi 2001), we found that the major strength in mangrove CS is the silvicultural activities using local mangrove species and effective reforestation programs (Table 4). The soil in most of the mangrove areas is suitable for supporting and growing mangrove species till now. Collaboration and cooperation of local communities and shrimp firm owners are useful to make a successful rehabilitation program (Iftekhar 2008).

The weaknesses identified are that the lease of forest lands for shrimp culture and unscientific management of remnant mangrove forests. Ecologically and economically valuable mangrove and wetland habitats and the debasement of adjacent coastal and marine ecosystems can be devastated due to excessive shrimp culture. Shrimp farming also negatively affects biodiversity conservation as well as coastal ecosystem healthiness (Barua and Rahman 2020).

Policy and law enforcement are not strong enough to protect the existing mangroves. Sedimentation by newly accreted sand and silt cover the pneumatophore especially in the new plantations that restrict the growth performance (Alam et al. 2014). Local communities and settlers are haphazardly utilizing natural resources for their livelihoods. According to the report of Hoque and Datta (2005), adequacy of knowledge and lack of responsiveness of the Forest Department (FD) to the social issues are remarkable problems for the CS mangrove utilization. Lack of consciousness of the local people is also responsible for the destruction of mangrove plantations (Table 4). Proper attention is needed in every aspect of mangrove resource exploitation, handling and processing, export and marketing of shrimp and aquatic resources as well as in biological and institutional management strategies (Islam 2003).

The opportunity is that the soil and water salinity are within the optimal range for healthy growth of commercially important mangrove species (Table 4). Involvement of local communities in mixed silvi-aquaculture practices also provides hope for mangrove restoration and conservation (Rahman and Mahmud 2018). Shrimp farming, excessive collection of non-wood products, over-grazing, human settlement, salt production, etc. are the major threats to the conservation of mangrove species in CS mangroves (Ahmed et al. 2017; Barua and Rahman 2020; Rashid 2019).

Importance of CS mangrove restoration

Influence of the degraded CS mangroves on the environment is alarming due to the disappearance of natural forests. Nowadays, soil of the mangroves turned into salty, human health at risk, seawater in absence of forests often flooded the adjacent area, has abolished the natural mangrove ecosystems (Rahman 2015). Though the restoration process of CS mangroves is quite challenging, but it is very important to restore the CS mangrove ecosystems soon.

According to Hamid and Frank (1999), mangroves are the most productive natural habitats. Giri et al. (2011) and Rahman (2011) reported the following significant aspects of mangrove ecosystems: (i) provide important and unique ecosystem goods and services to human society, and coastal and marine systems; (ii) protect shorelines; (iii) reduce the devastating impact of natural disasters; (iv) provide breeding and nursing sites for marine and pelagic species; (v) catch metals and nutrients; (vi) trap sediments; (vii) supply food, medicine, fuel and building materials for local communities.

In Bangladesh, about two-thirds of people depend on wetlands and coastal mangroves (e.g. CS) for different purposes (Chaudhury 2008; Haroon and Kibria 2017). CS mangrove ecosystems are the source of a variety of natural products such as food production, water, fishing, livestock grazing, bird hunting, fire and fuelwoods, construction materials, medicinal plants, wild food, honey, grasses, seafood, and tourism activities (Daudouch-Guebas et al. 2000; FAO 2007; Haroon and Kibria 2017; Rasolofo 1997; Ronnback et al. 2007).

CS mangroves provide protective habitat for shrimp, prawn, spawning, nursery, and feeding ground for juvenile fish and crustacean species that spend part of their lives in these habitats. Mangroves and surrounding areas contribute many different functional ways to fisheries (Rahman 2011; Robertson et al. 1992). Not only biodiversity and livelihood support, but also the CS coastal mangrove ecosystem provides tremendous significance as a source and sink for greenhouse gases, and climate change mitigation in Bangladesh.

Mangrove forests play a potential role in carbon cycle by storing carbon and act as distributors of dissolved organic carbon to the oceans (Dittmar et al. 2006; Rahman 2011). CS mangrove generates various ecosystem services, i.e. protecting coastal areas from cyclone, floods, and storms, saving coastal lands from tidal surge and wind erosion, reduction of coastal and riverbank erosion, maintenance of water quality through salinity and sediment regulation, harboring a wide range of flora and fauna, etc. (Saenger et al. 1983; Vantomme 1995; Ewel et al. 1998; Moberg and Ronnback 2003; Forbes and Braodhead 2007; Shah and Datta 2010). Further, CS mangroves help to protect the aquatic resources and are also considered an attractive landscape for ecotourists (Hamid and Frank 1999; Roy and Hossain 2015). So, it is urgently needed to restore this oldest mangrove forest. A list of ecosystem services derived from the CS mangrove forests is shown in Table 5.

Table 3. Adverse impacts of actions in the Chakaria Sundarbans and their mitigation measures

Actions affecting Environment	Potential environmental impacts	Recommended mitigation measures
Shrimp culture	Changed topography Submergence of adjacent homestead and garden areas Contamination of ponds	To use least amount of topsoil for dike construction To make dikes wide enough to practice agriculture To take protective measures to prevent entry of saline water
Fry collection	Reduction of fish biodiversity	To regulate wild fry collection from natural sources To motivate only catching of mother shrimp and target fries To establish hatcheries for Baghda shrimp culture in the CS mangrove areas To ensure quality management of hatchery process Personal training, public education and social services
Loss of forest land for shrimp culture	Reduction forest production Reduced employment in agriculture and forestry Changed livelihood some of a farmers' group Permanent or temporary migration of some people	To implement "donation" for shrimp culture To use improved traditional method of shrimp culture To rehabilitate the affected people To cultivate salt-tolerant agricultural crops Schemes for green belt around the affected areas of the CS mangroves

Table 4. SWOT analysis of Chakaria Sundarbans mangrove conservation

Strengths	Weaknesses
1. Adequate silvicultural considerations	1. Unscientific management
2. Effective reforestation programs	2. Lack of people's consciousness
3. Collaboration among several stakeholders	3. Lack of policy and law enforcement
Opportunities	**Threats**
1. Good soil and water quality	1. Shrimp firming
2. Silvi-aquaculture practices	2. Overgrazing and encroachment
3. Involvement of local people	3. Excessive fishing

Table 5. Ecosystem services from the Chakaria Sundarbans mangrove forests

Category	Ecosystem services from the CS mangroves
Provisioning services	Food products; Salt; Energy; Water; Natural medicines
Supporting services	Habitat formation; Soil formation; Breeding ground; Coastal protection; Primary and secondary production; Nutrient cycling; Thermal buffering; Biological diversity (flora and fauna)
Regulating services	Air quality regulation; Climate regulation; Water regulation; Erosion control; Water purification; Waste treatment; Water chemistry; Disease regulation; Pest regulation; Pollination; Natural hazards regulation; Char formation; Coastal processes
Cultural services	Recreation and ecotourism; Aesthetic values; Spiritual and religious values; Educational; Literary

Effectiveness of CS mangroves to mitigate climate change

Climate change has severe impacts on the biodiversity, ecosystem, and functions of CS mangroves. According to Rahman et al. (2011), the coastal mangrove of Bangladesh has lost a significant amount of resources since the 1970s, greatly attributed to the effects of sea-level rise (SLR). Agriculture, aquaculture, and coastal livelihoods are vulnerable due to the impacts of SLR (Islam and Rahman 2015). Huxham et al. (2010) suggested multispecies mangrove forests for increasing the resilience to SLR. CS mangroves play a vital role to increase the surface elevations through biogenic processes (Lang'at et al. 2014) and are also essential for the long-term resilience to SLR (Islam and Rahman 2015; Ward et al. 2016).

Coastal erosion, cyclones, storm surges, and several disasters severely affect the coastal infrastructure, specifically housing, industrial facilities, energy and sanitation systems, transportation, and communication networks (Hossain et al. 2010). CS mangroves are likely to be increasingly disturbed by such high-magnitude, low-frequency events, and obviously protect the coastal areas from tidal storms (Ward et al. 2016). Fritz and Blount

(2007) reported that CS mangroves can reduce tidal wind and storm wave effects along with velocities. Meanwhile, dense vegetation of CS mangroves has significant aspects to reduce the height of tides (Islam and Rahman 2015; Siddiqi 2002). Islam and Rahman (2015); Patil et al. (2012) reported that mangroves can play an important action in the sequestering of carbon and reducing greenhouse gases. An estimated 25.5 million tons (approximately) of carbon are sequestering by mangroves every year (Patil et al. 2012).

Climate-change related physical processes have substantial influences on CS mangrove communities. Coastal mangroves of CS serve as a natural barrier against storms, typhoons, tsunami, hurricanes, and other natural calamities, and also protect coastal inhabitants (Islam and Rahman 2015; Islam et al. 2015). Hence, we can consider CS mangrove as a unique and highly efficient natural resource to combat and mitigate climate change.

Restoration and bringing back the CS mangroves

Sustainable aquaculture development can bring real and lasting benefits to dependent coastal communities. But the environmental consequences of inappropriate or excessive development would adversely impact the plant communities and the farmers themselves. Hence, there is an increasing need for good planning and management of CS mangroves along with shrimp farming (Barua and Chakraborty 2011). Forest Department of Bangladesh (BFD), without having proper social management tools, is unable to protect the lands of CS with legal instruments (Khan 2009). Haroon and Kibria (2017) suggested that livelihood diversification, awareness, and education of local communities and surrounding people on protection, preservation, and conservation of wetlands and coastal zones would be needed to reduce excessive pressure on coastal resources.

Biswas et al. (2009) recorded three challenges for mangrove restoration in Southeast Asia, i.e. the effect of intensive human intervention, poor socio-economic conditions of the local communities and poor knowledge on mangrove ecology. Islam and Wahab (2005) reported that the mangrove ecosystem of CS has been under intensive pressure of exploitation for the last few decades in addition to direct clearance and conversion have placed the mangroves under extreme threats.

According to the report of Iftekhar (2008), few common elements in mangrove management are choice of silvicultural system, protection of existing natural forests, people's participation, biodiversity conservation, zoning, promotion of non-exploiting uses, plantation for land reclamation and water infrastructure protection, etc. To rehabilitate the CS, we urgently need a sustainable management approach. Sustainable management requires trade-offs between society, economy, and the environment (Swart and Bakkes 1995). Meanwhile, beneficiaries and stakeholders at all levels of resource exploitation must take part and contribute to conservation and management of mangroves (Islam and Wahab 2005).

Sohel and Ullah (2012) recommended an ecohydrology-based shrimp farming (ESF) approach which has the potential to reverse the degradation of coastal ecosystems. Jahan and Ancev (2014) reported the necessity of a well-defined shrimp policy that would focus on new environmentally friendly technologies and ensure sustainability to conserve coastal ecology. Hossain et al. (2017) suggested an integrated bio-economic and environmental modeling for sustainable management of CS mangrove forests.

Mangroves integrated with shrimp farming (integrated silvofishery) could be the best economic and ecological composition for the society to accept and adapt a mangrove restoration idea (Rahman and Mahmud 2018). Proper implementation of resilient strategies, such as incorporating all stakeholders, awareness programs, reduced forest dependency of local people, implementation of legal bindings, adequate research and monitoring, ecological and silvicultural considerations, etc. can be useful for sustainable management of CS mangroves (Islam and Bhuiyan 2018).

Paul (2012) suggested alternative farming of shrimp and rice for the sustainability of CS mangroves. Afroz and Alam (2013) suggested that policy integration is mandatory to create a balance between the expansions of shrimp farming and protecting the environment of CS. Rahman and Mahmud (2018) reported that without social and political will, restoration efforts are difficult and quite challenging in the CS mangrove areas. However, management of coastal mangroves of CS requires clear guidance, a well-organized government structure, and a well-defined set of actions (Hossain 2001). Recent information is also needed on forest conditions along with cause-effect relationships, and socio-economic and environmental effects of policy measures.

A serious thought needs are given to rehabilitate the CS with mangroves at least partially. Under proper designed management system, it may be possible to develop a compatible and coexisting system for aquaculture and mangrove reforestation model (Figure 4). This would be beneficial from both the economic and conservation points of view, and ultimately would play a considerable role in improving the socio-economic conditions of the local people.

Conclusion

The oldest mangrove forest of the Indian subcontinent, Chakaria Sundarbans mangrove forest, is now only a space for producing large amount of shrimp and salt rather than wood, non-wood or natural products. Though such production is contributing greatly to the national economy of Bangladesh, but enormously disturbed the biodiversity, and depleted the forest products. So, this mangrove forest of Bangladesh needs to be protected with strong emphasis on prevention and conservation of mangrove biodiversity through strict controls of shrimp farming and grazing. To combat the growing human pressures on natural resources along with biodiversity loss, sea-level rise and climate change, restoration of mangrove forest species through sustainable management approach (SMA) should be considered. Proper forest management should be ensured to improve the potentiality of this oldest mangrove forest of Bangladesh. Effective land management should be encouraged by ensuring the local peoples' participation with the help of political awareness and the implication of forest law.

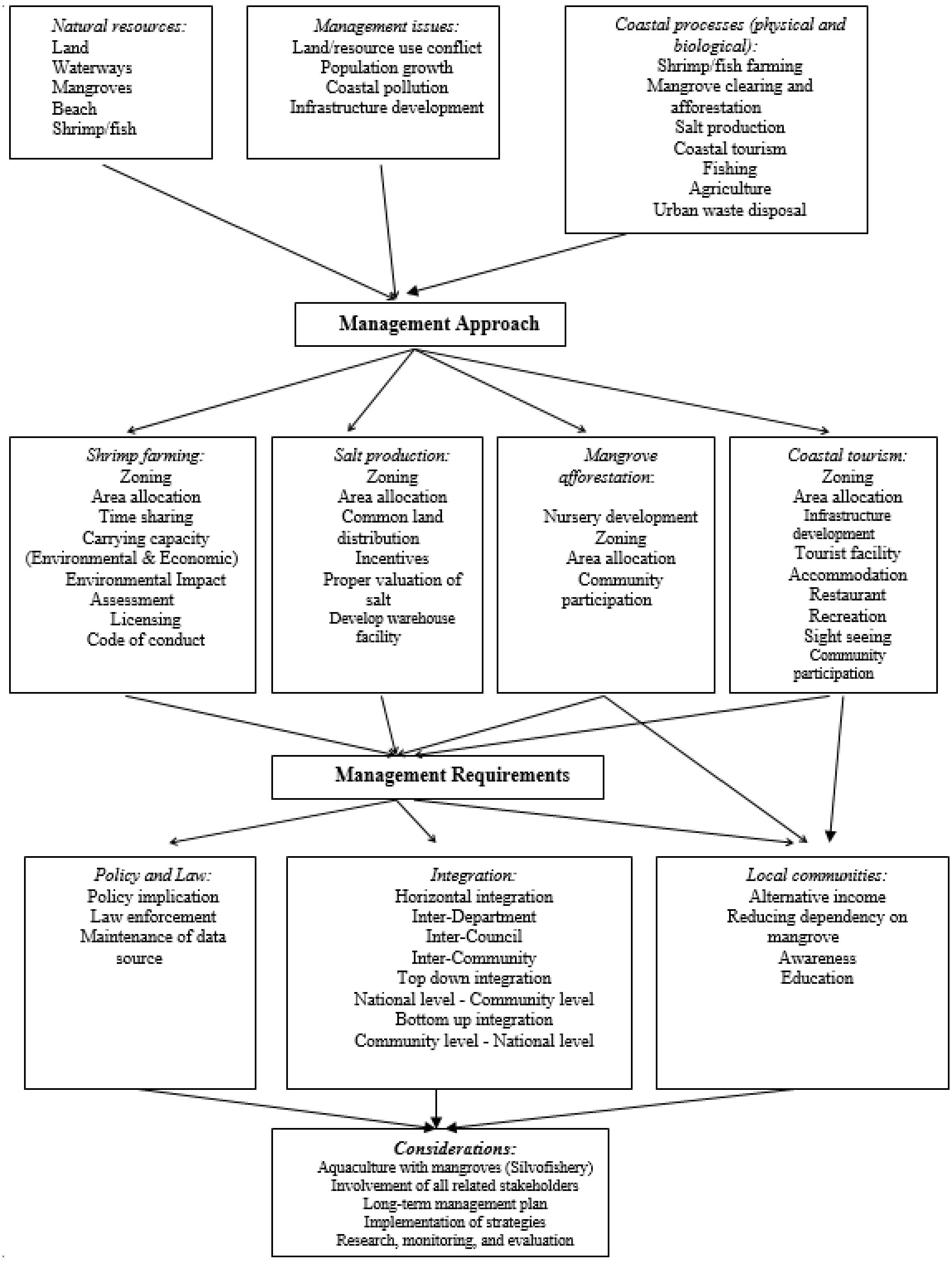

Figure 4. Bringing back the CS mangroves through proper designed sustainable management approach (SMA)

Recommendations

The management of CS would be effective when the forest resources maintain in its natural condition (FAO 1994). In this review, we highly recommended the sustainable management approach (SMA) to restore and rehabilitate the natural CS mangroves. We also made the following recommendations after consulting the major findings of the review: (i) Amalgamation of aquaculture, silviculture, and conservation (Silvo-fishery) is the best practice for bringing back the CS. (ii) Reforestation of mangrove plant species should be increased in degraded areas to restore and conserve the plant diversity in different ecological zones of CS. (iii) Policymakers should give emphasize coastal conservation and environmental amelioration rather than aquaculture expansion and salt production. (iv) Formulation of the new policy about ecological aspects to maintain the existing CS mangroves could be considered. (v) Synergies among governmental, non-governmental, and international organizations and local communities including all stakeholders should develop to ensure the sustainable management of the CS mangroves.

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Tree species diversity and structural composition of village common forest in Bandarban District, Bangladesh

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Abstract. *Jannat M, Kamruzzaman MD, Hossain MK. 2020. Tree species diversity and structural composition of village common forest in Bandarban District, Bangladesh. Asian J For 4: 76-83.* Village common forests (VCF) are community-based forest management that has been practiced for a long time in Bangladesh. Currently, this form of forest management is threatened with various anthropogenic factors, urging for study regarding the state of its biodiversity. The study was conducted to explore indigenous tree species diversity of Babu Para village common forest (VCF) in Bandarban District, Bangladesh. Tree species diversity was assessed through stratified random sampling method using sample plots of 20 m × 20 m in size. Babu Para VCF with an area of 40 acres had more than 406 individuals of 74 tree species belonging to 30 families, including eight unidentified species. Euphorbiaceae and Moraceae were the most dominant families containing 7 species followed by Anacardiaceae (5 species), Mimosaceae (6 species), and Meliaceae (5 species). Both the number of tree species and number of individuals decreased regularly with the increase of total height except ≥ 30 m height range. Number of species and number of individuals was highest in the height range of (5-<10) m. Similar trend was found for dbh (cm) class distribution. Both the number of species and number of individuals were highest in the dbh range of (5-<15) cm. Babu Para VCF had diverse floristic resources that were reflected from the Shannon-Wiener's diversity index (3.94), Simpson's diversity index (0.025), Margalef's richness index (12.15) and Species evenness index (0.92). The results depict the presence of rich indigenous tree species diversity in the studied VCF.

Keywords: Biological diversity, height class, diameter class, importance value index, indigenous tree species, village common forest

INTRODUCTION

Village Common Forests (VCFs), also known as Para Reserve, are a sort of common property in Chittagong Hill Tracts (CHT) (Kamruzzaman et al. 2018). The VCFs play important roles in providing pure drinking water, timber, bamboo, fuelwood, leaves, tubers, and fodder, fruits, etc. for community members and their management has set a standard model for the protection of biodiversity, environment, and natural resources. Such common properties have been maintained traditionally for more than hundreds of years (Jannat et al. 2020; Baten et al. 2010).

VCFs are good examples of effective community-based forest management under certain customary rules and regulations in CHT (Halim and Roy 2006; Baten et al. 2010). Since time immemorial, VCFs have been used by the tribal people for hunting ground, gathering food, swidden cultivation, grazing, charcoal making and collection of minor forest produce including medicinal or herbal produces as major means of livelihood (Roy 2002; Halim and Roy 2006; Chowdhury 2008; Jannat et al. 2018). The VCFs management responsibility belongs to the respective community who depend largely on water sources and forest products to fulfill their basic subsistence requirements and cash income (Miah and Chowdhury 2004; Rasul and Karki 2006; Rasul 2007).

There are no clear statistics about the number and distribution of the VCFs in CHT. An estimation indicated that there are more than 300 VCFs across the region. Nonetheless, in the last two decades degradation of the forest resources occurred in the VCF due to deforestation, over-extraction of tree and vegetative resources, annual commercial crop cultivation (i.e., ginger, turmeric, etc.), disturbance of the hill slopes by shifting cultivation and horticulture that induced soil erosion. Thus, present study is carried out with an aim to explore tree species diversity of Babu Para Village Common Forest (VCF) in Bandarban District, Bangladesh. The results of this study are expected to provide baseline information for monitoring forest changes in CVFs which serves as reference for management and policies in VCFs in the future.

MATERIALS AND METHODS

Study area

The study was carried out in Babu Para VCF, Rowangchhari Sub-district, Bandarban District located in Southeast side of Bangladesh between 21.15° and 22.20 °N latitudes and 91.05 ° and 92.40 ° E longitudes (Figure 1). Area of Bandarban District is about 4,479 km^2 with two-thirds of the area are characterized by steep slopes. Bandarban District is not only the most remote district of the country, but also is the least populous (population 292,900) (Jannat et al. 2020). As per the 2011 census, there were 215,934 Bengalis and 142,401 indigenous people in the district. Population density is about 87/km^2. The studied VCF was established in 1985 and other relevant information regarding study area is presented in Table 1.

Table 1. General information of studied Babu Para VCF in Bandarban District, Bangladesh

Village	Babu Para
Mouza	9 no. ward Alekkhayong mouza
Year of village establishment	1817
Total household (No.)	20
Current population of the village (No.)	150
Year of VCF establishment	1985
Area (Acre)	40
Distance (km) from Upazilla	42
Electricity availability	No
Drinking water sources	GFS, Chora

Methods of sampling

The methods of the study consisted of reconnaissance surveys, fieldwork, data analysis, and report writing. A pilot survey before main survey (field visits as well as formal discussion with director of Tahzingdong, a Non-Governmental Organization) was conducted to have an idea about location, accessibility, communication means, and VCF area prior to selection of sampling procedure.

Stratified random sampling was carried out for the inventory of the tree species. The whole VCF was divided into three broad areas/blocks considering forest patches having few, medium, and dense tree cover. The sampling plot size for tree species diversity was 20m × 20m. A total of 15 randomly selected plots with nearly 3.70% sampling intensity were surveyed. Area of each plot was demarcated by measuring tape and rope. In each plot, dbh (diameter at breast height; 1.3 m above the ground) and height of all the trees having dbh ≥ 5 cm were recorded. Total height and diameter at breast height (dbh) of all trees inside the demarcated plots were measured using Santo Clinometer and diameter tape respectively. All the tree species in the plots were identified and recorded in local and scientific names. In case of unknown species, plant samples were collected to identify through consulting with taxonomists.

Data analysis

The value of diversity has a proportional impact on the stability of a plant community (Jannat et al. 2019). There are many indices available which measure species richness and biodiversity. In this study, different phytosociological attributes were calculated for all the plots. These are species relative density, relative frequency, relative dominance and importance value index (IVI) following Chaturvedi and Khanna (1982) and Shukla and Chandal (2000). Four diversity indices, i.e. Shannon-Wiener's index (H), Simpson's diversity index (D), Margalef's species richness index (R) and Species evenness index (E) were analyzed following Shannon and Wiener (1963), Simpson (1949), Margalef (1958) and Pielou (1966), respectively, to get a picture of tree species diversity in Babu para VCF. Empirical data were analyzed using MS Excel.

Density of a species =
$$\frac{\textit{Total no.of individuals of a species in all the quardrats}}{\textit{Total no. of quadrats studied}}$$

Relative density of a species =
$$\frac{\textit{Total No. of individuals of the species}}{\textit{Total No. of individuals of all the species}} \times 100$$

Frequency of a species =
$$\frac{\textit{Total no. of quardrats in which the species occurs}}{\textit{Total no. of quadrats studied}}$$

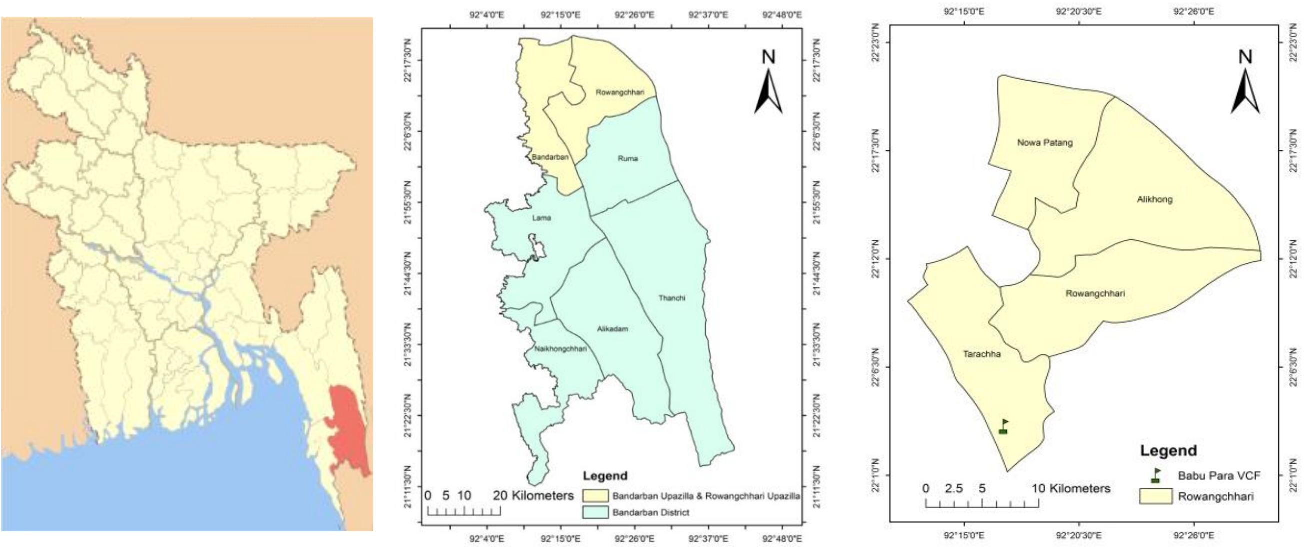

Figure 1. Map of the study area in Babu Para VCF of Bandarban District, Bangladesh

Relative frequency = $\frac{Frequency\ of\ one\ species}{Total\ frequency} \times 100$

Relative dominance = $\frac{Basal\ area\ of\ one\ species}{Total\ basal\ area} \times 100$

IVI = Relative density + Relative frequency + Relative dominance

Shannon-Wiener diversity index (1963) was calculated as the following equation:

$$H = -\sum_{i=1}^{n} P_i \ln P_i$$

Where,
H = Shannon-Wiener's diversity index
P_i = No. of individuals of one species.

One of the best-known diversity indexes based on measures of the quantities of different species in each sample plot is Simpson's index of concentration. Concentration of dominance (D) was measured by using in the calculation of the Simpson's index, which is usually formulated as following equation (Simpson 1949):

$$D = \sum Pi^2$$

Where,
$P_i = ni/N$ and
n_i = the number of individuals of each species;
N = the total number of trees of all species.

Margalef's (1958) index of species richness was calculated by following equation:

$$R = (S-1)/\ln N$$

Where,
R = Species richness index
S = Total no. of species
N = Total no. of individuals of all species

Pielous's measure of evenness is as followed (Pielou 1984):

$$E = H/\ln S$$

Where,
E = Species evenness
H = the Shannon-Weiner Index of Diversity
S = Total No. of species.

RESULTS AND DISCUSSIONS

Species composition

In the sampled sites in Babu Para VCF, there were 406 individuals of 74 tree species belonging to 30 families, including eight unidentified species. Euphorbiaceae and Moraceae were the most dominant family (7 species) followed by Anacardiaceae (5 species), Mimosaceae (6 species), and Meliaceae (5 species). Bignoniaceae, Lauraceae, and Verbenaceae family had three species. Remaining families had 1-2 species each (Table 2).

Quantitative structure of tree species

The study revealed that the highest stem/ha was found for *Albizia chinensis* (43.33) followed by *Gmelina arborea* (38.33), *Bombax insigne* (35.0), *Lannea coromandelica* (30.0), *Oroxylum indicum* (25.0) and *Protium serratum* (25.0). Study revealed that *Albizia lucidior* occupied the highest basal area (0.47 m^2) followed by *Toona ciliata* (0.24 m^2), *A. chinensis* (0.22 m^2), *L. coromandelica* (0.21 m^2), and *Elaeocarpus tectorius* (0.21 m^2). The highest relative density was found for *A. chinensis* (6.40%) followed by *G. arborea* (5.67%), *B. insigne* (5.17%), *L. coromandelica* (4.43%), *O. indicum* (3.69%) and *P. serratum* (3.69%). The highest relative frequency (5.06%) was found for *A. chinensis* followed by *G. arborea* (4.28%), *L. coromandelica* (3.89%), *B. insigne* (3.5%), *O. indicum* (3.5%) and *P. serratum* (2.72%). Study revealed that *A. lucidior* showed the highest relative dominance (8.86%) followed by *T. ciliata* (4.63%), *A. chinensis* (4.15%), and *L. coromandelica* (4.04%). It was found that *A. chinensis* occupied the highest IVI (15.61) followed by *G. arborea* (12.59), *L. coromandelica* (12.37), *B. insigne* (12.16), and *A. lucidior* (10.13) (Table 3).

Distribution of height (m) and dbh (cm) classes

Both the number of species and number of individuals decreased regularly with the increase of total height except at ≥30 m height range. Both the number of species and number of individuals were highest in the height range of 5-<10 m (Figure 2).

Number of tree species and number of individuals decreased regularly with the increase of total dbh except **for ≥**55 cm dbh range. Both the number of species and number of individuals were highest in the dbh range of (5-<15) cm (Figure 3).

Diversity indices

Shannon-Wiener's Diversity Index was 3.94 whereas Simpson's Diversity Index was 0.025. Moreover, Margalef's Richness Index was calculated as 12.15 and Species Evenness Index was 0.92 (Table 4).

Table 2. Tree species with their local, scientific and family name at Babu Para VCF, Bandarban District, Bangladesh

Family	Scientific name	Local name	No. of trees
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	Bhadi	18
	Swintonia floribunda Giff.	Civit	1
	Holigarana longfolia Buch.-Ham. *ex* Roxb.	Jhawa/Barola	3
	Spondias pinnata (L.f) Kurz	Jongli amra	2
	Mangifera sylvatica Roxb.	Uriam	3
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	Chatian	7
	Holarrhena antidysenterica (L.) Wall. *ex* Decne	Kuruch	14
Bignoniaceae	*Fernandoa adenophylla* (Wall. ex G.Don) van Steenis	Dakrum	3
	Stereospermum colais (Buch.-*ex* Dillw.) Mabberley	Dharmara	11
	Oroxylum indicum (L.) Kurz	Thona/Kanaidinga	15
Bombacaceae	*Bombax insigne* Wall.	Shimul Tula	21
Burseraceae	*Protium serratum* (Wall. *ex* Coelbr.) Engl.	Gutgutia	15
Caesalpiniaceae	*Saraca asoca* (Roxb.) de Wild.	Ashok	4
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	Bohera	3
	Anogeissus acuminata (Roxb. *ex* DC.) Gull. & Perr.	Sikori	9
Dipterocarpaceae	*Dipterocarpus turbinatus* Gaertn.	Garjan	2
Ebenaceae	*Diospyros* sp.	N/A	4
Elaeocarpaceae	*Elaeocarpus tectorius* (Lour.) Poir.	Jalpai	2
Euphorbiaceae	*Antidesma* sp.	N/A	2
	Suregada multiflora (A. Juss.) Bail.	Bon-naranga	12
	Bridelia sp.	N/A	2
	Macaranga denticulata (Blume) Mull.-Arg.	Bura	5
	Gmelina arborea Roxb.	Gamar	23
	Mallotus tetracoccus (Roxb.). Kurz	Kumari-bura	1
	Mallotus philippensis (Lamk.) Mull.-Arg.	Sindhuri	5
Fabaceae	*Erythrina fusca* Lour.	Mandar	2
Fagaceae	*Lithocarpus* sp.	Batna	3
Lauraceae	*Cinnamomum tamala* (Buch.-Ham) Nees & Eberm.	Jongli Tejpata	3
	Litsea glutinosa (Lour.) Robinson	Menda	3
	Litsea monopetala (Roxb.) Pers.	Oirga	6
Leeaceae	*Leea macrophylla* Roxb. *ex* Hornem.	Chaigas	2
Lythraceae	*Lagerstroemia speciosa* (L.) Pers.	Jongli Jarul	2
Meliaceae	*Walsura robusta* Roxb.	Bonlichu	2
	Swietenia macrophylla King	Jongli Mehogoni	3
	Azadirachta indica A. Juss.	Neem	2
	Aphanamixis polystachya (Wall.) R.N. Parker	Pitraj	5
	Toona ciliata M. Roem.	Toon	3
Mimosaceae	*Albizia chinensis* (Osb.) Merr.	Chakua Koroi	26
	Albizia sp.	Gol koroi	1
	Albizia lebbeck (L.) Benth. & Hook.	Kalo Koroi	1
	Albizia procera (Roxb.) Benth	Koroi	8
	Albizia odoratissima (L.f.) Benth.	Tetua Koroi	3
	Albizia lucidior (Steud.) I.C.Nielsen	Sil Koroi	2
Moraceae	*Ficus pyriformis* Hook. & Arn.	Bon Dumur	5
	Ficus benghalensis L.	Bot	6
	Artocarpus chama Buch.-Ham. *ex* Wall.	Chapalish	5
	Ficus hispida L.f.	Dumur	9
	Ficus sp.	*Ficus* sp.	2
	Ficus racemosa L.	Jogya Dumur	4
	Streblus asper Lour.	Sheora	2
Myristicaceae	*Myristica linifolia* Roxb.	Amberala	3
Myrtaceae	*Syzygium cumini* (L.) Skeels	Jam	1
	Syzygium fruticosum (Wall.) Masamune	Putijam	4
Rhizophoraceae	*Carallia brachiate* (Lour.) Merr.	Keubong	2
Rubiaceae	*Hymenodictyon orixensis* (Roxb.) Mabb.	Ful Gamari	4
	Neolamarckia cadamba (Roxb.) Bosser	Kadam	4
Rutaceae	*Zanthoxylum rhetsa* (Roxb.) DC.	Bajna	2
Sonneratiaceae	*Duabanga grandiflora* (Roxb. *ex* DC.) Wall.	Bandorhola	12
Sterculiaceae	*Sterculia villosa* Roxb. *ex* Smith	Udal	4
Theaceae	*Schima wallichii* (DC.) Korth.	Kanak	5
Tiliaceae	*Grewia nervosa* (Lour.) Panigr.	Assargula	8
	Brownlowia elata Roxb.	Moos	10
Ulmaceae	*Trema orientalis* (L.) Blume	Banjiyal/Banjiga	6
Verbenaceae	*Callicarpa macrophylla* Vahl	Boro Bormala	10
	Vitex peduncularis Wall. *ex* Schauer	Goda/Arsol	2
	Tectona grandis L.f.	Segun	2
Unidentified	*Unidentified-1*	Damka	4
	Unidentified-2	Eidgas	2
	Unidentified-3	Jati	4
	Unidentified-4	Puronja	9
	Unidentified-5	Rangma	6
	Unidentified-6	X	1
	Unidentified-7	Y	3
	Unidentified-8	Z	1

Table 3. Stem/ha, basal area, relative density, relative frequency, relative dominance and Importance Value Index

Scientific name	Stem/ha	BA (m^2)	RD (%)	RF (%)	RDo (%)	IVI
Myristica linifolia	5.00	0.05	0.74	1.17	0.89	2.80
Antidesma sp.	3.33	0.01	0.49	0.78	0.12	1.39
Saraca asoca	6.67	0.01	0.99	1.17	0.10	2.25
Grewia nervosa	13.33	0.01	1.97	1.95	0.19	4.10
Zanthoxylum rhetsa	3.33	0.06	0.49	0.39	1.23	2.12
Duabanga grandiflora	20.00	0.12	2.96	2.33	2.21	7.50
Trema orientalis	10.00	0.01	1.48	1.56	0.07	3.10
Lithocarpus sp.	5.00	0.03	0.74	0.78	0.62	2.14
Lannea coromandelica	30.00	0.21	4.43	3.89	4.04	12.37
Terminalia bellirica	5.00	0.03	0.74	1.17	0.65	2.56
Ficus pyriformis	8.33	0.02	1.23	1.56	0.35	3.14
Walsura robusta	3.33	0.02	0.49	0.78	0.44	1.71
Suregada multiflora	20.00	0.01	2.96	3.11	0.21	6.27
Callicarpa macrophyla	16.67	0.04	2.46	1.95	0.74	5.15
Ficus benghalensis	10.00	0.14	1.48	1.56	2.67	5.71
Bridelia sp.	3.33	0.01	0.49	0.39	0.25	1.13
Macaranga denticulata	8.33	0.03	1.23	1.56	0.50	3.28
Leea macrophylla	3.33	0.07	0.49	0.78	1.34	2.61
Albizia chinensis	43.33	0.22	6.40	5.06	4.15	15.61
Artocarpus chama	8.33	0.03	1.23	1.17	0.59	2.99
Alstonia scholaris	11.67	0.01	1.72	1.56	0.26	3.54
Swintonia floribunda	1.67	0.02	0.25	0.39	0.35	0.99
Fernandoa adenophylla	5.00	0.04	0.74	0.78	0.69	2.21
Stereospermum colais	18.33	0.20	2.71	2.72	3.77	9.20
Diospyros sp.	6.67	0.03	0.99	1.17	0.49	2.64
Ficus hispida	15.00	0.02	2.22	2.33	0.46	5.01
Ficus sp.	3.33	0.02	0.49	0.39	0.43	1.31
Hymenodictyon orixensis	6.67	0.02	0.99	1.17	0.38	2.53
Gmelina arborea	38.33	0.14	5.67	4.28	2.64	12.59
Dipterocarpus turbinatus	3.33	0.10	0.49	0.78	1.84	3.11
Vitex peduncularis	3.33	0.01	0.49	0.78	0.11	1.39
Albizia sp.	1.67	0.03	0.25	0.39	0.54	1.17
Protium serratum	25.00	0.12	3.69	2.72	2.30	8.72
Elaeocarpus tectorius	3.33	0.21	0.49	0.78	3.93	5.20
Syzygium cumini	1.67	0.01	0.25	0.39	0.22	0.85
Holigarana longfolia	5.00	0.19	0.74	0.78	3.57	5.09
Ficus racemosa	6.67	0.02	0.99	1.17	0.43	2.58
Spondias pinnata	3.33	0.10	0.49	0.78	1.94	3.21
Lagerstroemia speciosa	3.33	0.01	0.49	0.78	0.14	1.41
Cinnamomum tamala	5.00	0.01	0.74	0.78	0.21	1.73
Neolamarckia cadamba	6.67	0.02	0.99	1.17	0.38	2.53
Albizia lebbeck	1.67	0.03	0.25	0.39	0.51	1.14
Schima wallichii	8.33	0.01	1.23	1.56	0.20	2.99
Carallia brachiata	3.33	0.06	0.49	0.78	1.17	2.44
Albizia procera	13.33	0.01	1.97	1.95	0.23	4.15
Mallotus tetracoccus	1.67	0.01	0.25	0.39	0.22	0.85
Holarrhena antidysenterica	23.33	0.02	3.45	2.33	0.44	6.23
Erythrina fusca	3.33	0.02	0.49	0.78	0.32	1.59
Swietenia macrophylla	5.00	0.09	0.74	0.78	1.66	3.18
Litsea glutinosa	5.00	0.01	0.74	1.17	0.13	2.04
Brownlowia elata	16.67	0.01	2.46	2.72	0.09	5.27
Azadirachta indica	3.33	0.02	0.49	0.78	0.43	1.70
Litsea monopetala	10.00	0.14	1.48	1.56	2.75	5.79
Aphanamixis polystachya	8.33	0.01	1.23	0.78	0.15	2.16
Syzygium fruticosum	6.67	0.02	0.99	1.17	0.44	2.59
Albizia odoratissima	5.00	0.07	0.74	1.17	1.34	3.25
Tectona grandis	3.33	0.06	0.49	0.78	1.19	2.46
Streblus asper	3.33	0.01	0.49	0.39	0.23	1.11
Bombax insigne	35.00	0.18	5.17	3.50	3.49	12.16
Anogeissus acuminata	15.00	0.05	2.22	1.95	1.00	5.16
Albizia lucidior	3.33	0.47	0.49	0.78	8.86	10.13
Mallotus philippensis	8.33	0.01	1.23	1.17	0.23	2.63
Oroxylum indicum	25.00	0.01	3.69	3.50	0.21	7.41
Toona ciliata	5.00	0.24	0.74	0.78	4.63	6.15
Sterculia villosa	6.67	0.05	0.99	1.17	1.00	3.15
Mangifera sylvatica	5.00	0.01	0.74	0.78	0.17	1.69
Unidentified-1	6.67	0.01	0.99	0.78	0.17	1.94
Unidentified-2	3.33	0.01	0.49	0.78	0.27	1.54
Unidentified-3	6.67	0.14	0.99	1.17	2.57	4.73
Unidentified-4	15.00	0.01	2.22	1.95	0.08	4.24
Unidentified-5	10.00	0.45	1.48	1.56	8.55	11.58
Unidentified-6	1.67	0.19	0.25	0.39	3.56	4.20
Unidentified-7	5.00	0.02	0.74	0.78	0.29	1.80
Unidentified-8	1.67	0.37	0.25	0.39	6.99	7.62
Total			100.00	100.00	100.00	300.00

Note: BA= basal area; RD= relative density; RF= relative frequency; RDo= relative dominance; IVI= Importance Value Index

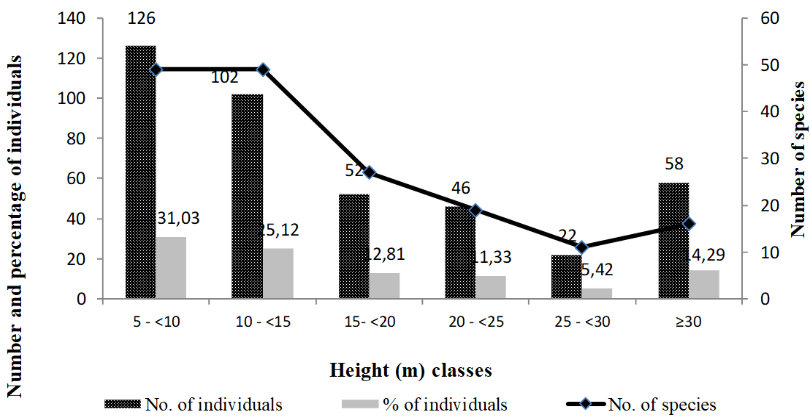

Figure 2. Distribution of tree height (m) classes at Babu Para VCF, Bandarban District, Bangladesh

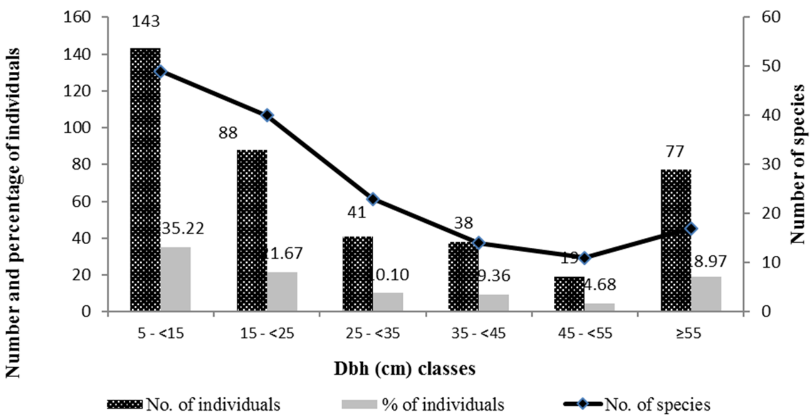

Figure 3. Distribution of tree dbh (cm) classes at Babu para VCF, Bandarban District, Bangladesh

Table 4. Biological diversity indices for recorded tree species

Name of the indices	Diversity index values
Shannon-Wiener's Diversity Index (H)	3.94
Simpson's Diversity Index (D)	0.025
Margalef's Richness Index (R)	12.15
Species Evenness Index (E)	0.92

Discussion

The sampled sites in Babu Para VCF supported 406 individuals of 74 tree species belonging to 30 families whereas Jannat et al. (2020) documented 576 individuals of 85 tree species belonging to 31 families in Renikhayong para VCF, Bandarban. Baten et al. (2010) recorded 173 floral species from the VCF in CHT. Hossain and Hossain (2014) reported 240 tree species under 61 families from Chunati Wildlife Sanctuary. A total of 182 tree species belonging to 50 families were recorded from the DDWS (Feeroz et al. 2012). Feeroz et al. (2011) reported 142 tree species belonging to 57 families from Rema-Kalenga Wildlife Sanctuary. Compared to such areas, Babu Para VCF is quite poor in terms of tree species richness. This might be caused by smaller extent (only 40 acres) of the sampled area in this study. However, Malaker et al. (2010) reported about 78 tree species from Lawachara forest. Sobuj and Rahman (2010) reported 26 tree species from Khadimnagar National Park. About 82 species under 31 families were found in Dulahazara Safari Park (Uddin and Misbahuzzaman 2007). Baten et al. (2010); Adnan and Dastidar (2011); Jashimuddin and Inoue (2012) reported that VCF shows rich biodiversity compared to government-managed reserve forests in CHT and has similarities with the present findings.

In the present study, both the number of species and number of individuals were highest in the height range of 5-<10 m. Hossain and Hossain (2014) reported that maximum number of tree species was represented by the height class 3-<8 cm in Chunati Wildlife Sanctuary (WS). Number of species and number of individuals was found highest in the dbh range of 5-<15 cm in the present study which is almost similar to the findings of Nath et al. (1997). They found maximum individuals in the dbh range of 10-19.9 cm for the natural forests of CHT (South Forest Division).

The Shannon-Wiener's Diversity Index (3.94) found in the present study is higher than that of 2.98 in Sithapahar Reserve Forest (Nath et al. 2000) and 3.25 in Tankawati natural forest in Chittagong (South) Forest Division (Motaleb and Hossain 2011). The index is comparable to Shannon-Wiener's Diversity Index (4.45) found in Dhudpukuria-Dhopachori Wildlife Sanctuary (Hossain et al. 2013) and 4.27 of Garo Hills of India (Kumar et al. 2006). The Value of Shannon-Wiener's Index (3.94) and Margalef's Index (12.15) and lower value of Simpson's Index (0.025) in the present index indicate higher species diversity in Babu Para VCF of Bandarban compared to other natural forests of the country. Shannon-Wiener Index found in the present study was 3.94 which has similarities with the findings of Tripathi et al. (2004); Kumar et al. (2006); Velho and Krishnadas (2011); and Ndah et al. (2013). They found Shannon-Wiener Index within 3.50 – 4.27 for natural forests.

Species Evenness Index was found 0.92 in the present study which is similar to the findings of Jannat et al. (2019); Tripathi et al. (2004); Ndah et al. (2013); Panda et al. (2013). They reported species Evenness Index within 0.88-0.99. However, present findings are quite higher compared with Bhuiyan et al. (2003) and Hayat et al. (2010). Simpson's index was found 0.028 which is comparable with the findings of Ndah et al. (2013) and Panda et al. (2013). However, Mishra and Garkoti (2016) differ with that.

The VCF that harbors more than 74 tree species of different habit forms indicates the importance and potentiality of the VCF for conservation and natural ecosystem. Various diversity indices, regular distribution of tree species in different height and dbh (diameter at breast height) classes indicate rich biodiversity and existence of complex ecosystem functions in the study area. VCFs are equipped with valuable medicinal plants, which help disadvantaged indigenous communities to get rid of various diseases.

From the study, it can be concluded that the management of VCF is increasingly becoming essential for the subsistence of people in the area. The management practices in VCFs are effective to sustain a balance between conservation and exploitation of forest resources. The formation of local institutions and setting of forest management practices by indigenous communities restrict users from over-exploitation of forest resources, which can be used as an influential model for managing government forests.

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