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Modelling spatial biodiversity in the world's largest mangrove ecosystem—The Bangladesh Sundarbans: A baseline for conservation

Swapan Kumar Sarker, Richard Reeve, Nirmal K. Paul, Jason Matthiopoulos

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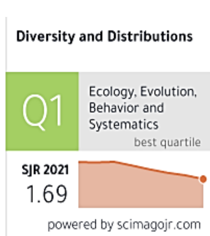

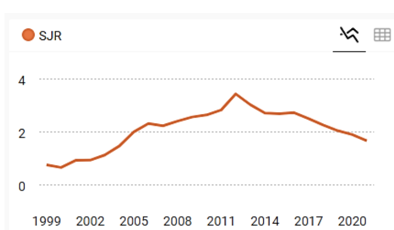

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MANUSCRIPT DETAILS
TITLE: Modelling spatial biodiversity in the world's largest mangrove ecosystem - the Sundarbans: A baseline for conservation

ABSTRACT:
Aim Mangrove forests are amongst the most threatened and rapidly vanishing, but poorly-understood ecosystems. We aim to uncover the variables driving mangrove biodiversity and produce baseline biodiversity maps for the Sundarbans world heritage site – the Earth's largest mangrove ecosystem.
Location The Sundarbans, South Asia.
Methods We collected species abundance, environmental and disturbance data from 110 permanent sample plots covering the entire Bangladesh Sundarbans (6017 km2). We applied generalized additive models to determine the

key variables shaping the spatial distributions of mangrove diversity and community composition. Biodiversity maps were constructed using covariate-driven habitat models and their predictive performances were compared with covariate-free (i.e. direct interpolation) approaches to see whether the inclusion of habitat variables bolster spatial predictions of biodiversity or if we can rely on direct interpolation approaches when environmental data are not available.

Results Historical forest exploitation, disease, siltation and soil alkalinity were the key stressors causing loss of alpha and gamma diversity in mangrove communities. Both alpha and gamma diversity increased along the downstream-to-upstream and riverbank-to-forest interior gradients. Mangrove communities subjected to intensive past tree harvesting, disease outbreaks, and siltation were more homogeneous in species composition (beta diversity). In contrast, heterogeneity in species composition increased along decreasing salinity and downstream-to-upstream gradients. We find that the surviving biodiversity hotspots (comprising many globally endangered tree species) are located outside the established protected area network and hence open to constant human exploitation, and we therefore suggest bringing them immediately under protected area management.

Main conclusions We provide the first habitat-based modelling and mapping of alpha, beta and gamma diversity in threatened mangrove communities. In general, habitat-based models showed better predictive ability than the covariate-free approach. Nevertheless, the small margin of differences between the approaches demonstrates the utility of direct interpolation approaches when environmental data are unavailable.

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Modelling spatial biodiversity in the world's largest mangrove ecosystem—The Bangladesh Sundarbans: A baseline for conservation

Swapan Kumar Sarker[1] | Richard Reeve[1] | Nirmal K. Paul[2] | Jason Matthiopoulos[1]

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Editor: Franz Essl

Abstract

Aim: Mangrove forests are among the most threatened and rapidly vanishing, but poorly understood ecosystems. We aim to uncover the variables driving mangrove biodiversity and produce baseline biodiversity maps for the Sundarbans world heritage site—the Earth's largest contiguous mangrove ecosystem.

Location: The Bangladesh Sundarbans, South Asia.

Methods: We collected species abundance, environmental and disturbance data from 110 permanent sample plots (PSPs) covering the entire Bangladesh Sundarbans (6,017 km^2). We applied generalized additive models to determine the key variables shaping the spatial distributions of mangrove diversity and community composition. Biodiversity maps were constructed using covariate-driven habitat models, and their predictive performances were compared with covariate-free (i.e., direct interpolation) approaches to see whether the inclusion of habitat variables bolster spatial predictions of biodiversity or whether we can rely on direct interpolation approaches when environmental data are not available.

Results: Historical forest exploitation, disease, siltation and soil alkalinity were the key stressors causing loss of alpha and gamma diversity in mangrove communities. Both alpha and gamma diversity increased along the downstream-to-upstream and riverbank-to-forest interior gradients. Mangrove communities subjected to intensive past tree harvesting, disease outbreaks and siltation were more homogeneous in species composition (beta diversity). In contrast, heterogeneity in species composition increased along decreasing salinity and downstream-to-upstream gradients. We find that the surviving biodiversity hotspots (comprising many globally endangered tree species) are located outside the established protected area network and hence open to human exploitation. We therefore suggest bringing them immediately under protected area management.

Main conclusions: We provide the first habitat-based modelling and mapping of alpha, beta and gamma diversity in threatened mangrove communities. In general, habitat-based models showed better predictive ability than the covariate-free approach. Nevertheless, the small margin of differences between the approaches

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Modelling spatial biodiversity in the world's largest mangrove ecosystem - the Sundarbans: A baseline for conservation

Journal:	*Diversity and Distributions*
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Manuscript Type:	Biodiversity Research
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Modelling spatial biodiversity in the world's largest mangrove ecosystem - the Sundarbans: A baseline for conservation

Running head: Mangrove biodiversity in the Sundarbans

ABSTRACT

Aim Mangrove forests are amongst the most threatened and rapidly vanishing, but poorly-understood ecosystems. We aim to uncover the variables driving mangrove biodiversity and produce baseline biodiversity maps for the Sundarbans world heritage site – the Earth's largest mangrove ecosystem.

Location The Sundarbans, South Asia.

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Keywords Biodiversity conservation, endangered species, generalized additive models, habitat rehabilitation, protected area, sea-level rise.

1. INTRODUCTION

Tropical and subtropical mangrove forests (between 30° N and 30° S) provide numerous ecosystem services and support coastal livelihoods worldwide (Lee et al., 2014). However, they are amongst the most threatened and rapidly vanishing habitats on Earth (Polidoro et al., 2010; Richards & Friess, 2016). The mangrove biome has already lost about 50% of its coverage since the 1950s (Feller et al., 2010), and IUCN has listed 40% of mangrove tree species as Threatened (Polidoro et al., 2010). Increasing anthropogenic pressures and anticipated sea level rise (SLR) are likely to alter the structure and functions of the remaining endangered mangrove forests (Duke et al., 2007), in particular, the Sundarbans UNESCO world heritage site - the Earth's largest mangrove ecosystem.

Making spatial predictions of biodiversity is important for pinpointing the locations or communities requiring immediate or long-term protection and conservation actions, in evaluating threats to those communities, and in monitoring spatial distributions and temporal dynamics in biodiversity (Socolar et al., 2015). A variety of biodiversity modelling approaches (e.g. stacked species distribution models, macroecological models, ordination, and stochastic models – Ferrier & Guisan, 2006; Mateo et al., 2017) have been applied to understand the spatial patterns of species richness and composition in different forest ecosystems (e.g. neo-tropical, boreal and temperate forests). However, their application to mangrove forests is limited (but see Record et al., 2013) due to the scarcity of field data (Ellison, 2001), thus resulting in poor understanding of mangrove biogeography.

Each of the three established components of biodiversity (alpha, beta and gamma – Whittaker, 1960) characterizes different fundamental attributes of natural communities, and therefore has specific conservation implications. For example, spatial maps of alpha diversity

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can help in specifying the most species-rich habitats while beta diversity maps can determine the most heterogeneous communities, where protecting larger areas will encompass more biodiversity. Similarly, gamma diversity measures can identify the overall areas with the highest biodiversity. Thus far, mangrove biodiversity studies have mostly relied on alpha diversity, and in particular species richness (Ellison, 2001; Record et al., 2013; Osland et al., 2017) which, by ignoring the variability in species relative abundances, has known weaknesses in identifying areas for prioritisation (Veach et al., 2017). At a regional scale, mangrove plant communities may look spatially homogeneous because mangrove forests are relatively species-poor compared to the upland tropical forests. However, at finer scales, considerable heterogeneity in vegetation structure becomes apparent (Farnsworth, 1998). Therefore, looking at how the components of biodiversity respond to biotic and abiotic variables is important for constructing more informative and practically useful biodiversity maps.

Constructing maps of biodiversity indices is important in order to investigate spatio-temporal variations in natural communities, to locate habitats or communities or species that require immediate protection and to support spatially explicit conservation planning (Devictor et al., 2010). Both habitat-based and covariate-free (direct interpolation methods such as Kriging) approaches have been used for mapping biodiversity indices. Although covariate-free approaches have been criticized for low predictive ability (Granger et al., 2015), the relative performance of the approaches has rarely been tested using field data.

Testing the 'zonation' hypothesis (i.e. the distinct ordering of tree species along the shore-to-inland gradient, Ellison et al., 2000) and explaining the 'biodiversity anomaly' (i.e. why mangrove plant species richness drops along the latitudinal gradient, Ricklefs et al., 2006), have been the key agendas dominating the mangrove biodiversity literature in the last two decades. While such studies have substantially improved our insight into species sorting and richness, limited attention has been paid to understanding how abiotic, biotic and historical anthropogenic pressures have contributed to spatial variations in mangrove diversity and composition. Such knowledge gaps have obstructed the success of conservation initiatives in many tropical coastal regions (Lewis, 2005) such as the Sundarbans.

This study focused on the threatened mangrove plant communities of the Sundarbans which are under severe threat from historical forest exploitation, habitat degradation and future

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climate change impacts (Sarker et al., 2016). Using a newly introduced abundance-based framework for biodiversity partitioning (Reeve et al., 2016) and a habitat-based biodiversity modelling approach, our overarching goal was to uncover the influences of fine-scale habitat conditions and historical events in shaping the current spatial distributions of alpha, beta and gamma diversity. Our more specific questions include: What are the key drivers of mangrove biodiversity? How do the predictive abilities of covariate-driven habitat models compare with those of covariate-free direct interpolation approaches? Where are the biodiversity hotspots in the Sundarbans currently located? Are these hotspots well protected? Finally, we demonstrate and discuss the potential applications of these novel insights and biodiversity maps for future mangrove research, biodiversity protection, monitoring, and spatial conservation planning.

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2. METHODS

2.1 Study system

The Sundarbans (10,017 km^2), a part of Earth's largest delta, the Ganges-Brahmaputra, is distributed in Bangladesh and India. Due to its outstanding universal ecological and economic value, the Bangladesh part of the Sundarbans (21°30′ - 22°30′N, 89° 00′ – 89°55′E, 6017 km^2) was declared a UNESCO world heritage site in 1997 (Gopal & Chauhan, 2006). It was also declared a Ramsar wetland ecosystem under the Ramsar Convention in 1992 (Chowdhury et al., 2016a). The Sundarbans is washed by the tide twice a day, and freshwater flowing from the Ganges and the opposing saltwater influx from the Bay of Bengal together control its hydrology (Wahid et al., 2007). The climate is humid tropical with four main seasons: pre-monsoon (March–May), monsoon (June–September), post–monsoon (October–November) and the dry winter season (December–February). The average annual precipitation is 1700 mm and the mean temperatures in pre-monsoon, monsoon, post-monsoon and dry winter are 29, 30, 26 and 20°C, respectively (Chowdhury et al., 2016b).

2.2 Tree and environmental data collection

Abbreviation of PSPs need to write fully in the first time

We collected tree data from the 110 PSPs (100 × 20 m, divided into 5 20 × 20 m subplots) covering all salinity zones (i.e. hypo-, meso-, and hypersaline zones) and forest types (see Iftekhar & Saenger, 2008) in the Bangladesh Sundarbans. The Bangladesh Forest Department (BFD) established these PSPs (Fig. 1) in 1986. As part of the 2008 – 2014 surveys, our team, together with the BFD tagged every tree (d.b.h ≥ 4.6 cm at 1.3 m from the ground) with a unique tree number and recorded tree counts for the PSPs. In total, we recorded 49,409 trees from 20 mangrove species (see Appendix S1 in Supporting Information).

[Figure 1]

In 2014 (January – June), we collected 9 soil samples from each PSP (soil depth = 15 cm) adopting a soil sampling design (See Appendix S1 in Supporting Information) to account for the within-plot variations in soil variables. We then determined soil sand, silt and clay percentages, salinity, pH, oxidation reduction potential (ORP), NH_4, P, K, Mg, Fe, Zn, Cu and sulphide concentrations. For each soil variable, we recorded the average reading from 9 soil samples.

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We retrieved 5 elevation readings (above-average sea level) from each PSP using the available digital elevation model (accuracy at pixel level = ±1 m) (IWM, 2003) and then averaged them to account for sampling error. We also calculated the "upriver position" (URP), the straight-line distance of each PSP from the river-sea interface (Duke et al., 1998) and classified their position as – (i) 'downstream', representing the lower third (0 - 33% upriver from the sea – Bay of Bengal), (ii) 'intermediate', representing the middle third (34 - 66% upriver from the sea), and (iii) 'upstream', representing the upper third (67 - 100% upriver from the sea) of the estuarine system. This classification system is useful for understanding variability in diversity and species compositions along the downstream (saltwater dominated river system) - upstream (freshwater dominated river system) gradient.

2.3 Covariate selection

We followed Twilley & Rivera-Monroy's (2005) mangrove-centric conceptual framework to construct a biologically informative variable set for our mangrove biodiversity models. This framework integrates abiotic and biotic constraints to explain vegetation structure and productivity at local and regional scales. The abiotic constraints comprise resources, regulators and hydroperiod. Resources (i.e. nutrients) are assimilated by trees. Here, we selected three essential plant macro-nutrients - soil NH_4, P and K – for their critical roles in mangrove growth and development (Reef et al., 2010). Regulators are non-resource variables that control tree eco-physiology (Guisan & Thuiller, 2005). Here, we selected soil salinity, pH and silt. Hydroperiod (i.e. inundation frequency, duration, and depth) controls the regional and local hydrology that in turn influence species distributions in coastal environments (Crase et al., 2013). PSP-level hydroperiod data were unavailable, so we used elevation as a proxy of the likely variation in hydroperiod across the region.

What method did you use to determine the concentrations of the variables? Should be clearly but just written in short.

Biotic interactions (e.g. competition or facilitation) between plants can influenc composition at a local scale (Howard et al., 2015). Competitive exclusion competitors in stressed mangrove habitats may lead to species-poor mangrove com dominated by a single or few opportunistic species (Saenger, 2002). To account for such influences, initially, we considered two candidate biotic variables: (i) 'community size' – total number of individuals in each PSP, and (ii) total basal area in each PSP. Diversity models using basal area as a covariate had lower explanatory powers, compared to models with 'community size (CS)'. Therefore, we selected CS as a proxy of biotic interactions.

We incorporated URP of each PSP in our covariate set to account for the influence of the river systems on species composition along the downstream-upstream gradient. In riverine estuaries, tidal inundation levels, soil physical and chemical properties can significantly vary along the riverbank - inner forest gradient, which influences colonization success and survival of mangrove plants (Berger et al., 2008). To account for such variations, we included the straight-line distance of each PSP from the nearest riverbank (henceforth DR).

Tropical coastal ecosystems are prone to both natural and anthropogenic disturbances (Feller et al., 2017). Natural disturbances (such as tree disease and mortality) and anthropogenic disturbances (such as tree harvesting) offer opportunities for tree recruitment through gap creation, thus influencing vegetation composition (Duke, 2001). To account for the influences of natural and human disturbances on current diversity and species composition, we incorporated historical harvesting (HH) and disease prevalence (DP) as covariates in our models. Here, HH and DP represent the total number of illegally harvested and diseased (for example, 'top dying' disease (dieback of the foliage and twigs in part of the crown) of *Heritiera fomes*, 'heart rot' disease of *Xylocarpus. mekongensis* etc.) trees in each PSP from historical records (1986 to 2014). Finally, using Variance Inflation Factors (VIF, Robinson & Schumacker, 2009) we checked for multi-collinearity in our covariates (see Appendix S2) and removed covariates leading to VIF greater than 2.5. This led to the removal of ORP from our covariate set (see Appendix S2).

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2.4 Biodiversity partitioning

For partitioning biodiversity, we used Rényi's generalised relative entropy (Rényi A., 1961), an extension of Hill (1973), Jost (2006; 2007) and Leinster and Cobbold's (2012) notions of ecosystem diversity. Implemented in Reeve et al's 2016 framework, this allows us to partition the alpha, beta and gamma diversity of an ecosystem (called a *metacommunity*) into its *subcommunity* components, thus allowing comprehensive and consistent quantification and modelling of all biodiversity components in a spatial context.

In this study, each PSP represents a *subcommunity* (SC), and the combined PSPs form the *metacommunity* (MC). This approach allows us to understand and easily compare the species diversity and composition in every single SC in relation to the MC (the whole Sundarbans ecosystem). We measured SC alpha, beta, and gamma diversity. Here, the normalised alpha diversity index (denoted $\overline{\alpha}$) represents the diversity of a single SC (PSP) in isolation. The normalised beta diversity index (denoted $\overline{\rho}$) measures representativeness and assesses how well a SC represents the species composition of its MC. It is maximised (1) when the MC is homogenous, and a SC's species composition is identical to that of the MC and therefore represents it perfectly. Low $\overline{\rho}$ therefore suggests high spatial heterogeneity in species composition within the MC, and high $\overline{\rho}$ suggests spatial homogeneity.

The gamma diversity (denoted γ) is the conventional gamma diversity (Hill, 1973; Jost, 2006; Leinster & Cobbold, 2012) at the MC level that reflects the total species diversity in an unpartitioned ecosystem. The framework partitions the MC gamma diversity into SC gamma diversity that measures each PSP's average contribution to (or influence on) the MC diversity per tree. This diversity measure combines the alpha diversity of a SC with its beta diversity to form an assessment of the overall contribution of the PSP to the MC (Reeve et al., 2016).

Following Hill (1973), Jost (2006; 2007) and Leinster and Cobbold's (2012), the values of all the biodiversity measures are moderated by a viewpoint parameter, q, taking a value between 0 and ∞ representing how conservative the measure is in accounting for species abundance. For $\overline{\alpha}$ and γ, the diversity at $q = 0$ measures species richness; at $q = 1$ measures the exponential of Shannon entropy (Shannon, 1948); and at $q = 2$ measures the inverse of Simpson's concentration index (Simpson, 1948). For all analyses, we present the results using the above three q values (0, 1, and 2), writing them as ${}^{0}\overline{\alpha}$, ${}^{1}\overline{\rho}$, ${}^{2}\gamma$, etc.

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2.5 Biodiversity modelling

We constructed generalized additive models (GAMs, Wood, 2011) to quantify how the different biodiversity components responded to different variables. Guided by data and using non-parametric smoothing functions, GAMs can capture response-predictors relationships without a priori knowledge of the functional form of these relationships (Guisan & Thuiller, 2005). These advantageous features of GAMs are well suited for uncovering unknown biodiversity-environment linkages in dynamic ecosystems such as the Sundarbans where multiple environmental gradients have interactive effects on species distributions (Sarker et al., 2016). All analyses were done in R version 3.2.3 (R Core Team, 2016). Biodiversity GAMs were built using cubic basis splines with the Gamma error distribution using the 'mgcv' package version 1.8 - 7 (Wood, 2011). Model selection and model averaging were carried out using the 'MuMIn' package version 1.15.1 (Barton, 2015). Biodiversity measures were calculated using the 'rdiversity' package version 1.0 (Mitchell & Reeve, 2017).

We exhaustively fitted GAMs for each diversity index with all possible combinations of covariates. Then we ranked the fitted GAMs using the second-order AIC (AICc) because the ratio between sample size and the number of covariates was < 40 (Burnham & Anderson, 2002). Models whose AIC_c had values less than 2 units from the best model (ΔAIC_c <2) were retained as competing models (Burnham & Anderson, 2002). The relative support for each of the competing models was then determined using their Akaike weights (AIC_{cw}, vary between 0 to 1, and the sum of all AIC_{cw} across the competing models is 1). To reduce model selection uncertainty and bias, we then conducted model averaging to predict the diversity indices. To determine the strength of the covariates, we ranked them based on their Relative Importance (RI) values. RI of each covariate was calculated by totalling the AIC_{cw} of the models in which the covariate was included. RI values vary between 0 and 1, where 0 specifies that the target covariate is not included in any of the competing models while 1 means that the covariate is included in all competing models. We measured goodness-of-fit of the biodiversity models using the R^2 (coefficient of determination) statistic between the observed and estimated values of the diversity indices.

2.6 Biodiversity mapping

We applied two different approaches to make spatial biodiversity predictions. First, we used our habitat-based models (GAMs) and interpolated covariate surfaces to produce model-

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averaged predictions. Second, we used a direct interpolation method, Ordinary kriging (OK), that simply relied on the empirical spatial autocorrelation between neighbouring PSPs (did not consider environmental covariates) to make purely spatial predictions. We compared these two approaches because environmental data collection is challenging, whereas tree surveys are conducted annually at the PSPs. Hence, it is useful to know how close the predictions of the habitat-based biodiversity models were compared to direct interpolation methods. The size of each grid-cell of the interpolated surfaces was 625 m^2 (25m × 25m). We compared the predictive abilities of GAMs with OK, using the normalized root mean square error (NRMSE) statistic derived from a leave-one-out cross-validation (LOOCV) procedure. For normalization, the root mean square error statistic was divided by the range of the actual diversity values. OK was performed using the ‘gstat’ package version 1.0 - 26 (Pebesma, 2004) in R.

The largest mangrove protected area network (PAN) comprising three Wildlife Sanctuaries (WS) – East WS, West WS, and South WS, has been operational in the Sundarbans since the 1970s. To evaluate its capacity to support the remaining biodiversity hotspots in the Sundarbans, we superimposed this onto our biodiversity maps. All the biodiversity maps were constructed using the ‘raster’ package version 2.4 - 18 (Hijmans, 2017) in R.

3. RESULTS

3.1 Habitat-based biodiversity models

The explanatory power and the goodness-of-fit of the alpha, beta and gamma diversity GAMs varied when we increased weight on species relative abundances (q = 0, 1 and 2) in the subcommunities (SCs). ${}^{1}\overline{\alpha}$ (Shannon entropy) GAM explained more deviance (DE = 71%) and showed a better fit to the data (Adj. R^2 = 0.71) compared to those for ${}^{0}\overline{\alpha}$ (species richness) and ${}^{2}\overline{\alpha}$ (Simpson’s concentration) (Table 1), suggesting that, for alpha diversity, the model with a moderate focus on species relative abundances in the SCs (i.e. q = 1) could capture more signal compared to the models that only considered species presence-absence (q = 0) or offered more importance to the more dominant species (q = 2) in the SCs. Like ${}^{1}\overline{\alpha}$, the ${}^{1}\gamma$ GAM could capture more signal than ${}^{0}\gamma$ and ${}^{2}\gamma$ GAMs. In contrast, for beta diversity, with DE = 65% and Adj. R^2 = 0.70, the ${}^{2}\overline{\rho}$ GAM captured more signal than the ${}^{0}\overline{\rho}$ and ${}^{1}\overline{\rho}$ GAMs, implying that our covariates could more successfully explain the variability in species

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composition across the SCs when the variability was mostly contributed by more dominant species.

[Table 1]

3.2 Drivers and responses of biodiversity components

The relative importance (RI) of the covariates in influencing biodiversity indexes also varied when we changed weight on species relative abundances in the SCs. For example, while historical harvesting (HH) had no influence on ${}^{0}\overline{\rho}$ (possibly due to high number of shared species between SCs or HH did not lead to species extirpation), it had stronger effects on ${}^{1}\overline{\rho}$ and ${}^{2}\overline{\rho}$, indicating that the influence of past tree harvesting in shaping current community composition becomes clearer when we account for the variability in species relative abundances across the SCs. In general, several abiotic and biotic drivers had combined effects on the spatial distributions of the biodiversity indexes. SC alpha diversity was mainly influenced by CS, URP, DR and silt (Table 1, Appendix S3). CS, URP, salinity, HH, silt and DP were the predominant drivers for spatial variations in SC beta diversity. SC gamma diversity was mostly influenced by CS, URP, salinity, DR, HH, pH and silt.

The partial response plots of the best alpha, beta, and gamma diversity GAMs (for q = 0, 1 and 2) showed similar relationships across the models (Fig. 2, Appendix S3). While alpha diversity (for ${}^{1}\overline{\alpha}$) increased with increasing DR (> 1500 m) and URP (> 80%), it decreased with increasing HH (> 175 tree cuts/0.2 ha), silt (> 20%), CS (> 450 trees/0.2 ha) and pH (> 7.25). The response of alpha diversity varied for different nutrients. The K concentration that maximised ${}^{1}\overline{\alpha}$ was 5.5 gm Kg^{-1} whilst increasing soil P (> 35 mg Kg^{-1}) was related to decreasing ${}^{1}\overline{\alpha}$. Mangrove communities showed increasing representativeness (for ${}^{2}\overline{\rho}$) i.e. homogeneity in species composition with increasing HH (> 150 tree cuts/0.2 ha), silt (> 20 %), DP (> 25 diseased trees/0.2 ha), and CS (> 450 trees/0.2 ha). In contrast, communities showed decreasing representativeness i.e. increasing heterogeneity in species composition with increasing salinity (> 6.5 dS m^{-1}) and URP (> 70%). Gamma diversity (for ${}^{1}\gamma$) showed strong positive responses to increasing DR (> 1000 m), salinity (> 8 dS m^{-1}), and URP (> 70%), and negative responses to increasing HH (> 175 tree cuts/0.2 ha), silt (> 20%), CS (> 500 trees/0.2 ha) and pH (> 7.25).

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[Figure 2]

3.3 Biodiversity maps

Spatial alpha, beta and gamma diversity maps produced via GAMs are presented in Fig. 3. Alpha diversity maps (first row) uncovered that hotspots in species richness (q = 0), Shannon entropy (q = 1) and Simpson's concentration (q = 2) were restricted to the northern (specifically, the Kalabogi region) and eastern (specifically the Sharankhola region) Sundarbans. Beta (second row) and gamma (third row) diversity maps revealed that the entire Sundarbans looks homogeneous when we only looked at species presence or absence (q = 0) i.e. not accounting for the between-species variability in relative abundances. Allowing increasing weight on species abundance (q = 1 and 2) revealed that the most heterogeneous mangrove communities and the communities that contributed most to the overall biodiversity of the ecosystem were restricted to the northern upstream habitat. Additionally, our maps indicated that the established protected area network (PAN) does not currently include the most diverse (i.e. biodiversity hotspots) and heterogeneous mangrove communities. Prediction error was always reduced by the use of environmental covariates, but particularly for predictions of alpha and gamma diversity. In case of beta diversity, while the predictive ability of the GAM was better than that of Kriging for ${}^{0}\overline{\rho}$ and ${}^{1}\overline{\rho}$, both approaches had almost similar prediction error for ${}^{2}\overline{\rho}$ (Table 2).

[Figure 3]

[Table 2]

4. DISCUSSION

This study provides a baseline quantification and habitat-based modelling of alpha, beta and gamma diversity of threatened mangrove communities. Contrary to the common assumption that one or two straightforward environmental gradients (salinity and inundation) control mangrove biodiversity (Ellison, 2001), our results revealed that several environmental drivers, biotic interactions and historical events contribute to the emergence of observed spatial patterns of mangrove diversity and species composition. The high explanatory and predictive power of our biodiversity models confirm their usefulness in constructing spatially

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explicit predictions of species diversity and composition. The ability of the models to reveal previously unknown linkages between the biodiversity components and abiotic, biotic and disturbance variables have yielded novel biological insights and thus now prompt many ecological questions for future studies.

4.1 Drivers and responses of biodiversity components

Inclusion of URP in the best biodiversity GAMs suggest a strong influence of the downstream/upstream gradient in shaping spatial distributions of all aspects of biodiversity in the Sundarbans. Alpha diversity, SC contribution to the overall diversity of the ecosystem (gamma) and heterogeneity of the communities (beta) increased along the downstream/upstream gradient (URP > 65%), suggesting downstream and intermediate-stream areas are no more suitable for many salt-intolerant species (e.g. *H. fomes*) that were abundant in the past (Gopal & Chauhan, 2006) while the late successional upstream areas are the most suitable habitats for widespread coexistence of salt-intolerant, salt-tolerant and many rare species, corroborating the previous findings of Sarker et al. 2016.

Inclusion of CS in all the best GAMs demonstrates the importance of including at least proxies of biotic variables in habitat-based biodiversity models. Increasing CS significantly contributed to decreasing SC alpha and gamma diversity, and increasing homogeneity in species composition (beta), providing a strong signal for biotic filtering in harsh estuarine settings. From the response plots (Figures 2, S2 & S3), it appears that this pattern arises when SCs have > 450 trees. These SCs are, indeed, distributed in the north-western and south-western hypersaline habitats and Sarker et al. (2016) reported super dominance of small-diameter and early-successional generalists (*E. agallocha* and *C. decandra*) there. On the other extreme, northern hyposaline mangrove communities which are dominated by large-diameter, late-successional specialists (e.g. *H. fomes* and *X. mekongensis*) are usually less populated and support many associated rare endemics, thus are more diverse and distinct than the densely populated hypersaline communities (Fig. 3).

Our analyses uncovered a strong impact of HH and DP in shaping current distributions of the biodiversity components in the Sundarbans, implying the importance of integrating past disturbance events in habitat-based models for more accurate predictions. We detect a significant negative effect of HH on alpha and gamma diversities, although DP has no visible

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effect. This discrepancy may be related to local extinction of many rare endemics during past formal and informal logging activities and high DP (top-dying and heart rot diseases) in the specialists (i.e. *H. fomes* and *X. mekongensis*) (Banerjee et al., 2017) that might not lead to their extirpation but reduced their relative abundances in a higher amount compared to the generalists. However, for beta diversity, both HH and DP contributed to increasing homogeneity in species composition across the SCs (Fig. 2). This again indicates that the diseases have not infected all trees equally rather, they have only infected and removed a few specialists such as *H. fomes* (top-dying disease) and *X. mekongensis* (heart rot disease) which have resulted in increasing homogeneity in the mangrove communities. Therefore, by using the approach of Reeve et al. (2016) to look at how DP simultaneously affects alpha, beta and gamma diversity, we are now able to get indications of the pathogenicity of the disease (i.e. whether it is a generalist and infects and removes all species equally or it is specialised on specific host species). Mangrove habitats with past logging history are commonly nutrient-poor, absorb higher amounts of heavy metals, and are prone to species invasion (Ngole-Jeme et al., 2016). Harvesting- and disease-induced tree mortalities have created many large as well as small forest gaps in the Sundarbans. Intriguingly, the large diameter tree species (i.e. *H. fomes* and *X. mekongensis*) that still dominate the less saline habitats, recruit poorly in the forest gaps (Iftekhar & Islam, 2004). Instead, these forest gaps are increasingly colonized by the disturbance specialists (e.g. *C. decandra*) (Mukhopadhyay et al., 2015). Therefore, increasing colonization and dominance of disturbance specialists in the historically disturbed SCs are the possible mechanisms responsible for increasing similarity among mangrove communities. This result somewhat contrasts with the Intermediate Disturbance Hypothesis which states that diversity of coexisting species is maximum at intermediate intensities of disturbance (Connell, 1978).

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Highly silted mangrove communities in the Sundarbans are not only poor in alpha and gamma diversities but also almost similar in species composition (Fig. 2). These results are in agreement with Mitra & Zaman (2016), reporting limited growth and regeneration of many mangroves due to sediment burial of aerial roots in the Sundarbans. Sediment burial of aerial roots (inhibits root aeration) is a major reason for worldwide mangrove mortality (De Deurwaerder et al., 2016). However, at species level, sensitivity of individual species to sediment burial can vary substantially. For example, Thampanya et al. (2002), in their experimental work on Thailand mangroves, observed 100% mortality in *Avicennia officinalis*, 70% in *Rhizophora mucronata*, and 40% in *Sonneratia caseolaris* under extreme sediment accretion level (32 cm). The Sundarbans is an active delta where the river network annually transports about 2.4 billion tons of sediments (Mitra & Zaman, 2016). Therefore, future research is required to understand species-specific sensitivities and adaptations (e.g. modified rooting architecture) to siltation because this will help to forecast which species may colonize the newly formed islands, and which are compatible for replanting in future siltation scenarios.

Although in their pioneering work, Ellison et al. (2000) found no evidence for 'zonation' in the Sundarbans, we detect a clear pattern of increasing alpha and gamma diversities along the riverbank/forest interior gradient. Communities that are at least 1500 m away from the riverbank have higher alpha diversity and 800 m away have higher gamma diversity compared to the near-bank communities (Fig. 2), implying late successional forest interior communities are more diverse than the early successional riverbank communities.

Salinity has been considered a key constraint limiting species richness in coastal ecosystems (Feller et al., 2010). It appears from our analyses that salinity has no effect on species richness although the importance of salinity slightly increased for Shannon entropy and Simpson concentration, implying the role of salinity becomes clearer when we account for between-species variability in relative abundance. Considering beta diversity, increasing salinity contributes to increasing compositional heterogeneity among the SCs (Fig. 2). This pattern suggests high plot-to-plot variation in composition in the degraded saline soils for population declines and range contraction of many salt-intolerant specialists (e.g. *H. fomes*) and increasing colonization success of the salt-tolerant generalists such as *E. agallocha* and *C. decandra* (Iftekhar & Saenger, 2008; Aziz & Paul, 2015; Mukhopadhyay et al., 2015).

Nitrogen (N), phosphorus (P), and potassium (K) were found to be the important soil nutrients limiting mangrove forest structure in coastal areas in Brazil, Florida, and South Africa (Lovelock et al., 2006; Naidoo, 2009; Da Cruz et al., 2013). Interestingly, these resource variables received less support in our biodiversity models, reconfirming the high importance of regulators and historical disturbances in structuring mangrove communities (Twilley & Rivera-Monroy, 2005).

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4.2 Mangrove biodiversity maps

Our biodiversity maps for the Sundarbans (Fig. 3) reveal that currently the most species-rich (${}^{0}\overline{\alpha}$) mangrove communities are confined to the northern (specifically, Kalabogi) and eastern (specifically, Sarankhola) regions. Due to the proximity of Baleshwar and Posur rivers, these areas receive greater amount of freshwater than the rest of the ecosystem, thus securing suitable conditions for many salt-intolerant and rare plant species. The remaining ecosystem is relatively species-poor. ${}^{1}\overline{\alpha}$ (Shannon entropy) and ${}^{2}\overline{\alpha}$ (Simpson's concentration index) maps not only show similar patterns but also pinpoint the areas – the north-western and south-western Sundarbans – where the super-dominance of generalists has resulted in lower alpha diversity. These areas are prone to regular saltwater flooding and high salinity fluctuation which together were found to inhibit regeneration and growth of many species (Ghosh et al., 2016). Spatial variability in beta diversity becomes clearer when more weight was put on the dominant species (${}^{1}\overline{\rho}$, ${}^{2}\overline{\rho}$), compared to the rare species (${}^{0}\overline{\rho}$). In general, the most heterogenous communities and the communities that contribute most to the overall biodiversity of the whole ecosystem (${}^{0}\gamma$, ${}^{1}\gamma$, ${}^{2}\gamma$), are currently restricted to the northern upstream habitats supporting tree species facing the risk of local (*X. mekongensis*) and global (*H. fomes*) extinction (Sarker et al., 2016).

Restricted distributions of diverse and distinct mangrove communities in a few specific areas clearly indicate for historical pressures on Sundarbans's floral composition, as reported by many (Gopal & Chauhan, 2006; Aziz & Paul, 2015; Ghosh et al., 2016). The freshwater supply from the transboundary rivers into the Sundarbans has substantially declined (3700 m^3/s to 364 m^3/s) since the construction of the Farakka dam (1974) in India (Mirza, 1998). The average soil salinity has already increased by 60% since 1980 (Aziz & Paul, 2015). Illegal harvesting of trees and heavy siltation in the internal channels are ongoing (Rahaman et al., 2015). Therefore, our findings lead us to conclude that additional harvesting, siltation, cuts in freshwater supply and range expansions of the generalists under projected SLR (Karim & Mimura, 2008) may convert the whole Sundarbans into a species-poor homogeneous ecosystem.

The existing approaches for biodiversity mapping without including environmental data [i.e. (i) predicting diversity from stacked species distribution layers, and (ii) estimating a diversity index in few sites and then predicting these estimated values for an entire study area using

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geostatistical interpolation methods] are shown to produce inaccurate spatial predictions of diversity indices (Granger et al., 2015). In this study, in general, the environmental data-driven GAMs showed better predictive ability than the covariate-free direct interpolation method (Table 2), thus, supporting the inclusion of fine-scale environmental, biotic and historical disturbance data for more accurate mapping of biodiversity indices when these data are available. However, similar performances of these approaches in predicting $^{2}\overline{\rho}$, and small differences in prediction error for $^{0}\overline{\alpha}$ (species richness) and $^{0}\gamma$, indicates the utility of direct interpolation methods when environmental data are not available.

4.3 Conservation applications

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Sea level rise is likely to have drastic impacts on riverine and sea-dominated mangrove forests worldwide, particularly, the Sundarbans. Under the projected SLR range by 2100 (30 – 100 cm) which is significantly higher than the global range (26 – 59 cm) (Karim & Mimura, 2008), the Sundarbans is likely to lose 10 – 23% of its present area (Payo et al., 2016) with alteration to soil biogeochemistry (Banerjee et al., 2017) and estuarine hydrology (Wahid et al., 2007). Given the severity of these future environmental impacts on Sundarbans, identifying the existing and future environmental stressors of mangrove biodiversity is important. We detect siltation, soil salinity and pH as the dominant environmental stressors responsible for decreasing mangrove diversity (Table 1, Fig. 2 & Appendix S3). These novel habitat insights and our biodiversity maps have valuable applications in designing and implementing climate-smart mangrove enhancement (reducing abiotic stresses that caused biodiversity loss), restoration (restoring specific areas where certain mangrove species/distinct assemblages previously existed) and reforestation initiatives in the Sundarbans. Previous studies (McKee & Faulkner, 2000; Lewis, 2005; Kodikara et al., 2017) show that considerable uncertainty remains in rebuilding the degraded mangrove habitats to their previous state. However, our results about the key stressors and their spatial distributions can help the forest managers about deciding which mangrove communities or which stressors to target for future reforestation and rehabilitation initiatives.

Our biodiversity maps (Fig. 3) reveal that the established protected area network (PAN), covering 1397 km^2, does not include the biodiversity hotspots. Having restricted distributions in the northern and eastern regions, these hotspots support the remaining populations of many globally endangered tree species (Sarker et al., 2016). These biodiversity hotspots are very close to local communities and vulnerable to opportunistic tree harvesting (Iftekhar & Islam, 2004), so we suggest bringing them under protected area management for their immediate protection and long-term conservation of the threatened species living there.

Our results have important implications for devising nutrient enrichment programs in coastal ecosystems. The negative response of alpha diversity to increasing soil P and K concentrations suggest that the mangroves of the Sundarbans may suffer from nutrient toxicity in highly silted hypersaline habitats. Previous nutrient enrichment programs in many coastal regions resulted in widespread mortality of many plant species (Lovelock et al., 2009). Therefore, we suggest for taking extreme cautions while implementing nutrient enrichment programs in the Sundarbans and elsewhere. Further, we advocate for experimental and field-based studies that explicitly investigate the responses of individual mangrove species to nutrients under different environmental settings.

Bangladesh, a signatory of the major conservation related conventions (e.g. World Heritage Convention, Ramsar Convention, Convention on Biological Diversity), have recently developed the 'Biodiversity National Assessment and Program of Action 2020' to assess and monitor its forest resources and to enforce appropriate actions to reduce further exploitation of these resources. Bangladesh has also formulated National Conservation Strategy (2016-2031) to foster development through the conservation and enhancement of natural resources within the framework of sustainable development, particularly as envisioned under the Sustainable Development Goals (SDG) (MoEF, 2016). The country has also ratified the 'Bangladesh Biodiversity Act 2017' to stop illegal trade of forest flora and fauna. It has also adopted a SMART (Spatial Monitoring and Reporting Tool) patrol management system since 2015 to expand the scope of its current mangrove protection efforts. Our baseline biodiversity maps can guide these valuable conservation, biodiversity protection and monitoring initiatives. In addition, these maps can contribute to successful implementation of the REDD+ (Gardner et al., 2012) initiatives for enhancing carbon stock (through biodiversity conservation) as well as financial returns.

5. CONCLUSIONS

This study provides the first comprehensive and coherent quantification and habitat-based modelling of alpha, beta and gamma diversity in threatened mangrove communities in the

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world's largest mangrove ecosystem. We find that several environmental drivers, biotic interactions and historical events have combined effects on the biodiversity components. Specifically, historical harvesting, increasing community size, siltation, salinity intrusion, disease, soil alkalinity and nutrient toxicity are the dominant stressors responsible for reducing mangrove diversity. Although habitat-based models showed better predictive ability than the covariate-free approach, the small margin of differences between the approaches demonstrates the utility of direct interpolation approaches when environmental data are unavailable. Our baseline biodiversity maps uncover that the most diverse and distinct mangrove communities (biodiversity hotspots), comprising many globally endangered tree species, have restricted distributions in the freshwater-dominated northern and eastern regions. Although these biodiversity hotspots are susceptible to human exploitation, they are not included in the existing PAN, thus suggesting for an immediate expansion of the protected area. We believe details on the drivers and their capacity to influence mangroves' diversity and composition, and our baseline biodiversity maps, collectively, will contribute to designing and implementing climate-smart mangrove enhancement, restoration, reforestation and nutrient enrichment initiatives. In addition, our maps can guide the existing and future mangrove biodiversity protection, monitoring and REDD+ initiatives. The existing PSP network covers 83% (20 out of 24) of the true mangrove species in the Sundarbans, suggesting that future studies may need to extend their sampling efforts beyond the current PSP network. Elevation, as a proxy of hydroperiod, received the least support in our models. Given that projected SLR is likely to alter the regional hydrology with changes in soil-biogeochemistry, we suggest adding hydroperiod as a predictor in future biodiversity models when these data become available.

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DATA ACCESSIBILITY

The species abundance data used in this study were gathered from the Management Plan Division (MPD) of the Bangladesh Forest Division (BFD). We and MPD together collected the environmental data. Data were used in our analyses with permission by the responsible administrators of the MPD. Data can be accessed upon request from MPD (nirmal@bforest.gov.bd).

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Table 1. Results of GAMs for nine diversity measures. Summaries of model fit in rightmost three columns are only shown for the best model (DE = deviance explained). Numbers in the main part of the table (enclosed in box) represent the Relative Importance (RI) of each covariate. Dark-shaded cells highlight covariates that were retained in the best model for each biodiversity index. Light-shaded cells represent covariates retained in other models within the candidate set. Dashed boxes indicate no participation of that covariate in any of the candidate models. The covariate short-hands are: community size (CS), upriver position (URP), salinity, distance to riverbank (DR), historical harvesting (HH), acidity (pH), silt concentration, disease prevalence (DP), soil total phosphorus (P), soil potassium (K), elevation above average-sea level (ELE), and soil NH_4.

Diversity types		CS	URP	Salinity	DR	HH	pH	Silt	DP	P	K	ELE	NH_4	AIC cw	DE (%)	Adj-R^2
α	$^{0}\bar{\alpha}$	1	1	--	0.57	0.40	--	0.08	0.06	--	0.34	--	--	0.16	41	0.45
	$^{1}\bar{\alpha}$	1	1	0.20	1	0.82	0.80	1	--	0.80	0.80	--	--	0.42	71	0.71
	$^{2}\bar{\alpha}$	1	1	0.28	0.15	0.11	0.40	--	--	1	0.72	0.42	--	0.28	68	0.65
β	$^{0}\bar{\rho}$	0.71	0.21	1	0.58	--	--	--	0.94	0.66	0.61	--	--	0.12	51	0.51
	$^{1}\bar{\rho}$	1	1	0.86	0.25	0.93	0.47	0.35	1	0.29	--	--	--	0.22	58	0.42
	$^{2}\bar{\rho}$	1	1	0.84	0.46	1	0.84	1	0.84	0.83	0.67	--	0.46	0.37	65	0.70
γ	$^{0}\gamma$	1	1	0.36	1	0.30	0.91	0.30	1	0.10	--	0.18	0.27	0.12	75	0.86
	$^{1}\gamma$	1	1	1	1	1	1	1	0.35	0.65	--	0.65	0.65	0.65	86	0.90
	$^{2}\gamma$	1	1	0.73	1	1	--	1	--	0.72	0.72	--	--	0.28	72	0.74

Table 2. Comparison of predictive accuracy (through leave-one-out cross validation) of the habit-based (GAMs) and Kriged diversity models using normalized root mean square error (NRMSE) of the predicted versus the actual diversity values. NRMSE is expressed here as a percentage, where lower values indicate less residual variance.

Diversity types		GAMs	Kriging
		NRMSE (%)	
Alpha	${}^0\overline{\alpha}$	16.52	18.40
	${}^1\overline{\alpha}$	14.41	16.03
	${}^2\overline{\alpha}$	14.44	16.22
Beta	${}^0\overline{\rho}$	20.95	24.66
	${}^1\overline{\rho}$	19.21	21.69
	${}^2\overline{\rho}$	23.83	23.44
Gamma	${}^0\gamma$	12.99	17.05
	${}^1\gamma$	9.90	11.33
	${}^2\gamma$	10.75	13.15

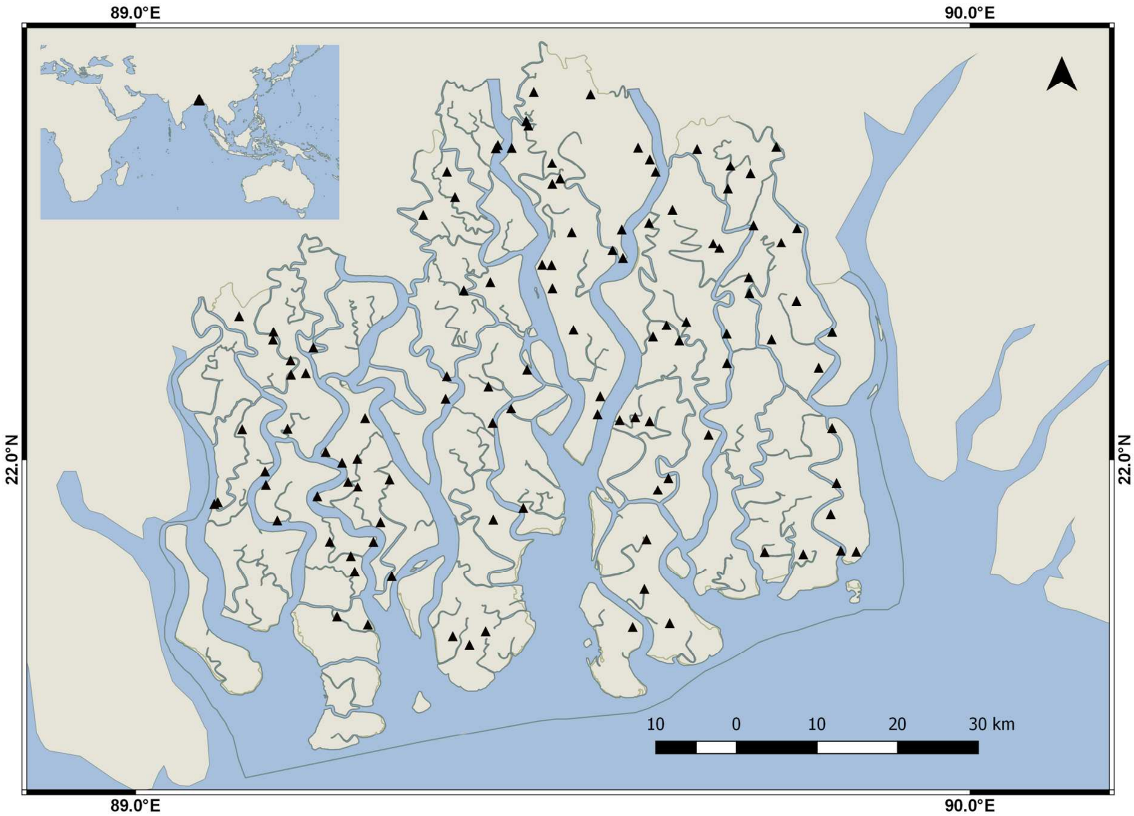

Figure 1. Sampling sites (triangles) in the Sundarbans, Bangladesh. Blue areas represent water bodies.

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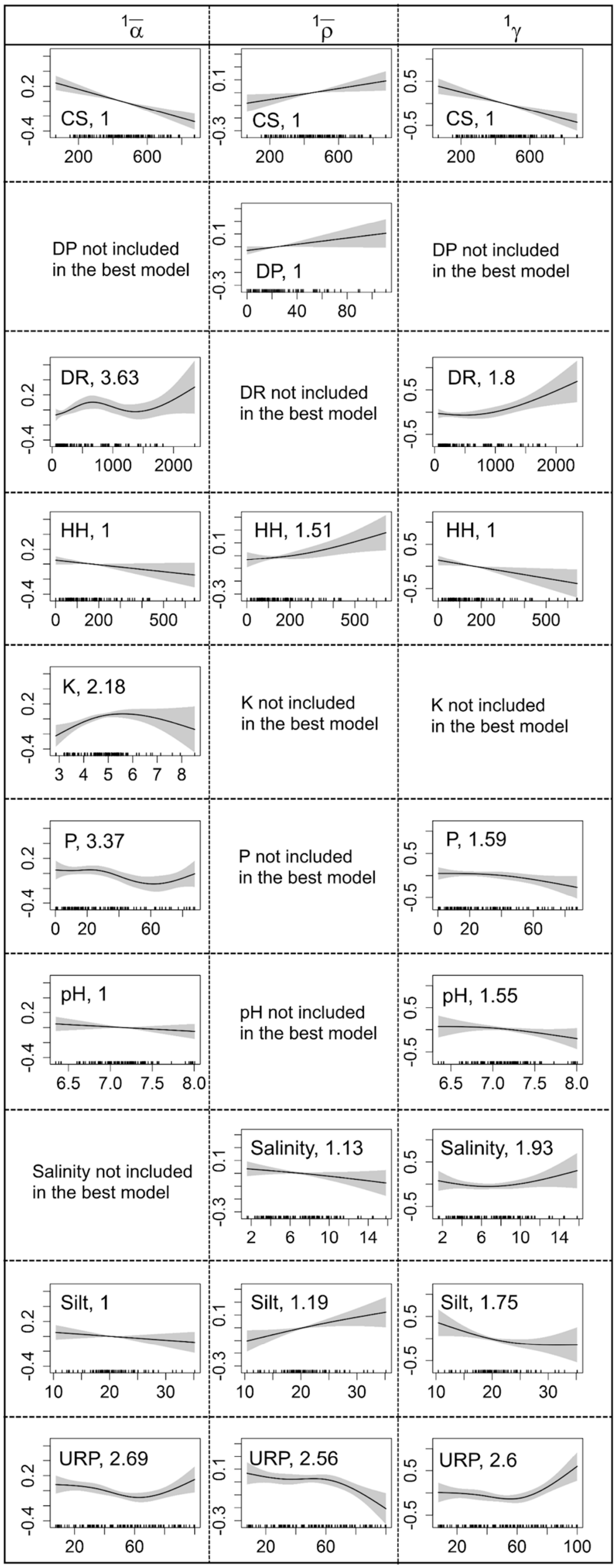
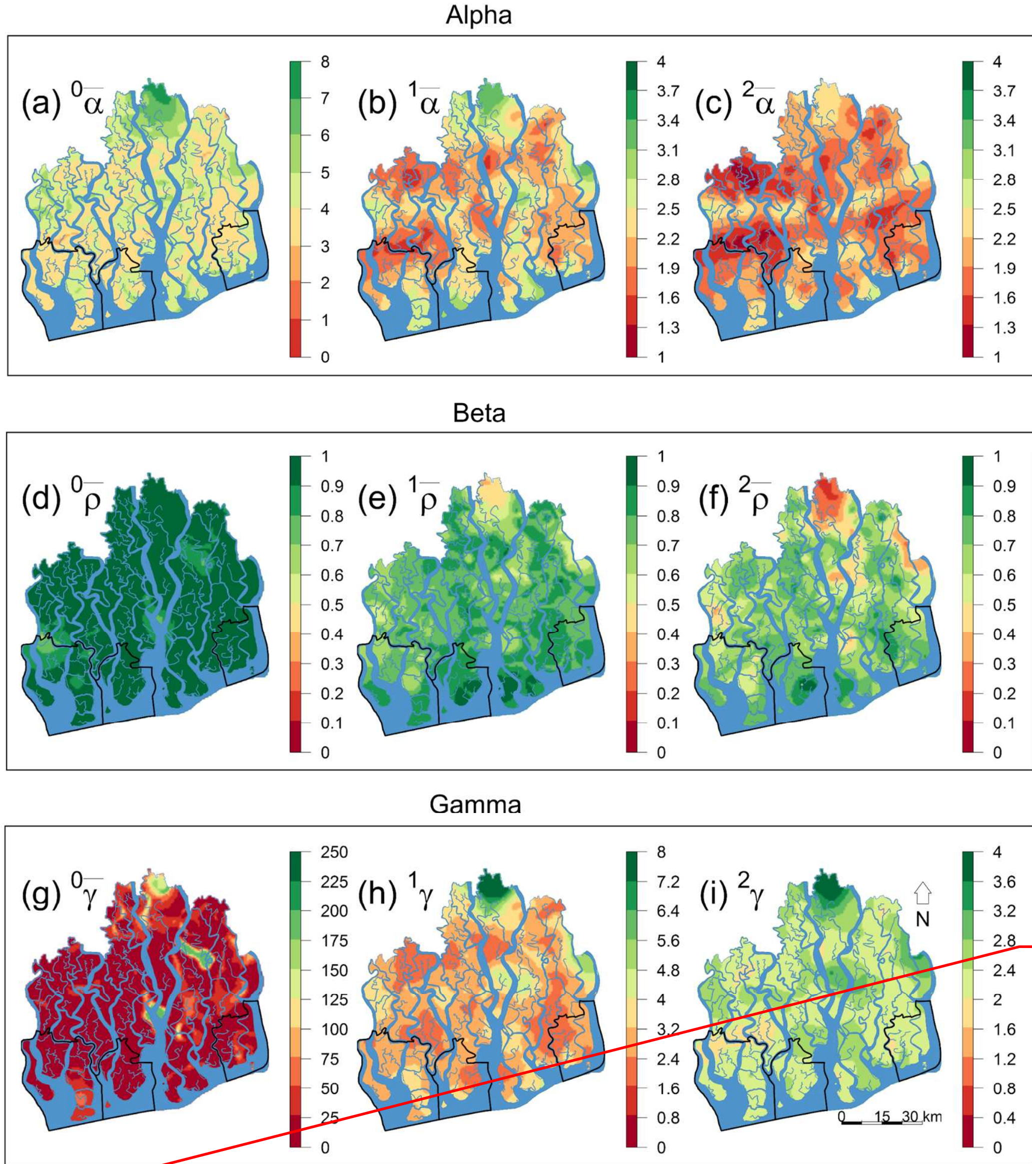


Figure 2. Effects of covariates inferred from our best GAMs fitted to the biodiversity indices for q = 1. The solid line in each plot is the estimated spline function (on the scale of the linear predictor) and shaded areas represent the 95% confidence intervals. Estimated degrees of freedom are provided for each smooth following the covariate names. Zero on the y-axis indicates no effect of the covariate on diversity index values. Covariate units: CS = total number of individuals in each plot, URP = % upriver, soil salinity = dS m^{-1}, DR = distance (m) of each PSP from the riverbank, Historical harvesting (HH) = total number of harvested trees in each plot since 1986, silt (%), disease prevalence (DP) = total number of diseased trees in each plot since 1986, P = mg Kg^{-1} and K = gm Kg^{-1}.



North arrow symbols for the map should be placed at each map

Figure 3. Spatial distributions of SC alpha, beta and gamma diversities (for q = 0 - 2) over the entire Sundarbans generated through GAMs. Higher values of $\overline{\alpha}$ and γ indicate greater species diversity and community contribution to the overall diversity of the ecosystem. Lower values of $\overline{\rho}$ indicate greater heterogeneity in species composition (i.e. community distinctness from the metacommunity) and higher values of $\overline{\rho}$ represent greater representativeness (i.e. homogeneity) in species composition. The black contours represent the three protected areas.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1

Table S1 Taxonomy, global conservation status, and mean abundances of the mangrove species censused in the 110 permanent sample plots in the Bangladesh Sundarbans. *IUCN global population trend, † Not assessed for the IUCN Red List, LC = Least concern, DD = Data deficient, NT = Near threatened, VU= Vulnerable, EN = Endangered, D = Decreasing.

Latin name	Local name	Family	IUCN conservation status	Global population trend*
Aegiceras corniculatum (L.) Blanco	Khalshi	Myrsinaceae	LC	D
Amoora cucullata Roxb.	Amur	Meliaceae	NA†	NA
Avicennia officinalis L.	Baen	Avicenniaceae	LC	D
Bruguiera sexangula (Lour.) Poiret	Kakra	Rhizophoraceae	LC	D
Cerbera manghas L.	Dagor	Apocynaceae	NA	NA
Ceriops decandra (Griffith) Ding Hou	Goran	Rhizophoraceae	NT	D
Cynometra ramiflora L.	Singra	Fabaceae	NA	NA
Excoecaria agallocha L.	Gewa	Euphorbiaceae	LC	D
Excoecaria indica (Willd.) Müll.Arg.	Batul	Euphorbiaceae	DD	D
Heritiera fomes Buch-Ham.	Sundri	Malvaceae	EN	D
Intsia bijuga (Colebr.) Kuntze	Bhaela	Leguminosae	VU	D
Lumnitzera racemosa Willd.	Kirpa	Combretaceae	LC	D
Hypobathrum racemosum (Roxb.) Kurz	Narikali	Rubiaceae	NA	NA
Pongamia pinnata (L.) Pierre	Karanja	Leguminosae	LC	Stable
Rhizophora mucronata Lam.	Jhana	Rhizophoraceae	LC	D
Sonneratia apetala Buch-Ham.	Keora	Lythraceae	LC	D
Talipariti tiliaceum (L.) Fryxell	Bhola	Malvaceae	NA	NA
Tamarix dioica Roxb.	Nona Jhao	Tamaricaceae	NA	NA
Xylocarpus granatum Koen.	Dhundal	Meliaceae	LC	D
Xylocarpus mekongensis Pierre	Passur	Meliaceae	LC	D

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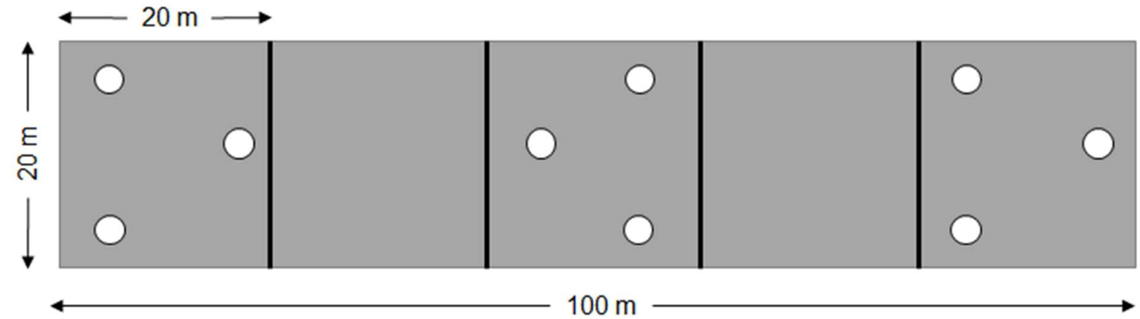

Fig. S1 Soil sampling design. Total 9 soil samples (circles, 0 – 30 cm depth) were randomly (3 samples/subplot) collected in the ends and middle of the 20 x 20 subplots in each PSP**.**

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Appendix S2

Table S2.1 Correlation (expressed as Pearson correlation coefficients) between the covariates.

	HH	DR	Elevation	K	DP	NH_4	P	pH	Salinity	Silt	CS	URP
DR	0.02											
Elevation	-0.07	0.09										
K	0.13	0.10	0.25									
DP	-0.18	0.02	0.16	0.11								
NH_4	0.3	-0.09	0.02	0.18	-0.06							
P	-0.18	-0.19	-0.05	-0.37	-0.02	-0.12						
pH	-0.01	0.00	-0.02	-0.13	-0.05	-0.18	-0.08					
Salinity	-0.22	-0.16	-0.02	-0.16	0.12	-0.29	0.28	-0.03				
Silt	0.09	0.09	0.11	0.11	0.04	0.01	0.02	0.06	-0.05			
CS	-0.16	-0.10	0.09	0.25	0.16	-0.04	-0.02	0.04	0.12	0.08		
URP	0.49	0.15	0.00	0.16	-0.22	0.15	-0.15	-0.15	-0.14	-0.03	-0.35	
ORP	0.06	0.04	0.01	0.20	-0.03	0.25	0.02	-0.89	-0.09	0.03	0.00	0.17

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Table S2.2 Stepwise VIF test outputs of the environmental covariates. The covariate short-hands are: community size (CS), upriver position (URP), salinity, distance to riverbank (DR), historical harvesting (HH), acidity (pH), silt concentration, disease prevalence (DP), soil total phosphorus (P), soil potassium (K), elevation above average-sea level (ELE), and soil NH4.

Covariates	VIF
CS	1.33
URP	1.65
Salinity	1.29
DR	1.13
HH	1.50
pH	2.43
Silt	1.09
DP	1.14
P	1.32
K	1.5
Elevation	1.12
NH_4	1.27
ORP	5.58

Appendix S3

Table S3 Results of GAMs for nine diversity measures. Summaries of model fit in rightmost three columns are only shown for the confidence set models i.e. models with $\Delta AIC_c \leq 2$. + symbol indicates that the covariates were retained and – symbol indicates that the covariates were not retained in the confidence set models for each biodiversity index. The covariate short-hands are: community size (CS), upriver position (URP), salinity, distance to riverbank (DR), historical harvesting (HH), acidity (pH), silt concentration, disease prevalence (DP), soil total phosphorus (P), soil potassium (K), elevation above average-sea level (ELE), and soil NH_4.

Diversity types		CS	URP	Salinity	DR	HH	pH	Silt	DP	P	K	ELE	NH_4	AIC_c	ΔAICc	AICcw
		+	+	--	+	--	--	--	--	--	--	--	--	362.58	0.00	0.16
		+	+	--	--	--	--	--	--	--	--	--	--	362.92	0.34	0.14
		+	+	--	+	+	--	--	--	--	--	--	--	363.25	0.67	0.12
		+	+	--	--	+	--	--	--	--	--	--	--	363.29	0.72	0.11
		+	+	--	--	+	--	--	--	--	+	--	--	363.64	1.07	0.09
Alpha	$^0\overline{\alpha}$	+	+	--	--	--	--	--	--	--	+	--	--	363.83	1.26	0.09
		+	+	--	+	--	--	--	--	--	+	--	--	363.96	1.39	0.08
		+	+	--	+	--	--	+	--	--	--	--	--	364.10	1.53	0.08
		+	+	--	+	+	--	--	--	--	+	--	--	364.14	1.56	0.07
		+	+	--	+	--	--	--	+	--	--	--	--	364.51	1.93	0.06
		+	+	--	+	+	+	+	--	+	+	--	--	118.89	0.00	0.42
	$^1\overline{\alpha}$	+	+	+	+	+	+	+	--	--	--	--	--	120.35	1.46	0.20
		+	+	--	+	+	--	+	--	+	+	--	--	120.42	1.53	0.20
		+	+	--	+	--	+	+	--	+	+	--	--	120.60	1.70	0.18
		+	+	+	--	--	+	--	--	+	--	+	--	96.88	0.00	0.28
		+	+	--	--	--	--	--	--	+	+	--	--	97.57	0.69	0.20
	$^2\overline{\alpha}$	+	+	--	+	--	--	--	--	+	+	--	--	98.18	1.30	0.15
		+	+	--	--	--	--	--	--	+	+	+	--	98.34	1.46	0.14
		+	+	--	--	--	+	--	--	+	+	--	--	98.59	1.71	0.12
		+	+	--	--	+	--	--	--	+	+	--	--	98.72	1.83	0.11
		+	--	+	+	--	--	--	+	--	+	--	--	-247.97	0.00	0.12
		--	+	+	+	--	--	--	+	+	--	--	--	-247.79	0.17	0.11
		+	--	+	--	--	--	--	+	--	+	--	--	-247.53	0.43	0.09
		+	--	+	--	--	--	--	+	+	--	--	--	-247.50	0.46	0.09
Beta	$^0\overline{\rho}$	+	--	+	+	--	--	--	+	+	--	--	--	-247.44	0.53	0.09
		+	--	+	+	--	--	--	+	+	+	--	--	-247.26	0.71	0.08
		--	--	+	--	--	--	--	+	--	+	--	--	-247.06	0.91	0.07
		+	--	+	--	--	--	--	+	+	+	--	--	-246.99	0.98	0.07
		+	--	+	+	--	--	--	--	+	+	--	--	-246.73	1.23	0.06
		+	--	+	+	--	--	--	+	--	--	--	--	-246.73	1.24	0.06
		--	+	+	+	--	--	--	+	+	+	--	--	-246.61	1.36	0.06
		--	--	+	--	--	--	--	+	+	+	--	--	-246.29	1.67	0.05
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		+	+	+	--	+	+	--	+	--	--	--	--	-105.60	0.21	0.14
		+	+	+	+	+	+	--	+	+	--	--	--	-105.56	0.25	0.13
		+	+	+	+	+	+	--	+	--	--	--	--	-105.31	0.51	0.12
		+	+	+	--	+	--	--	+	--	--	--	--	-104.99	0.83	0.10
	$^1\overline{\rho}$	+	+	+	--	+	+	--	+	+	--	--	--	-104.66	1.16	0.08
		+	+	--	--	+	--	--	+	--	--	--	--	-104.50	1.32	0.08
		+	+	+	--	--	--	+	+	--	--	--	--	-104.21	1.60	0.07
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		+	+	+	--	+	+	+	+	+	+	+	--	-61.93	0.00	0.37
		+	+	+	+	+	+	+	+	+	+	--	+	-61.55	0.39	0.30
	$^2\overline{\rho}$	+	+	+	--	+	+	+	+	--	--	--	--	-60.37	1.56	0.17
		+	+	--	+	+	--	+	--	+	--	--	+	-60.20	1.73	0.16

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Gamma	$^{0}\gamma$	+	+	--	+	--	+	--	+	--	--	--	--	786.94	0.00	0.12
		+	+	--	+	--	+	--	+	--	--	--	+	787.16	0.22	0.11
		+	+	--	+	--	--	--	+	--	--	--	+	787.53	0.59	0.09
		+	+	--	+	--	+	--	+	--	--	+	--	787.54	0.60	0.09
		+	+	+	+	+	+	--	+	--	--	--	--	787.99	1.06	0.07
		+	+	--	+	--	+	+	+	--	--	--	--	788.01	1.08	0.07
		+	+	+	+	+	+	+	+	--	--	--	+	788.09	1.15	0.07
		+	+	+	+	--	+	--	+	--	--	--	--	788.15	1.22	0.07
		+	+	--	+	+	+	--	+	--	--	--	--	788.20	1.26	0.06
		+	+	+	+	--	+	+	+	--	--	--	--	788.24	1.30	0.06
		+	+	--	+	--	+	+	+	+	--	--	--	788.73	1.79	0.05
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		+	+	+	+	--	+	+	+	+	--	--	--	788.78	1.85	0.05
		+	+	--	+	+	+	--	+	--	--	+	--	788.92	1.99	0.04
	$^{1}\gamma$	+	+	+	+	+	+	+	--	+	--	+	+	279.25	0.00	0.65
		+	+	+	+	+	+	+	+	--	--	--	--	280.51	1.26	0.35
	$^{2}\gamma$	+	+	+	+	+	+	+	--	--	--	--	--	98.50	0.00	0.28
		+	+	--	+	+	--	+	--	+	+	--	--	98.58	0.08	0.27
		+	+	+	+	+	+	+	--	+	+	--	--	98.90	0.40	0.23
		+	+	+	+	+	--	+	--	+	+	--	--	99.05	0.55	0.21

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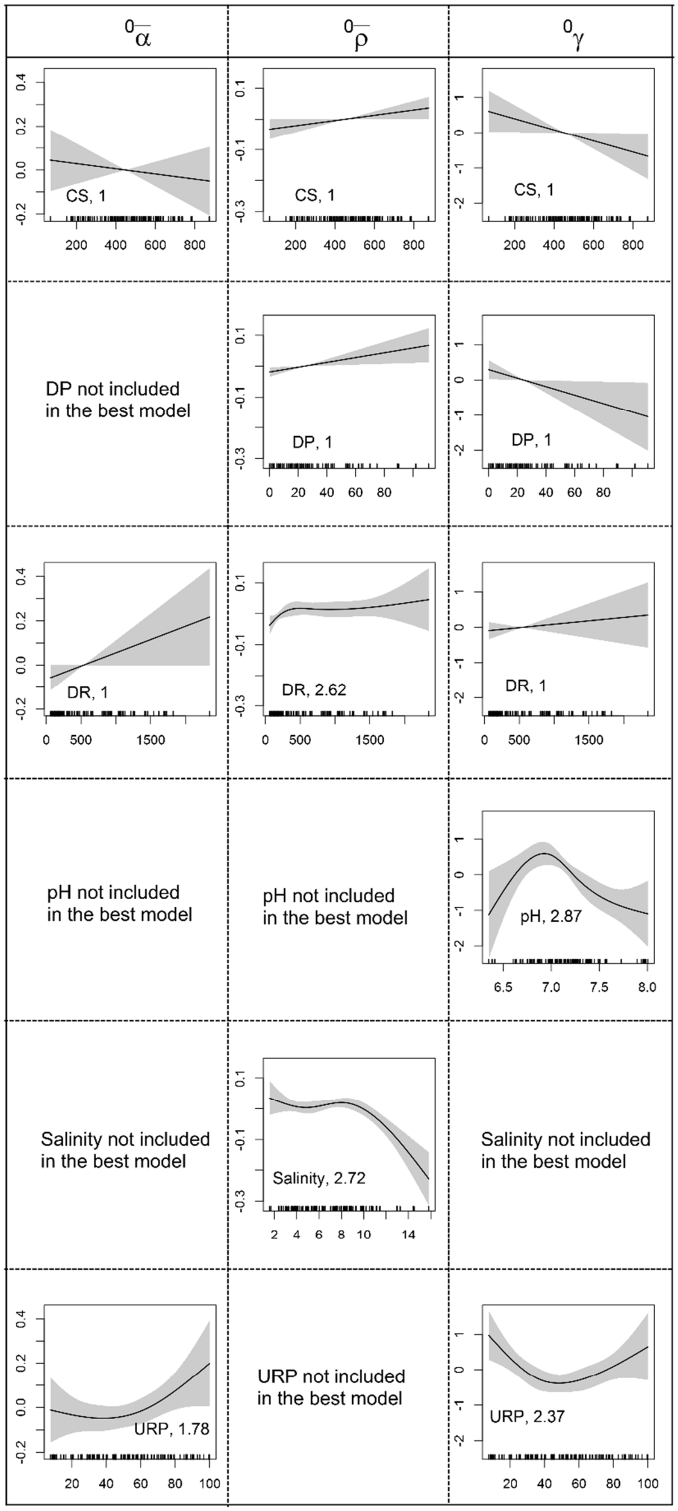

Fig. S3.1 Effects of covariates inferred from our best GAMs fitted to the biodiversity measures for $q = 0$.

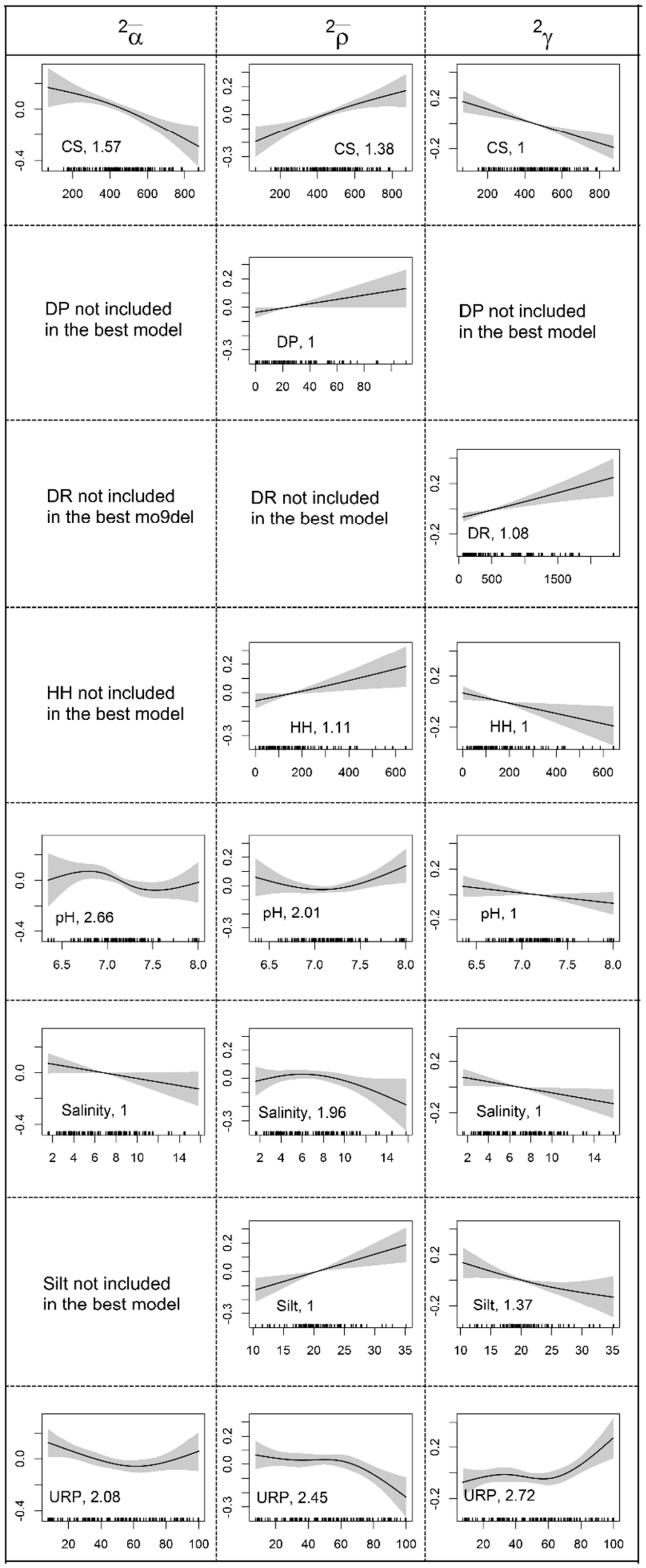

Fig. S3.2 Effects of covariates inferred from our best GAMs fitted to the biodiversity measures for $q = 2$.

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Nypa fruticans Wurmb leaf collection as a livelihoods strategy: a case study in the Sundarbans Impact Zone of Bangladesh

Md. Nazrul Islam, Nabila Hasan Dana, Khandkar-Siddikur Rahman, Md. Tanvir Hossain, Moin Uddin Ahmed & Abdulla Sadiq

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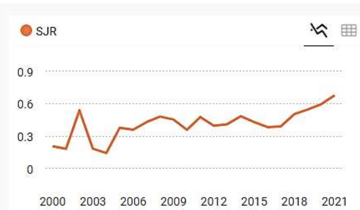

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Abdul Malik

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Abdul Malik, Ph.D.
Dept. of Geosciences & Natural Resource Management
University of Copenhagen
Øster Voldgade 10, 1350 København K

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Dear Dr. Malik,

In view of your expertise I would be very grateful if you could review the following manuscript which has been submitted to Environment, Development and Sustainability.

Manuscript Number: ENVI-D-18-00706

Title: Nypa fruticans Leaf Collection as a Livelihood Strategy: A Case Study in the Sundarbans Impact Zone of Bangladesh

Abstract: The Nypa fruticans Wurmb. (Nypa), a true mangrove palm, is abundant in the Sundarbans reserved forest of Bangladesh. Leaves are the primary product obtained from the Nypa palm and used them as thatching materials and they are the income source for forest resource dependent communities in the Sundarbans Impact Zone (SIZ) of southern coastal communities in Bangladesh. This study was aiming at assessing the usefulness of Nypa leaf (Nypa fruticans Wurmb.) collection as a livelihood strategy in the Sundarbans Impact Zone (SIZ) of Bangladesh. A total of 90 Nypa leaf collectors from three coastal unions were interviewed by administering a semi-structured interview schedule. Effects of social and economic factors on the household (HH) total income of the Nypa palm leaf collectors were analysed using linear regression and Pearson correlation, respectively. Moreover, the effect of physical factors on the HH total income was analysed by ANOVA and linear regression. Results
suggest that income from Nypa leaf collection, though making only a quarter percent of household total income, constrained by underdeveloped infrastructure, inaccessibility to fair market price, limitations of financial capital and frequent attack of royal Bengal tiger (Panthera tigris tigris). The study, therefore, suggest that Nypa leaf collection could not be a sustainable livelihood strategy for the forest dependent communities in the SIZ of Bangladesh, instead by promoting diversified husbandry activities which would reduce further dependency on forests and ultimately conserve the resources of the Sundarbans.

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ENVI-D-18-00706
"Nypa fruticans Leaf Collection as a Livelihood Strategy: A Case Study in the Sundarbans Impact Zone of Bangladesh"
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Editor in Chief
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Nypa fruticans Leaf Collection as a Livelihood Strategy: A Case Study in the Sundarbans Impact Zone of Bangladesh

Original Submission
Abdul Malik Reviewer 1

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Recommendation: Major revisions

Reviewer Blind Comments to Author:

The authors report the usefulness of Nypa leaf (Nypa fruticans Wurmb.) collection as a livelihood strategy in the Sundarbans Impact Zone (SIZ) of Bangladesh.
The review in the introduction is sufficiently insightful and gives a good justification for such a study. The hypothesis and method applied appears sound and the manuscript clearly describes the findings. However the discussion which is an important contribution to a sustainable livelihood strategy of Nypa palm collectors, and conclusion include the recommendations need to improve and revise. In addition, relating to the presentation of paper, the keywords are very general or not informative; there are several sentences in manuscript text should be in the right part; and the part of reference should be only listed the paper cited in the text.
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Dear Editor of Environment, Development and Sustainability.

The authors report the usefulness of Nypa leaf (Nypa fruticans Wurmb.) collection as a livelihood strategy in the Sundarbans Impact Zone (SIZ) of Bangladesh.
The review in the introduction is sufficiently insightful and gives a good justification for such a study. The hypothesis and method applied appears sound and the manuscript clearly describes the findings. However the discussion which is an important contribution to a sustainable livelihood strategy of Nypa palm collectors, and conclusion include the recommendations need to improve and revise. In addition, relating to the presentation of paper, the keywords are very general or not informative; there are several sentences in manuscript text should be in the right part; and the part of reference should be only listed the paper cited in the text. Please see a short list of the specific comments on a line by line in the manuscript attached file to complete the general comments and suggestions. It assists the authors in revising the manuscript.

Based on the comments and suggestions. To improve the quality of the paper, I recommend the authors to make a major revision to the manuscript.

Sincerely yours,

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Nypa fruticans Leaf Collection as a Livelihood Strategy: A Case Study in the Sundarbans Impact Zone of Bangladesh

Abstract

The *Nypa fruticans* Wurmb. (*Nypa*), a true mangrove palm, is abundant in the Sundarbans reserved forest of Bangladesh. Leaves are the primary product obtained from the *Nypa* palm and used them as thatching materials and they are the income source for forest resource dependent communities in the Sundarbans Impact Zone (SIZ) of southern coastal communities in Bangladesh. This study was aiming at assessing the usefulness of *Nypa* leaf (*Nypa fruticans* Wurmb.) collection as a livelihood strategy in the Sundarbans Impact Zone (SIZ) of Bangladesh. A total of 90 *Nypa* leaf collectors from three coastal unions were interviewed by administering a semi-structured interview schedule. Effects of social and economic factors on the household (HH) total income of the *Nypa* palm leaf collectors were analysed using linear regression and Pearson correlation, respectively. Moreover, the effect of physical factors on the HH total income was analysed by ANOVA and linear regression. Results suggest that income from *Nypa* leaf collection, though making only a quarter percent of household total income, constrained by underdeveloped infrastructure, inaccessibility to fair market price, limitations of financial capital and frequent attack of royal Bengal tiger (*Panthera tigris tigris*). The study, therefore, suggest that *Nypa* leaf collection could not be a sustainable livelihood strategy for the forest dependent communities in the SIZ of Bangladesh, instead by promoting diversified husbandry activities which would reduce further dependency on forests and ultimately conserve the resources of the Sundarbans.

Keywords: Household, socioeconomic factors, physical factors, income generating activities, market accessibility

Introduction

Since the beginning of human history, non-timber forest products (NTFPs) collection remains the center of interest to the forest dependent communities in the tropics for subsistence and income generation. Around 350 million people directly and another one billion indirectly depend on the forest resources across the world (Belcher et al. 2005). However, income obtained from the NTFPs ranges from 15 to 39% of the total household (HH) income (Meilby et al. 2014). Yet, NTFPs collection, a traditional practice, contributes to poverty alleviation by improving the rural livelihood strategies and facilitates the conservation of the natural resources by prohibiting deforestation and forest degradation (Soriano et al. 2017). Poor rural households are highly dependent on the forest products compared to the households with more assets (Meilby et al. 2014). In the last two decades, NTFPs collection has been highlighted as the rural development and livelihood strategy (Belcher et al. 2005). Like the other NTFPs collection, leaf collection from the *Nypa* palm is also considered as a livelihood strategy in the Sundarbans Impact Zone (SIZ) of Bangladesh.

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The keywords of abstract is very general and not represent of the manuscript. By using these keywords, the readers will difficult to find it using search engine. Please be specific such as: Nypa fruticant, mangrove palm, livelihood strategy, Sundarbans Impact Zone, Bangladesh.

The Sundarbans mangrove forest is one of the largest habitats of the monoecious palm *Nypa fruticans* Wurmb. in Bangladesh. This native species is also categorized as true mangrove palm (Hossain and Islam 2015). Like the other palm species, the *Nypa* palm does not have above ground stem (Päivöke 1985; Carandang et al. 2009; Hossain and Islam 2015). In addition, leaves of *Nypa* palm appear from the ground level and having height around 10m that form the crown (Hossain and Islam 2015). *Nypa* palm provides numerous ecosystem services to coastal ecosystem as well as to the inhabitants – dependent on forest resources. Accordingly, along with the regulating, supporting and cultural services, it provides provisioning services, including leave as thatching materials, fruit as food, new shoots as a source of medicine etc. (Miah et al. 2003). Among these, leaves are the primary product collected from the *Nypa* palm by the collectors in Bangladesh (Miah et al. 2003; Jahan et al. 2006; Tamunaidu and Saka 2011; Hossain and Islam 2015). The *Nypa* palm leaf collectors gather the leaves from the Sundarbans mangrove forest during October to March of each year (Forest Department 2010), and on an average, 60,000 metric tons of *Nypa* leaves are collected each season (Jahan et al. 2006). These leaves are used for the construction of rural housing in the coastal regions of Bangladesh (Miah et al. 2003; Jahan et al. 2006; Tamunaidu and Saka 2011; Hossain and Islam 2015) and are known as poor man's tin-sheet (Miah et al. 2003). Consequently, the leaves of *Nypa* palm are socioeconomically important for the coastal forest dependent communities of Bangladesh (Aziz and Paul 2015).

Many researchers have studied the socioeconomic (Nygren and Myatt-Hirvonen 2009; Zohora 2011; Stanley et al. 2012, Quaedvlieg et al. 2014; Soriano et al. 2017) and physical factors (Coomes et al. 2004; Belcher et al. 2005; Zeidemann et al. 2014; Soriano et al. 2017) that determine the livelihood strategies of the NTFPs dependent rural families and/or communities. Economic benefits from the forest products and local provisions have an effect on improving the income and livelihoods of the rural families (Porter-Bolland et al. 2012). Average annual contribution of *Nypa* palm in the Bangladesh economy is about US$ 16.25 million, while it generates a staggering 3,00,000 employment opportunities for each year. It contributes in the local (southwestern region) economy, thus, to national economy of Bangladesh (Zohora 2011). However, poor access to the local markets negatively affects the price of the products and impedes the income opportunities of the leaf collectors. Eventually, their families remain trapped in the poverty cycle (Coomes et al. 2004; Belcher et al. 2005). It has been reported that the income of forest resource dependent families' increases with the increasing amount of the harvested forest products (Stanley et al. 2012). Improved road infrastructure or access to the market (Zeidemann et al. 2014) and organization (Belcher et al. 2005) also reportedly have a positive effect on the income from the forest products. Negotiation skills of the NTFPs collector further determines the price i.e., income from the forest products (Quaedvlieg et al. 2014). Undeniably, to sustain the livelihood of the forest products dependent communities, access to the resources is essential (Brown et al. 2011). An intensive literature search revealed that Zohora (2011) studied the livelihoods of *Nypa* harvesters implicitly. Because indepth information regarding the effects of socioeconomic and physical factors on the household level income of the *Nypa* leaf collectors with reference to the Sundarbans Impact Zone of Bangladesh were not explored by the researcher. This study, therefore, was aimed at assessing the usefulness of *Nypa* leaf collection as a livelihood strategy for people in SIZ of Bangladesh. In order to accomplish the objective of this research, we seek the answer of following three research questions: (i) how do the socioeconomic factors affect the

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Author: USER Subject: Note Date: 2018-10-26 13:56:29

I suggest to cite paper of Malik et al. (2017). They also studied the socioeconomic of households in South Sulawesi Indonesia and they measured number of Nypa palm collection and income of households.

Malilk et al. (2017) Mangrove forests decline: Consequences for livelihoods and environment in South Sulawesi

Author: USER Subject: Note Date: 2018-10-26 14:02:55

Did you mean 3 million? if yes, please revise!

Author: USER Subject: Note Date: 2018-10-26 14:06:52

Please consistent to use the SIZ !

Author: USER Subject: Note Date: 2018-10-26 14:09:14

please add "the"

HH income of *Nypa* leaf collectors? (ii) do the physical factors determine the HH income of *Nypa* leaf collectors? and (iii) what are the major challenges of *Nypa* leaf collection from the Sundarbans affecting the livelihood of *Nypa* leaf collectors in the SIZ of Bangladesh?

Methodology

Study area

This study was carried out in three southwestern coastal districts of Bangladesh, namely Bagerhat, Khulna and Satkhira. These areas are identified as ecologically critical area and are situated within the Sundarbans Impact Zone (Fig. 1) (Aziz and Paul 2015). From these three districts, *Chila* union under *Mongla* upazila, *Sutarkhali* union of *Dacope* upazila and *Munshiganj* union under *Shyamnagar* upazila were selected purposively, because of their closeness to the Sundarbans mangrove forest (Forest Department, 2010). The unions are situated at north side of the Sundarbans mangrove forest and are relatively flat. The coastal areas are situated 0.8 to 4m above mean sea level. The areas experience sub-tropical climate with identical seasonal variations in rainfall, temperature and humidity. Consequently, the annual rainfall in the area ranges from 1,230 to 2,800 mm, while average temperature remains steady between 12-37˚C. The study areas are also prone to tropical cyclones (Shameem et al. 2015). However, the inhabitants of these unions are very much dependent on the NTFPs for the subsistence and income generation (Forest Department 2010; Aziz and Paul 2015). The NTFPs collection varies with seasonal availability (Forest Department 2010; Zohora 2011), such as *Nypa* palm leaves are available during the period from October to March of each year (Forest Department 2010).

Sampling, data collection and analysis

To achieve the research objectives, the participants – the *Nypa* leaf collectors – were identified and interviewed in a long and excruciating process. The inventory of *Nypa* leaf collectors from three unions were developed with the help of local community leaders. Afterwards, a total of 90 *Nypa* leaf collectors (30 each from three unions) were interviewed following cluster random sampling. All the interviewees were male because it is evident that no females were involved in leaf collection from the Sundarbans. It is noteworthy that the informants were actual *Nypa* leaf collectors involved in the collection of *Nypa* palm leaves from SIZ for generations. These people also perform husbandry activities for household income and almost all of them were household head (97%).

By administering a semi-structured interview schedule – containing both open and close-ended questions on socioeconomic conditions and physical factors – the *Nypa* leaf collectors were interviewed by a group of well-trained undergraduate students. The interviewers were trained extensively by the first author, through classroom lectures and role playing, about the research objectives as well as the content of the interview schedule to maintain the uniformity of the survey as well as to keep anonymity of the interviewees. The interviews, conversed in *Bengali* and later converted into English for input, lasted for

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Author: USER Subject: Note Date: 2018-10-26 14:12:15
Please consistent to use the SIZ !

Author: USER Subject: Note Date: 2018-11-10 05:05:57
What is the extent and abundance of Nypa palm area in the SIZ? if possible please provide it for the study area part.

Author: USER Subject: Note Date: 2018-11-10 05:07:24
Why did you divide 30 samples each from three unions of the total 90? is it really representative sample number of 3 unions?

Author: USER Subject: Note Date: 2018-11-10 05:08:09
What about the off-farm activities?
What does activities include the income from husbandry and off-farm income? I suggest to put here to understand the issue from the first

Author: USER Subject: Note Date: 2018-10-26 14:19:20
Please add "the"

half an hour. Considering the harvesting period, the fieldwork took three months to complete, from December 2016 to February 2017 that is the pick harvesting period.

Both quantitative and qualitative data were collected through the interview schedule. The data involves the social factors (age, education level, HH members involved in income generation), economic factors (income from Nypa leaf collection, income from husbandry, off-farm income), physical factors (unions, distance of HH from nearby market, road networks), primary and secondary occupation, frequency of trip to Sundarbans per year, stay in forest per trip, leaves harvested per day, off-farm activities. Moreover, challenges of harvesting Nypa leaves from the Sundarbans were noted. The monetary values were converted from BDT to USD. Total HH income (per month) was estimated by summing up the income from Nypa leaf collection, income from husbandry and off-farm income.

Statistical analysis

Statistical analysis of the data was carried out by using MS office excel (version 2016), statistical package for social science (version 16) and ATLAS.ti (version 8) software system. In order to answer the first research question, i.e. to observe the effect of social factors on HH total income, a linear regression with enter option was carried out as the unstandardized residuals followed the normal distribution. In this case, age, education level and number of HH members involved in income generating activities (IGAs) were independent variables and HH total income was dependent variable. Moreover, to analyze the effect of amount of leaf harvest on the income from *Nypa* leaf collection, we conducted a linear regression with the number of leaf collection (independent variable) and income from *Nypa* leaf collection (dependent variable), because unstandardized residual followed normal distribution. Later, relationship between economic factors, including income from *Nypa* leaf collection, income from husbandry and off-farm income and HH total income, was analyzed following Pearson's correlation as the unstandardized residual followed normal distribution.

Second research question was answered by analyzing the effect of physical factors on income from *Nypa* leaf collection and HH total income. To find out the spatial difference of income from *Nypa* leaf collection as well as from husbandry and off-farm sources, we conducted the ANOVA (unstandardized residual followed normal distribution) separately between the areas and mentioned economic activities. Moreover, we repeated the similar procedure with the areas and HH total income to observe the spatial difference in HH total income as the unstandardized residual followed normal distribution. In the meantime, to assess the effect of road networks on HH total income, ANOVA with road types and HH total income was conducted, because unstandardized residual followed normal distribution. Further, effect of distance to nearby market on HH total income was analyzed by using a linear regression due to the fact that the unstandardized residual followed normal distribution. Furthermore, we analyzed the challenges that the *Nypa* leaf collectors face to collect the leaves from the Sundarbans to answer the third research question. We employed ATLAS.ti (version 8) by qualitative coding each challenge as reported by the interviewees.

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Author: USER Subject: Note Date: 2018-11-05 15:24:16

What about husbandry activities? why did not include here?

Results

Effects of socioeconomic factors on HH income

Among the social factors, age and education level did not affect the HH total income (Fig. 2A and Fig. 2B). However, HH members involved in IGAs positively affected the HH total income of *Nypa* leaf collectors in the SIZ of Bangladesh (Fig. 2C) (Table 1).

Income from *Nypa* leaf increases with the increasing amount of *Nypa* leaf collection from the Sundarbans mangrove forest (Linear regression, Regression coefficient= 0.003, N=90, $p<0.05$) (Fig. 3). Moreover, income from *Nypa* leaf collection and off-farm activities moderately correlated to HH total income (Fig. 4A and Fig. 4C) (Table 2). Surprisingly, it was evident that the income from husbandry highly correlated to the HH total income, i.e. HH total income of *Nypa* leaf collectors highly depend on income from husbandry (Fig. 4B) (Table 2).

Effects of physical factors on HH income

Income from *Nypa* leaf collection (ANOVA, $F_{2,87}$=1.668, P>0.05) (Fig. 5A) and off-farm activities (ANOVA, $F_{2,55}$=0.149, P>0.05) (Fig. 5B) did not vary among the unions (ANOVA, $F_{2,87}$=1.668, P>0.05 and ANOVA, $F_{2,55}$=0.149, P>0.05) though the income from husbandry significantly varied among the unions (ANOVA, $F_{2,87}$=20.866, P<0.05). Accordingly, HH total income of *Nypa* leaf collectors varied spatially (ANOVA, $F_{2,87}$=21.245, P<0.05) (Fig. 6A). Moreover, HH total income varied depending on the road networks (ANOVA, $F_{2,87}$=21.245, P<0.05) (Fig. 6B). In addition to the road networks, HH distance to nearby market negatively affected the HH total income of *Nypa* leaf collectors (Fig. 6C) (Table 1).

Challenges of Nypa leaf collection

Apart from socioeconomic conditions, the *Nypa* leaf collectors were also asked to address the major constraints they were facing while collecting and marketing the *Nypa* palm leaves. The first thing they mentioned was the occurrence of tiger attack or fear of being attacked in the SIZ was a major hurdle for these people. Lack of financial capital for seasonal leaf collection also hampered the life and livelihood opportunities of the *Nypa* leaf collectors. Moreover, the monopoly business of the buyers in local markets, a syndicate who set the price of the leaves much lower than the expectations, was another challenge for these marginal poor depending on NTFPs for living.

Discussion

This study explored the livelihoods, HH total income, factors affecting the HH total income, and challenges of *Nypa* leaf collectors in the SIZ of Bangladesh. The results revealed that specific socioeconomic and physical factors affect the HH total income of *Nypa* leaf collectors in the SIZ of Bangladesh. Furthermore, the frequent tiger attack along with monopolized market systems are they key

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Author: USER Subject: Note Date: 2018-10-26 14:51:58

line 40-41 are method statements. So I suggest to move in the method part

Author: USER Subject: Note Date: 2018-11-10 13:36:40

To improve the quality of discussion part, I suggest to the author to more in depth address how to face the constrains (based on the research findings) of Nypa leaves collector for sustainable livelihood strategy than just to suggest to promote husbandry activities though it also the one of the research findings. See also my comments on page 7 line 44-49 and page 8 line 30-33

Author: USER Subject: Note Date: 2018-11-05 11:22:50

Page 5 line 55-60 to page 6 line 1 are the purpose and the findings of this study not a discussion. So I suggest to delete challenges faced by the *Nypa* leaf collectors in the SIZ of Bangladesh.

Effects of socioeconomic factors on HH total income

In this study, our expectation was that along with the number of HH members involved in income generation, age and education level would have an effect on the HH total income (Fig. 2A and Fig. 2B), because age might be related to experience and education level might have an effect the negotiation skills. However, number of family members involved in IGAs only has positive effect on HH total income (Table 1). Because, the income from *Nypa* leaf collection largely depends on availability of fresh leaves rather than the number of collectors, while the income from husbandry is more related to investing time to manage the farms that might increase with the helping hand from the same HH and eventually increase HH income from husbandry. Average age of the *Nypa* leaf collectors was 38 years that is comparable to the findings of Zohora (2011) who reported the average age around 40 years in other SIZ of Bangladesh. NTFPs collection behaviors were quite different from the results reported by Coomes et al. (2004). The researchers reported that young collectors collect more NTFPs than the older collectors do, which affect the HH total income. However, our results showed that age does not have any effect on HH total income. Our study also reveals that the local people of the study areas have very poor education, averaging only 4 years of schooling, and 14.4% of the total leaf collectors are totally illiterate. This is supported by the results regarding the poor education level of the forest dependent peoples in SIZ of Bangladesh (Forest Department 2010; Zohora 2011). The poor educational outcome, therefore, does not influence the HH total income in the study areas. In contrast to the findings of this study, Baiyegunhi et al. (2016) found that education level has a significant effect on the HH income. However, the number of family members involved in IGAs definitely has a positive effect on HH total income and such findings are in line with the study of Soriano et al. (2017).

Nypa leaf collection, husbandry and off-farm activities are considered as economic factors in this research. As expected, per day income from *Nypa* leaf increased followed by the increasing quantity of *Nypa* leaf collection per day from the Sundarbans mangrove forest (Fig. 3). This might be attributed to the fact that all the leaf collectors tend to increase their income within short time. Our result is supported by Soriano et al. (2017) where the researchers observed increased HH income of NTFPs dependent communities with higher harvest of NTFPs. However, *Nypa* leaf collection, i.e. income generation from *Nypa* palm leaf, depends on leaf quality and leaf availability that might be the reason for lower quantity of leaf collection. Moreover, the presence of undergrowth and other obstacles are the issues that might affect the harvesting efficiency of *Nypa* palm leaves. Even the collectors have to clear dead and undesired *Nypa* leaves to get access to the desired leaves, hence, reduce the income from *Nypa* leaves per day (Carandang et al. 2009).

Income from *Nypa* leaf collection contributed up to 28.21% of the HH total income – a moderate contribution to HH total income in the SIZ of Bangladesh (Fig. 4A). The syndicate of the buyers in local market set the price of the leaves, which in turn, reduce the income from *Nypa* leaf collection as market price of palm leaves is way down than the expected value, considering the obstacles and danger of

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Author: USER Subject: Note Date: 2018-11-05 12:23:45

You have compared your findings to other previous researchers, but you need to clearly address, why the age and poor education don't effect to HH total income? and why are different from other previous researchers?

Author: USER Subject: Note Date: 2018-11-05 14:32:35

you need to more address about the leaf quality that you meant here. Is It related to and due to collection tools as you said on page 7 line 42 or more than it?
In addtion, what did you meant also with depends on the leaf availability? as you said in abstract the Nypa palm is abundance in this area

collecting the NTFPs. Moreover, the leaf collectors, generally poor people, have insufficient financial capital for their venture of leaf collection in each season. Henceforth, the leaf collectors borrow money from the local money lenders, who are also member of syndicate, with high interest, and with certain conditions, such as the leaf collectors are bound to sell the collected leaves in a minimum price set by the money lenders - a handful of people monopolized the local market of *Nypa* palm leaves. As a result, leaf collectors remain trapped by losing grip on the collected materials and hardly have any share over the profits made by the syndicate. This might be another reason that reduces the contribution of income from *Nypa* leaf collection in HH total income compared to that of from husbandry. The findings suggest that the HH total income of *Nypa* leaf collectors largely depend on income from husbandry as it contributes 63.39% of HH total income (Fig. 4B), and depending on the HHs, it also varied from US$ 54 to US$ 138 per month. The husbandry activities include shrimp farming, fish farming, agro farming, and poultry farming. There is a provision for selling husbandry products in the local market and price of the products varies reasonably in time compared to *Nypa* palm leaves. Hence, the contribution of husbandry income is highly significant in the HH total income, considering its lion share in HH income. Despite the aforesaid drawbacks, the contribution of income from *Nypa* leaf collection (28.21%) in HH total income is in the range of income from NTFPs collection (15-39%) as reported by Meilby et al. (2014). Moradi et al. (2017) documented comparable findings that contribution of oak fruits in family income is about 29%. Soriano et al. (2017), on the contrary, found that income from Amazon nut has greater contribution (44%) in HH total income in Bolivian Amazon. Meanwhile, in Iran significant contribution (51%) of wild pistachio to the family income was recorded by Moradi et al. (2017). The differences, however, might be attributed to the differing management system of Amazon nut in Bolivian Amazon and *Nypa* palm in Bangladeshi Sundarbans. Moreover, the 44% income also includes income from timber harvesting. In Bolivia Amazon nut trees are managed through community based management (Soriano et al. 2017), while in the Sundarbans – a reserve forest – it is managed by the Bangladesh Forest Department (BFD) (Forest Department 2010). As a result, the *Nypa* palm leaf harvesters do not have ownership over the resources and have to pay revenue to the BFD. In addition, the only way to transport the leaves from the Sundarbans to the nearby local markets is water vehicle, which is expensive. All these factors inversely related to the net income from *Nypa* palm leaves. The situation is further worsen as the quality of collected leaf may have been affected by the cutting tools, which eventually influence the price of the leaf, thereby, reduce the chances of more income from *Nypa* leaf. The income from *Nypa* leaf collection, though meagre compared to husbandry as livelihood option, can help at its best to reduce poverty through increasing the number of HH members involved in income generating activities, and improve the life style and living conditions of forest resource dependent communities (Stanley et al. 2012).

Though the effect of off-farm income on HH total income was significant (Fig. 4C), its contribution in HH total income constitutes a mere 9%. Findings suggest that more than sixty percent (64.4%) of the *Nypa* leaf collectors are involved in off-farm activities, including day laborer, van pulling etc., yet its contribution is very poor compared to husbandry and palm leaves collection. The reasons for least input in HH income can be attributed to the leaf collector's irregular involvement in these works. They may also have minimum time at their disposal to earn money through these ways or the opportunities to get involved in off-farm activities may be scarce or uncertain in their localities, though it

Author: USER Subject: Note Date: 2018-11-05 15:56:59

Since the selling price have highly significant in the HH income, I thought and suggest the paper text need to provide information of the selling price of the Nypa palm leaves and other prices from husbandry activities and off-farm activities. So it make the readers more understand the comparison each other of the activities.

Author: USER Subject: Note Date: 2018-11-10 13:08:59

Although, oak fruits, Amazon nuts, and wild pistachio include in NTFPs, but comparing to the income of same product (Nypa leaves) in other places is better. Each of product have different in way of collection and challenges, price, market, management system. So it can be influence to the income contribution. In addition, it also can provide readers with new insights related to the livelihood of Nypa palm collectors in various places

Author: USER Subject: Note Date: 2018-11-10 12:37:04

This statement (lime 44-49) contrast with the statement in conclusion and abstract "Nypaleaf collection from the Sundarbans alone could not be a livelihood strategy". I suggest this statement include in conclusion and abstract as one of recommendations beside to promote husbandry activities as alternative.

increases the HH total income (Soriano et al. 2017). Hence, it could be a source of additional income rather than livelihood strategy for the *Nypa* leaf collectors in the SIZ of Bangladesh.

Effects of physical factors on HH total income

Spatial variation in income from *Nypa* leaf and off-farm activities was not significant (Fig. 5A and Fig. 5C), but the income from husbandry was significantly different among the unions (Fig. 5B). The price of *Nypa* leaves fixed by the local market syndicate, who remains in the top of value chain and govern the trade of *Nypa* leaves at sub-district and union levels. This might be the fact for no spatial variation in income from the *Nypa* leaf collection. Zohora (2011), however, reported a significant spatial variation in income from the NTFPs, including *Nypa* leaf collection, honey collection and goran (*Ceriops decandra*) harvesting. It is due to the opportunistic behavior of the local buyers to maximize their own profit and income from other NTFPs. It was not the case for this study. Moreover, off-farm activities are rare in the studied unions and it might be the reason for no spatial variation in income from these activities. This result also complements the results of Zohora (2011) regarding the income from and availability of off-farm activities like day laborer. Unlike off-farm activities, income from husbandry activities was statistically different for three unions and the reason could be related to the availability of resources and support from the family members and externals agents, like government and non-government agencies. Similar results regarding the spatial variation in income from husbandry activities (alternative income generating activities) in the other parts of SIZ of Bangladesh was evident in the work of Zohora (2011). The increasing income from husbandry activities, therefore, could be a potential solution to reduce forest dependency and livelihood strategy of the *Nypa* leaf collectors, because it contributes substantially in the HH total income.

Significant spatial variation in HH total income of *Nypa* leaf collectors observed among the unions, where Chila union has the highest HH income followed by Munshiganj and Sutarkhali unions (Fig. 6A). This variation can be attributed to the spatial variation as well as significant contribution of income from husbandry activities. Zohora (2011) reported similar results about the HH income of NTFPs collectors in other areas of SIZ in Bangladesh. In contrast, HH income of Brazil nut collectors varied among the HH rather than between geographical spaces and those differences mostly depended on income from NTFPs collection (44%) rather than husbandry or off-farm activities (Soriano et al. 2017).

Findings indicated that HH total income varied depending on the different types of road networks in the three unions (Fig. 6B). Basically, there are four distinct forms of the road networks in the study areas, *paka* (concrete), semi-*paka* (semi-concrete) and *kacha* (soil road) and *paka*, and waterways. Lower HH total income resulted from under developed road networks (waterways and *kacha* road) in *Sutarkhali* union, on the contrary *Chila* union has better roads (*paka*) connecting local markets with adjacent areas, thus, the HH total income is way better than *Sutarkhali*. It is strongly believed that high transportation cost along with wastage of time to reach outside markets from local area with underdeveloped road networks might have compelled the *Nypa* leaf collectors to sell the NTFPs in a minimum price set by local buyers or money lender. Subsequently, the local market remains under

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Author: USER Subject: Note Date: 2018-11-10 11:58:01

The author need to be carefully for this solution due to shrimp farming as one of husbandry activities in Bangladesh and other Asian countries, have been many negative environmental and social impacts (See paper Hossain et al. 2013). The shrimp farming development has trusted as the primarily driver mangrove loss in the world.

control of the syndicate of the local buyers (Forest Department 2010), which in turn negatively influence the HH total income. Furthermore, the HH total income of *Nypa* leaf collectors also inversely related with HH distance from nearby market (Fig. 6C). Because, long distance means substantial increase of transportation cost regardless of products, including both NTFPs and husbandry. Similar findings were reported by Melaku et al. (2014) that the distance to the market negatively affect the HH income from NTFP collection in Ethiopia. The finding of this study, however, do not comply with the result of Soriano et al. (2017) regarding the dependency of NTFP collectors on the income from NTFP collection.

Challenges of Nypa leaf collection and livelihood

Apart from socioeconomic and physical constraints, the *Nypa* leaf collectors also mentioned tiger attack as a key challenge during leaf collection from the Sundarbans. In Sundarbans, the leaf collectors often enter into the deepest areas, roamed by the tigers, therefore, become an easy picking for the tigers during the leaf collection season. Every year, a number of harvesters either lost their lives or become handicapped. Zohora (2011) also reported the incidences of tiger attack during the harvesting of *Nypa* palm leaves in the Sundarbans. Among other hurdles, as mentioned by the harvesters, the insufficient financial capital during leaf collection season and the syndicate of local buyers to influence the price of goods are major issues. The *Nypa* leaf collectors, belonging to the poor families, do not earn much to have savings and they are not organized enough to form an association, which eventually force them to borrow money from local money lenders or to take advance from the possible buyers at the local markets. Hence, the collectors remain trapped in the cycle of lending money and selling the products at minimum cost without having any control of both money and goods, and such result also reported by Zohora (2011). The author, however, also reported the interference of forest bandits during and after harvesting of *Nypa* palm leaves and other NTFPs from the Sundarbans (Zohora 2011). This indicates the need for group or association formation of NTFPs producers/collectors, and policy makers and development practitioners might be interested in it.

Conclusion

This research highlighted the livelihood options, HH total income, factors affecting HH total income and challenges of the *Nypa* leaf collectors, which would be helpful to take further necessary actions for improving their livelihood strategy. However, findings of this research are context specific, but it might be applicable for the other palm leaf collectors across the world. Results of this study revealed that *Nypa* leaf collection from the Sundarbans alone could not be a livelihood strategy. It does not contribute much in the household income compared to husbandry, additionally, it involves life threatening challenges, e.g., tiger attack during leaf collection. Promotion of effective husbandry livelihood activities for *Nypa* leaf collectors in the SIZ of Bangladesh would be a better alternative livelihood strategy to reduce forest resource dependency, as it possesses substantial prospects in the southwestern regions of Bangladesh. Therefore, this study emphasizes the need for not only formulation and strengthen the policy regarding the sustainable livelihood development of the coastal inhabitants but also to ensure the access to the social safety net programs.

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See my previous comments on page 7 line 44

Author: USER Subject: Note Date: 2018-11-10 13:11:23

See my previous comments on page 8 line 33

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Page:16

Author: USER Subject: Note Date: 2018-11-10 04:46:48

This reference do not find in the text! So please don't put a reference in reference list if you do not cite. Please check carefully for the others.

Decision reached by the Editor on ENVI-D-18-00706R1

em.envi.0.62b96b.9d1bcddf@editorialmanager.com on behalf of
Environment, Development and Sustainability (ENVI) <em@editorialmanager.com>

Sun 4/21/2019 4:44 PM

To: Abdul Malik <jwp495@alumni.ku.dk>;

Dear Dr. Malik,

The Editor has made a decision on ENVI-D-18-00706R1, which you recently reviewed for us.

The decision is: Major revisions.

You can also view the decision letter and the reviewers' comments at the Editorial Manager Website.

Your username is: AbdulMalik-995
If you forgot your password, you can click the 'Send Login Details' link on the EM Login page at
https://www.editorialmanager.com/envi/

Thank you again for your contribution to Environment, Development and Sustainability.

Best regards,

Luc Hens
Editor in Chief
Environment, Development and Sustainability

Reviewer #4: The second review is much like the first, and my comments are much the same.

The English is not always clear. I strongly recommend that the manuscript be reviewed by someone for whom English is his/her first language. Such a reviewer could spot the numerous errors and smooth out the style of the writing. As it stands, the writing is so bad that I cannot recommend publication, no matter how novel, useful or interesting the findings.

An example:
P. 10, lines 19, 20: "Because, long distance means a substantial increase of the transportation cost regardless of products, including both NTFPs and husbandry." This is not a complete sentence.

The correct name of the palm is Nypa fruticans Wurmb - with no full-stop, as Wurmb is not an abbreviation. The authors failed to correct this the first time and, in fact, compounded the error by adding a spurious authority.

P. 2, line 3: "Like the other palm species, the Nypa does not have an above ground stem" should read "Unlike most other palm species, Nypa does not have an above-ground stem...." Nypa is unusual in having a prostrate, dichotomously branching stem. An important reference for this statement is: Dransfield, J., N.W. Uhl, C.B. Asmussen, W.J. Baker, M.M. Harley & C.E. Lewis. 2008. Genera Palmarum - the Evolution and Classification of Palms, ed. 2. Royal Botanic Gardens, Kew, Richmond, UK. Pp. 732.

The conclusion seemed self-evident: leaf collection is not a viable livelihood strategy, which is why collectors are not doing it full time, and it is not the sole source of household income. I think some of the discussion could be removed to tighten the narrative.

I again stress that the bar graphs should have some indication of significance/non-significance among the bars. In most publications, this is simply accomplished by adding letters to each bar, such that bars with the same letters are not significantly different and bars with different letters are significantly different.

Reviewer #8: Methodology
1) Study area: Frequent repetitions of same information.
2) Theoretical framework: I am not sure why this subhead is here. I don't see anything under this subhead that talks about theoretical framework of Methods. And I believe, 'Methodology' should be replaced with 'Methods'. However, the two paragraphs (composed mostly of some definitions and conditions) written under this subhead are not needed at all. The readers of this article are considered know these preliminary definitions.
3) Sampling and data collection:
- What is the basis of sampling size being 90? I did not see any rationality. This is too small a sample to represent the population, and thus, the results are not beyond question.
- What surprised me most is choosing 'cluster random sampling' to select households. I don't think clustering is a valid sampling method for this particular case. Again, what are the variables considered for cluster sampling?
- "The sample size for each union was determined at confidence interval of 95% and precision level of ±5%" - Where is it from? What does it mean? What estimate is it talking about?
- The authors selected three villages "because of their closeness to the Sundarbans mangrove forest". Proximity could be a better word for closeness. However, this choice of villages does not match with the third research question specified in the Introduction section- "what are the major challenges of Nypa leaf collection from the Sundarbans affecting the livelihood of Nypa leaf collectors in the SIZ of Bangladesh"? (SIZ) Sundarbans Impact Zone is no way confined to small adjacent villages. Thus, the results from such sampling cannot be generalized for the SIZ.
- The whole article contains repetitive and unnecessary description of both relevant and irrelevant matters. For example, let's look at this quote - "By administering a semi-structured interview schedule - containing both open and close-ended questions on socioeconomic conditions and physical factors - the Nypa leaf collectors were interviewed by a group of well-trained undergraduate students. The interviewers were trained extensively by the first author, through classroom lectures and role playing, about the research objectives as well as the content of the interview schedule to maintain the uniformity of the survey as well as to keep the anonymity of the interviewees. It is noteworthy that to facilitate the interviews, the interview schedule was translated into Bengali language and all the interviews were conversed in Bengali to ease the communication with the participants as all of them had lower educational background. However, for data input the information was converted into English. Each of the interview lasted for half an hour. Considering the harvesting period, the fieldwork took three months to complete, from December 2016 to February 2017 - the prime time for harvesting". This whole paragraph is seemingly irrelevant for any peer-reviewed article.
4) Statistical analysis
- What is the use of this -"Statistical analysis of the data was carried out by using MS office excel (version 2016), statistical package for social science (version 16) and ATLAS.ti (version 8) software system"? Would the results be different if other statistical packages were used?
- "In this case, age, education level and number of HH members involved in income generating activities (IGAs) were independent variables and HH total income was dependent variable."- My guess is some pair of the explanatory variables (Education and HH members, for example) are most likely significantly correlated. Thus, the models so run are likely affected by multicollinearity issues. This has inflated regression R-squared from its actual value.
- In many places the author claimed- "unstandardized residual followed normal distribution"! This is unbelievable for a sample size of just 90!
- "we conducted a linear regression with the number of leaf collection (independent variable) and income from the Nypa leaf collection (dependent variable)" - what is the justification of this regression? The more leaves one collects, the higher would be one's income - do we need to test it?
- "Later, the relationship between economic factors, including income from the Nypa leaf collection, income from husbandry and off-farm income and HH total income, was analyzed following Pearson's correlation as the unstandardized residual followed normal distribution." The authors did it later. But it was required to be done earlier the regressions were run. Ordinary least square regression, which the authors appear to have run, needs to declare that the regressors are uncorrelated.
- "In the meantime, to assess the effect of road networks on HH total income, ANOVA with road types and HH total income was conducted, because unstandardized residual followed normal distribution." - What is the use of this activity in this study? How is Nypa related to it? By the way - using the clause "unstandardized residual followed normal distribution" everywhere is extremely irritating. It doesn't make sense.

Results
- "Surprisingly, it was evident that the income from husbandry highly correlated with the HH total income." - Why is it surprising? It is obvious and we don't actually need a regression to prove it.
- Throughout the result section the authors have reported all the insignificant estimates ($P>0.05$). We don't really need it. There are hundreds of events that are not significantly related to this study; should we report them all? It appears to be irrational from scientific standpoint.
- "The first thing almost all the respondents mentioned that the occurrence of tiger attack or fear of being attacked in the Sundarbans was a major hurdle for these people. For example, "people know that most of the tiger attack happens inside the

Sundarbans during the leaf collection, but they have to go to Sundarbans for increasing their income as much as possible". In addition, lack of financial capital for seasonal leaf collection also hampered the life and livelihood opportunities of the Nypa leaf collectors as described by 75% respondents. Moreover, the monopoly business of the buyers in local markets, a syndicate who sets the price of the leaves much lower than the expectations, was another challenge for these marginal poor depending on NTFPs for living." - Extremely irrelevant to this article. Remove it.

Conclusion
Extremely choppy. Poor language and irrelevant to the study data and facts. The conclusion failed to give us a succinct take home message as to why this study is important.

Overall:
1) Language: The manuscript needs a thorough revision of its English. Some of the many concerns are: subject-verb disagreement, poor choice of appropriate words, mixing of tenses, and unclear sense of sentences, redundant and repetitive information.
2) Information: Some information are just willingly made. For example- Unions are not geographical units; it is an administrative unit. Again, this is not the smallest local government unit; a ward is probably the smallest. Again, upazilas are NOT sub-districts in Bangladesh.
3) Final Comment: Rejected. The article cannot be published in its current form.

Reviewer #10: Dear authors

Overall, the manuscript highlights an important topic and shows some interesting results, especially those on the challenges for nypa leaf collectors. It deserves to be published after revisions. Unfortunately, a clear message seems to be lacking, instead the authors are proposing to promote animal husbandry as viable livelihood strategy, which is already the case. The presentation of the results and parts of the discussion need improvements and the conclusion needs to be more clear and backed up by the results. Below please find specific comments:

P1, L 10 - 13 In these two sentences you should mention which specific factors you are talking about.
P1, L 18 - 20 This conclusion seems rather too obvious.
P1, L 28 - 30 NTFP collection prohibits forest degradation? This is not a direct link. NTFPs can also be overharvested, which can in some cases lead to degradation. Whether something is prohibited or not depends on rules and laws and the management plan of that forest area, not on the actual collection of NTFPs. Please clarify.
P2, L 6 Ecosystem services are per se the benefits that humans obtain from nature, not services to the ecosystem. Please adjust your wording.
P2, L 7 Which are the regulating and cultural services from Nypa? Please specify.
P2, L 33 - 35 Do you mean your intensive literature research? In that case delete. If you mean Zohora 2011 did the extensive literature research please write it accordingly.
P2, L 35 - 37 Suggest formulating sentence as: "However, in depth information regarding ... had not yet been explored."
P2, L 40ff Without a more detailed clarification of which factors you are talking about, the research questions are not well understood. E.g. for R.Q. II: physical factors could be anything from climatic conditions over road infrastructure to the property of boats. Please clarify.
P3, L 2 - 3 Suggest: "what are the major challenges for Nypa leaf collectors in the SIZ of Bangladesh?" for a better wording.
P3, L 12 Is closeness to the Sunderban mangroves the only selection criteria for your unions? Are they representative for a larger area? Please indicate what this could mean for the results (in the discussion).
P3, L 18 If you talk about NTFPs in general, you should at least mention a few other than Nypa.
P3, L 27 "livelihoods" (throughout)
P4, L 10 - 14 I am not convinced this is true. Furthermore, please adjust the sentence so it is clearer and easier to read.
P4, L 23ff It would be nice if you could give information on the total number of households collecting nypa leaves within the studied communities. This information could also be included in the description of the study area.
P4, L 24 delete "excruciating"
P4, L 28 This is interesting. In other countries, women mostly benefit from nypa (although mostly men collect the leaves, women thatch them and get an income). Maybe you can add an explanation here.
P4, L 31 "animal husbandry" (throughout)
P4, L 32 please explain "agro-farming"
P6, L 9ff I need to stress that for a better understanding of the results you need to explain the individual factors in advance. E.g. L 15 - 16: How did you measure / ask this? Do you mean the available leaves per area or do you mean the collected leaves? Please clarify directly in the text.
P6, L 15 - 18 To give a better foundation to your results, I suggest adding some numbers here to show just how much nypa collectors depend on income from nypa (percentage of total HH income??)
P6, L 17 - 20 Can you add information on the type of correlation?

P6, L 28 - 29 It would be very interesting to have this result specifically for income from nypa. Please add. Or clarify the term market (is it for nypa or for the sale of animals or ...)
P6, L 31 Can you specify a number or percentage instead of "almost all"?
P7, L 1 - 3 Please specify.
P7, L 5 "these marginal poor depending on NTFPs for living": Firstly, when did you define your respondents as generally marginal poor? Secondly, in the results you showed that total HH income mostly depends on the income from animal husbandry as well as off-farm income. That means they do not depend primarily on NTFPs... Please state your message clearly. Again, it is important that you present the percentage of total hh income they get from nypa.
P7, L 18 - 19 also Nypa?
P7, L 28 - 30 As these are very different contexts, you need to elaborate.
P8, L 4 - 7 This is the first time you talk about this. Is it part of your results? If not, please give a reference and also discuss how that relates to your results.
P8, L 12ff Very interesting paragraph. But these are all results, which should be presented in the results section and only discussed in more detail here (as you do starting from L 30ff).
P9, L 8 - 9 Yes, good conclusions. You should also refer to the fact that this is exactly what people are doing, they depend much more on other income sources because nypa alone is not a viable livelihood strategy.
P11, L 11 Before you mentioned that one of the main challenges is the low price and limited bargaining power of nypa collectors. If you suggest now to adjust the mangrove and nypa management, you need to base it on your findings. Should the emphasis be on improved natural resource management or market access?
P11, L 15 - 19 From this paper we do not know any details about effective animal husbandry. We only know that people already follow this strategy (mostly animal husbandry and nypa in addition), so what exactly do you recommend to improve? Are poorer households limited to follow this strategy? If so, please already discuss this earlier.

Reviewer #12: 1. On Introduction (Page 1 Line 32), the word "In the last two decades" might be better to be written "Since the 1980s". This is important to avoid readers' misunderstanding in terms of time frame (period), because you cited a reference published in 2005 (Belcher et al. 2005). In fact, studies and interests in NTFPs started in the 1980s in response to calls for using forest resources sustainably for the benefit of the wider society, especially for the rural people.

2. Page 2 Line 3, the sentence "Like the other palm species, the Nypa does not have an above ground stem" is not correct and should be revised, as many or most palm species do have above ground stem. However, some of the palm species do not have it, like Nypa fruticans, Raphia regalis, Johannesteijsmannia altifrons, J. magnifica, etc. Just for an additional information for Page 2 Line 7-8, Nypa fruticans is a very potential source of sugar, by tapping the inflorescences/infructescences.

3. Page 2 Line 35, the word "Because" is not appropriately used and it can be replaced with "However".

4. Page 2 Line 35, page 3 line 22 and 23, the word "Nypa" should be written in italics, please check this word throughout the paper carefully.

5. Page 3 Line 7 (Study Area), the word "an ecologically critical area" needs to be explained or elaborated a bit further in the paper, why is it important, as you mentioned that the three study areas belong to an ecologically critical area but then you did not explain the importance of choosing an ecologically critical area in your study (research), but rather because of their closeness to the Sundarbans mangrove forest.

6. Page 3 Line 16 (Study Area), the sentence "while the average temperature remains steady between 12-37oC" needs to be revised, as it is not an average but a range. In a tropical condition, the temperatures range from 12 to 37oC indicate a wide temperature variation, and not a steady temperature. I am wondering whether a temperature of 12oC could be experienced somehow or sometime in the Sundarbans mangrove, coastal, tropical forest? Did you measure the temperature range by using your own equipment?

7. Page 3 Line 23-25, is there any information gathered that Nypa leaf was collected from specific habitat or certain population condition, e.g. from abundant or small population, or from ecologically critical area, or core zone of the forest? Such information would be important in order to develop a sustainable collection management.

8. Page 3 (Study Area), it will be informative and useful if the distance of each union/Nypa leaf collection location to the main road (e.g. concrete or semi-concrete road) is provided.

9. Page 4 Line 30-33 (Sampling and data collection), you mentioned/included husbandry and off-farm activities (aspects), but you did not sample or collect data on these two activities in the Sundarbans Impact Zone. Husbandry and off-farm

activities are not included (reflected) in the paper title either. However, you put some results on the off-farm activities on Page 6 Line 17-18 and the husbandry on Page 6 Line 18-20. It seems that you expanded the scope of your study but not represented in the paper title, and no keywords mentioning about off-farm activities and husbandry either.

10. Page 5 Line 15, the abbreviation of "BDT" and "USD" should be written completely.

11. Page 5 Line 27-29, is there any information gathered in your survey on the actual or average amount of Nypa leaf collected by collectors per clump per year? You have mentioned (on Page 8 Line 7 using references) that leaf availability was 3 leaves on average per clump per year, but this is not the actual (current) collection practised by the local collectors.

12. In the Discussion session (e.g. on Page 7 Line 36, Page 8 Line 24-28, Page 9 Line 34-37, Page 9 Line 8, and others), you performed some data and information on the husbandry and off-farm activities and the comparisons to Nypa leaf collection, but again, you did not sample or collect the data/information on these two aspects on the Methodology (Methods).

13. Page 8 Line 7, is there any regulation from the Bangladesh Forest Department on the Nypa leaf collection/harvest, for instance the maximum quantity of Nypa leaves that can be harvested by each HH per season or per year? If such regulation is available, it would be informative (useful) to be included and discussed in the Discussion session.

14. On Page 8 Line 12-13, income from the Nypa leaf collection is considered a moderate contribution (28.21%), but on Page 9 Line 8 it is only meagre (very little) compared to husbandry (63.39%) as livelihood. Please clarify this statement!

15. Page 9 Line 10-11, the statement "Though the effect of off-farm income on HH total income was significant (Fig. 4C), its contribution in HH total income constitutes a mere 9%" needs to be explained further in a more logical sense.

16. Page 9 Line 13, remove the word "etc." and please do/check throughout the manuscript.

17. On Discussion session, it will be worthwhile to discuss whether the ongoing (current) Nypa leaf collection affects the regeneration or sustainability of the Nypa population in the Sundarbans forest, especially for the long run. Unfortunately, such important information is not available in this paper.

18. In Conclusion session (Page 11), it is important to recommend the establishment of a better management system of Nypa leaf collection (e.g. developing community based management or farming association) in collaboration with the Bangladesh Forest Department. A strong support from the government as well as non-government organizations seems to be crucial particularly to control the local market syndicates. A practical training on the Nypa leaf collection technique particularly for the local collectors is also required in order to manage the Nypa population sustainably in the Sundarbans mangrove forest and consequently for achieving sustainable forest management.

19. On References (Page 12 and afterwards), some references are not correctly written in order. Baiyegunhi et al. should be put before Barik et al. (Page 12), Carandang et al. should go before Carney et al. (Page 12), and Ha et al. (Page15) should be placed on before Hossain & Islam (Page 13).

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Decision reached by the Editor on ENVI-D-18-00706R2

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Environment, Development and Sustainability (ENVI) <em@editorialmanager.com>

Thu 8/1/2019 4:24 PM

To: Abdul Malik <jwp495@alumni.ku.dk>;

Dear Dr. Malik,

The Editor has made a decision on ENVI-D-18-00706R2, which you recently reviewed for us.

The decision is: Accept.

You can also view the decision letter and the reviewers' comments at the Editorial Manager Website.

Your username is: AbdulMalik-995
If you forgot your password, you can click the 'Send Login Details' link on the EM Login page at
https://www.editorialmanager.com/envi/

Thank you again for your contribution to Environment, Development and Sustainability.

Best regards,

Luc Hens
Editor in Chief
Environment, Development and Sustainability

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Published: 12 August 2019

Nypa fruticans Wurmb leaf collection as a livelihoods strategy: a case study in the Sundarbans Impact Zone of Bangladesh

Md. Nazrul Islam, Nabila Hasan Dana, Khandkar-Siddikur Rahman, Md. Tanvir Hossain, Moin Uddin Ahmed & Abdulla Sadig

Environment, Development and Sustainability **22**, 5553–5570 (2020)

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Abstract

The *Nypa fruticans* Wurmb (*Nypa*), a true mangrove palm, is abundant in the Sundarbans reserved forest of Bangladesh. Leaves are the primary product obtained from the *Nypa,* which are often used as thatching materials and source of income for the forest-dependent communities in the Sundarbans Impact Zone (SIZ) of Bangladesh. Hence, this study aimed to assess the usefulness of the *Nypa* leaf collection as a livelihoods strategy in the SIZ of Bangladesh. A total of 90 *Nypa* leaf collectors from three coastal unions were interviewed by administering a semi-structured interview schedule. Effects of social factors [age, education level and household (HH) members involved in income generation] and economic factors (primary, secondary and tertiary occupation) on the HH total income of the *Nypa* leaf collectors were analyzed using linear regression and Pearson's correlation, respectively. Moreover, the effect of physical factors on the HH total income was analyzed by ANOVA and linear regression. Results suggested that income from the *Nypa* leaf collection, though making only a quarter percent of HH total income, was constrained by underdeveloped infrastructure, inaccessibility to fair market price, limitations of financial capital and frequent attack of Royal Bengal tiger (*Panthera tigris tigris*). The study, therefore, suggests that *Nypa* leaf collection from the Sundarbans alone could not be a sustainable livelihoods strategy for the forest-dependent communities in the SIZ of Bangladesh. Diversified and advanced husbandry activities, which have the potential to further reduce dependency on forest resources, would strengthen the livelihoods strategy and ultimately conserve the resources of the Sundarbans.

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Dynamics of mangrove community in revegetation area of Karangsong, north coast of Indramayu District, West Java, Indonesia

HENDRA GUNAWAN♥, SUGIARTI, SOFIAN ISKANDAR
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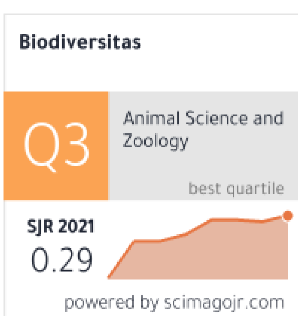

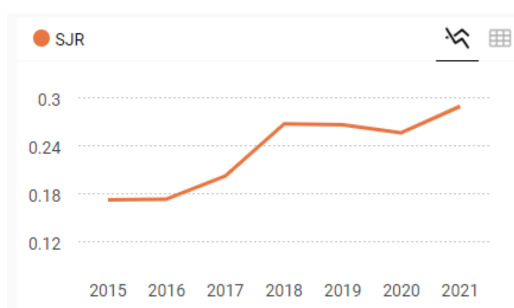

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Abdul Malik <abdulmalik@unm.ac.id>

Fwd: Invitation to review

6 messages

Managing Editor <unsjournals@gmail.com> Fri, Aug 5, 2016 at 11:41 AM
To: malik@ign.ku.dk, abdulmalik@unm.ac.id

Dear **Dr. Abdul Malik**,

We received a manuscript titled: **Dynamics of mangrove community in revegetation area of Karangsong, north coast of Indramayu District, West Java, Indonesia**.

We will be most grateful if you could find time to review the manuscript. The time is 2-3 weeks. Please find attached the full manuscript and Guidance for Author.
You may present your evaluations the way you deem fit. If you wish to correct parts of the manuscript itself, please indicate your corrections with a different color (for example, red for addition and blue for deletion) or use track change (for MS word program).

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Thank you,
Best Regards,

Ahmad Dwi Setyawan

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Abdul Malik <abdulmalik@unm.ac.id> Fri, Aug 5, 2016 at 3:47 PM
To: Managing Editor <unsjournals@gmail.com>

Dear Ahmad Dwi Setyawan
Managing Editor of Biodiversitas, Journal of Biological Diversity

Thank you for the invitation to review the manuscript. I will go through the manuscript and send back the result in the determined time.
I would like also inform to you for the next correspondence through this email address only.

Best regards,
Abdul Malik, Ph.D.

[Quoted text hidden]
--
Abdul Malik, Ph.D.

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Managing Editor <unsjournals@gmail.com> Fri, Aug 5, 2016 at 3:53 PM
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Sir,

Thank you so much for your willingness.

Thank you,
Regards,

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Abdul Malik <abdulmalik@unm.ac.id> Wed, Aug 24, 2016 at 11:47 AM
To: Managing Editor <unsjournals@gmail.com>

Dear Editor of Biodiversitas (Ahmad Dwi Setyawan)

Please find attached the reviewed manuscript.

Best regards,
Abdul Malik

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Dynamics of mangrove community in revegetation area of Karangsong_AM.doc
851K

Managing Editor <unsjournals@gmail.com> Wed, Aug 24, 2016 at 5:49 PM
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Sir,

Thank you so much for the evaluation.

Thank you,
Best Regards,

Ahmad Dwi Setyawan

Managing Editor,
- Biodiversitas, Journal of Biological Diversity (biodiversitas.mipa.uns.ac.id) (SCOPUS, DOAJ)
- Nusantara Bioscience (biosains.mipa.uns.ac.id/nusbioscience.htm) (Web of Science (ESCI), DOAJ)

Chairman/Co-Chairman
- National Seminar & International Conference on Biodiversity, http://biodiversitas.mipa.uns.ac.id/snmbi.html

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Abdul Malik <abdulmalik@unm.ac.id> Sun, Aug 28, 2022 at 2:43 AM
To: reviews@webofscience.com

Forwarded email corresponding review receipt from Biodiversitas, Journal of Biological Diversity, for your verification (Review ID number: 16949578)
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Dynamics of mangrove community in revegetation area of Karangsong, north coast of Indramayu District, West Java, Indonesia

Mangrove along the ~~north~~ North coast of Java is heavily degraded due to ~~the~~ conversion ~~of land~~ into fish ponds and human settlement areas. A revegetation program has been initiated by the local community of Karangsong Village, Indramayu District, supported by PT. Pertamina RU VI Indramayu. ~~Our~~ The research aimed to study the population dynamics of the mangrove revegetation in Karangsong. Secondary data was collected from the Fishery and Maritime Services of Indramayu and PT. Pertamina~~.~~, while primary data was ~~We~~ carried out ~~on location~~by field observations and ~~we~~ interview~~ed key respondents~~. Data was analyzed to describe trends in the diversity index and population dynamics of the mangrove. The results showed that the revegetation effort in shoreline of Karangsong has covered ± 69.08 hectares which consisting of six species of mangrove and three tree species of coastal vegetation i.e. *Rhizophora mucronata* Lam., *Rhizophora stylosa* Griff., *Rhizophora apiculata* Blume, *Avicennia marina* (Forssk.) Vierh., *Avicennia alba* Blume, *Sonneratia caseolaris* (L.) Engl, *Terminalia catappa* L., *Casuarina equisetifolia* L., and *Ziziphus mauritiana* Lam. The mangrove population increased dramatically, from estimated 25,000 individuals in 2008 to 690,835 individuals in 2016. *Rhizophora mucronata* Lam. was the most dominant species (68.85%), followed by *Rhizophora stylosa* Griff. (18.33%) *and Rhizophora apiculata* Blume (9.53%). The Shannon diversity index was fluctuated but tends to be increase from 0.80 to 0.95.

Keywords: mangrove, re-vegetation, Indonesia, West Java~~north coast, Karangsong~~.

INTRODUCTION

There are roughly 166,876 km^2 of mangrove habitat along the shorelines of the world, with the largest proportion of mangrove occurring in Asia (77,169 Km^2) and the Americas (43,161 Km^2) (Valiela et al. 2001). Countries with the largest area of mangroves are Indonesia (4.25 x 10^4 km^2) (Spalding et al. 1997), followed by Brazil (1.34 x 10^4 km^2) (Spalding et al. 1997), Nigeria (1.05 x 10^4 km^2) (Saenger & Bellan 1995), and Australia (1.00 x 10^4 km^2) (Robertson & Duke 1990).

Globally, the area of mangrove area is declining rapidly as it is cleared and converted to mariculture, agriculture, urban development, logged timber concessions, and fuel production areas (Fortes 1988; Marshall 1994; Primavera 1995; Twilley 1998; Polidoro et al. 2010). At least 35% of the world's mangrove forest area has been lost in the past two decades (Valiela et al. 2001). It is apparent that maricultural practices are responsible for the bulk of the increasing loss of mangrove worldwide. For example, pond culture has been reported to be responsible for 50%–80% of the loss of mangrove in Southeast Asia (Wolanski et al. 2000). Most of the damage is attributable to the direct loss of habitat from conversion of "cheap" mangrove land to "valuable" shrimp, prawn, and fish ponds (Valiela et al. 2001).

In 1999, Indonesia's mangrove forest covered 8.6 million hectares which consisted of 3.8 million hectares of forest area and 4.8 million hectares of non forest area. Degradation of mangrove in forest area is 1.7 million hectares (44.73%) and in non forest area is 4.2 million hectares (87.50%) (Gunawan & Anwar 2005). Indonesia has lost 40% of its mangrove in the last three decades (FAO 2007). The deforestation rate for mangrove in Indonesia is estimated to be 6% or 0.05 million hectares of the total annual forest loss (Margono et al 2014; Ministry of Forestry Republic of Indonesia 2014). The Ministry of Forestry has reported that only 31% of the remaining mangrove is in an intact condition and the rest (69%) is heavily degraded (Ministry of Forestry 2007). FAO (2007) reported that mangrove forest in Indonesia is 3,062,300 hectares or 19% of the world's mangrove and still the largest in the world, followed by Australia and Brazil.

Mangrove forest in Java Island is decreasing as the impact of conversion to mariculture, human settlement and other uses worsens. This impact is due to limited understanding and awareness by surrounding communities of the ecological importance of mangrove and to uncertainty about land status (Said & Smith, 1997). In 2011, mangrove in West Java Province was estimated as covering 40,130 hectares which was distributed between forest area 32,314 ha (80.52%) and non-forest area, 7,816 ha (19.48%), including 13 ~~regencies~~ Districts (Forestry Service of West Java Province 2013). The degraded mangrove in this province is 15,276 hectares (38.06%), with the largest occurring in Karawang District 13,181ha (32.85%) followed by Bekasi 10,481ha, Indramayu 8,720ha, Subang 7,346 ha, Cirebon 190 ha, Ciamis 170 ha, Garut 32 ha and`Sukabumi 9 ha (Ministry of Forestry 2012). The loss of mangrove in the Indramayu District has impacted on the disappearance of Ujung Gebang, Limbangan and Jatinyuat villages (Forestry Service of West Java Province 2016).

Mangrove forest in Indonesia provides benefits for local communities; supporting livelihoods by producing items of food, fuel wood, charcoal, construction materials, and furniture timber, as well as by generating income (Armitage 2002). Mangrove is also important in social-cultural terms in fulfilling various religious, spiritual, aesthetic, and recreational

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Commented [AM2]: I suggest to use one of area units (km or hectare) in your manuscript for facilitate the reader to understand.

Commented [AM3]: I think this sentence or information could combine to the first paragraph (line 22-25).

Commented [AM4]: Please consistent to "Regency" or "District" functions that benefit ecotourism (UNEP 2014). Mangrove ecosystems support essential ecological functions such as intercepting land-derived nutrients, pollutants, and suspended matter before these contaminants reach deeper water (Marshall 1994, Rivera-Monroy and Twilley 1996, Tam and Wong 1999). Mangroves also perform other important services, such as preventing coastal erosion by stabilizing sediments (Marshall 1994, Tam &Wong 1999), furnishing nursery and spawning areas for commercially important coastal fish and shellfish species (Rodelli et al. 1984, Sasekumar et al. 1992), and providing stopover sites for migratory birds, fish, and mammals (Saenger et al. 1983). Any loss of mangrove forest, therefore, means a loss of their important contributions to subsistence uses, and to ecological, economic, and conservation functions (Valiela et al. 2001).

Based on the essential functions of mangrove for human life, the Ministry of Environment and Forestry Republic of Indonesia has designated mangrove as an essential ecosystem which will be treated as a protected area or conservation area under the Directorate of Essential Ecosystems Management. The Ministry of Environment and Forestry Republic of Indonesia has also launched a National Movement on Forest and Land Rehabilitation (NMFLR) - a national initiative to plant trees in forest land and bare lands - including mangroves - as a commitment to improving the quality of environment for people's prosperity. The total extent of the national program for mangrove rehabilitation during 2010-2014 is 33,394 hectares (Ministry of Environment and Forestry 2015). The rehabilitation program in West Java Province has planted 365 hectares of mangrove in 2008, 50 hectares in 2009, 311 hectares in 2010, 480 hectares in 2011 and 270 hectares in 2012 (Forestry Service of West Java 2013).

The local community of Karangsong village in Indramayu District which is supported by PT. Pertamina Refinery Unit VI Indramayu has initiated a mangrove re-vegetation program on private land (non- forest land) along the ~~north~~ North shoreline of Indramayu District. They started planting mangrove ~~species~~ in 2008 and have consistently extended the area of rehabilitation in a project that has involved many stakeholders. They are also developing an ecotourism program and are practicing sustainable utilization of non-timber mangrove products for generating income to raise local people's prosperity.

The research described here, aimed to study the population dynamics of this mangrove vegetation that has been planted in Karangsong village, Indramayu District.

MATERIALS AND METHODS

This research was conducted in Karangsong ~~village~~Village, Sub District of Indramayu, Indramayu District. The research site is located between 6°17'38.52"S - 6°18'17.52"S and 108°22'03.60"E - 108°22'17.94"E, on the ~~north~~ North coast of Indramayu District. The site is a mangrove habitat combined with coastal habitat and the estuary of the Prajagumiwang River which crosses the Karangsong Village and joins with the Java Sea. This area is part of the Cimanuk watershed, with the main Cimanuk River crossing the territory of Indramayu District. Secondary and primary data were collected on May to June 2016.

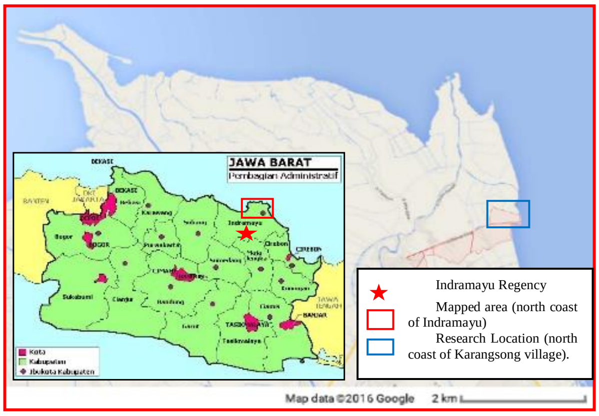

Figure 1. Research location.

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Commented [AM7]: I guess you can find new references for this citation

Commented [AM8]: Due to protection and conservation mangrove area become International program, I suggest you to put broader information regarding it (not only in Indonesia). It also become international readers can be more interested and make your paper stronger.

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~~Data of about the mangrove~~ Mangrove plantation data was collected from the Fishery and Maritime Service of Indramayu District and PT. Pertamina RU VI Indramayu. Information collected included the species, the number of plants, the date of planting, an estimation of the site extent, and details of the institutions and community groups involved in the plantation. In-depth interviews with resource persons and key respondents were needed to complete and confirm the data and information collected. The point count method was applied for the bird survey (Hill et al. 2005) with an observation radius of 50 m: the result was a list of bird species (van Lavieren 1982). Identification of birds referred to the Field Guide for the Birds of Java and Bali (Mackinnon 1991) and Field Guide to the Birds of Borneo, Sumatra, Java and Bali (MacKinnon et al. 1992).

All information and data were analyzed to describe the dynamics of the ecosystem, including the abundance trend, species composition, and diversity and evenness indices of the mangrove population. The results will be used to evaluate the program of mangrove rehabilitation and provide recommendations for future action.

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RESULTS AND DISCUSSION

National Program of Rehabilitation on Forest and Bare Land

The Ministry of Environment and Forestry has launched a National Movement on Forest and Land Rehabilitation (NMFLR). It is a national initiative to plant trees in forest land and bare land, including mangroves, as a commitment to improving the quality of environment for people's prosperity. In the period 2010-2014, the NMFLR program planted 2,279,380 hectares. The national program for rehabilitation of degraded mangrove in the period 2010 – 2014 planted 33,394 hectares (Ministry of Environment and Forestry 2015). In the decade 2003-2012, mangrove rehabilitation in West Java Province through the NMFLR program covered 3,681 hectares (Figure 2) (Forestry Service of West Java Province 2012; 2013a; 2013b; 2016). Rehabilitation of mangrove along the ~~north~~ North coast of Java is crucial, and not only for ecological reasons; the socio-economic arguments are even more significant, due to the threat that mangrove degradation poses to the surrounding communities who depend on mangrove and the fishery it sustains. Gunawan et al. (2007a) reported that the presence of mangrove can improve the quality of water in fish ponds. Gunawan et al. (2007b) also found that mangrove rehabilitation through a silvofishery program can increase the household income of the adjacent community of Subang District, on the ~~north~~ North coast of West Java Province.

Commented [AM12]: I suggest to change or delete this beginning statement due to has been written previously on the line 63-66.

Commented [AM13]: Very descriptive. I suggest to analyze and describe the trend of mangrove rehabilitation in West Java, and how is their contribution to the national program for mangrove rehabilitation and especially from the North Coast of Java.

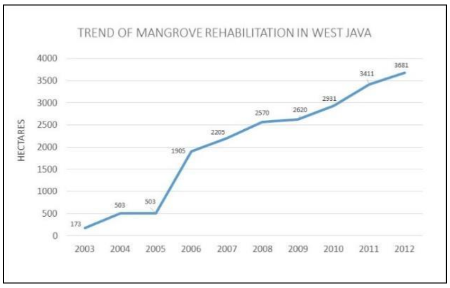

Figure 2. Trend of mangrove rehabilitation in West Java Province.
Sources: Forestry Services of West Java Province (2012; 2013a,b; 2016);
Ministry of Forestry (2007; 2012; 2014); Ministry of Environment and Forestry (2015)

Mangrove Rehabilitation in Karangsong Village, Indramayu District

The revegetation program to rehabilitate degraded mangrove in Karangsong ~~village~~ Village was initiated in 2008 through the planting of three species of mangrove (*Rhizophora mucronata*, *R. stylosa*, *R. apiculata*) covering 2.5 hectares of shoreline ~~in Karangsong Village~~. The plantation was initiated by a group of fishermen named "Kelompok Pantai Lestari" who were supported by PT. Pertamina RU VI Indramayu through the Corporate Social Responsibility ~~(~~(CSR) program. One of the crucial reasons for the involvement PT. Pertamina RU VI, is that the Java Sea to the ~~north~~ North of Indramayu is a route for oil tankers transporting refined oil from Balongan Indramayu to Jakarta. The sea has been polluted by oil spills from tankers, which negatively impacts on the local sea-water quality and ~~on the~~ fishery. The suspicion occurs based on the ~~that this was happening was supported by the research results of~~ Gunawan and Anwar (2008) report, who detected the pollutants Lead (Pb), detergent (MBAS) and Mercury (Hg) in the waters of Subang District ~~,~~ (a District on the ~~north~~ North coast next to Indramayu District). ~~In this area, Gunawan and Anwar~~They found

Commented [AM14]: If you use the taxonomic authority name after species name, please consistent throughout your paper text.

that the lead (Pb) content and detergent (MBAS) of waters were higher than the threshold for fishery culture. Furthermore, ~~They~~ they also found that eight species of fishes and a species of shrimp in silvofishery ponds, and six species of fishes and a species of shrimp in common ponds ~~without mangrove~~ were contaminated with mercury (Hg). However, ~~but~~ the concentration of pollutants in the silvofishery ponds was lower than ~~that of~~ the common ponds.

It is believed that revegetation of mangrove can improve the quality of ~~the coastal~~ sea water and in turn restore the habitat of ~~the~~ biota living in the water. As a corporation who~~that~~ produces and transports oil through the Java Sea to the ~~north~~ North of Indramayu, PT. Pertamina RU VI has a high commitment to restore the mangrove ecosystem and ~~coastal~~ sea water~~s~~ along the ~~north~~ North shoreline of Indramayu. The mangrove revegetation program which was initiated by the people of Karangsong and PT. Pertamina RU VI ~~was~~ has ~~then followed~~ involved ~~by~~ 37~~other~~ community groups (Table 1) and 13 institutions including ~~and supported by~~ NGOs, private sectors, ~~national~~ National government, ~~provincial~~ Provincial government and ~~district~~ District government (Table 2). ~~There are 37 community groups and 13 institutions involved in the development and plantation of mangrove at Karangsong (Table 1 and Table 2).~~ However, ~~The~~ the private sector has a critical role in mangrove rehabilitation at Karangsong (31%) alongside the national government (23 %) (Figure 3). The facts demonstrate that the success of mangrove rehabilitation program depends upon the involvement of all stakeholders. ~~Gunawan & Anwar (2005) similarly found that the~~ A similar success of mangrove rehabilitation ~~that on the north coast of Central Java Province is~~ determined by the participation of the local community has been reported on the North coast of Central Java Province (Gunawan & Anwar (2005)~~around the mangrove area~~.

Table 1. Community groups involved in mangrove revegetation of ~~north~~ North coast of Indramayu District.

Community Group	**Planting Site**		
	Block	**Village**	**Sub District**
Karang Taruna Putra Balongan	Sawah laut, Pertamina, Kesambi, Pesisir, Balongan	Majakerta, Balongan	Balongan
Kelompok Dwi Jaya	Waki	Brondong	Pasekan
Kelompok Karya Muda	Salkri	Lamarantarung	Cantigi
Kelompok Lamaran Jaya	Agus	Lamarantarung	Cantigi
Kelompok LMDH Bangsal Sari	Bangsal	Pagirikan	Pasekan
Kelompok Rapi Jaya Putra	Tiris	Pabean Ilir	Pasekan
Kelompok Tani Anugerah	Kastal	Cangkring	Cantigi
Kelompok Tani Bala Dewo	Blubbuk	Totoran	Pasekan
Kelompok Tani Blubuk Sejahtera	Blukbuk	Totoran	Pasekan
Kelompok Tani Brawijaya Putra	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Jaka Kencana	Udik	Pabean Udik	Indramayu
Kelompok Tani Langgeng Jaya	Singkil Tanah Timbul, Langen	Singaraja	Indramayu
Kelompok Tani LMDH Paluh Adin Jaya	Blubbuk	Totoran	Pasekan
Kelompok Tani Loka Jaya	Muara	Lamarantarung	Cantigi
Kelompok Tani Makmur Jaya	Muara	Lamarantarung	Cantigi
Kelompok Tani Mulia Jaya	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Muncul Jaya Mangrove	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Pal Jaya	Toeni	Lamarantarung	Cantigi
Kelompok Tani Pancer Pindang Jaya	Kastal	Cangkring	Cantigi
Kelompok Tani Pelangi Mangrove	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani PH Pabean Hilir	Bangsal & Keci, Blukbuk	Pasekan, Pabean Ilir	Pasekan
Kelompok Tani Putra Kujang	Kastal, Toeni	Cangkring, Lamarantarung	Cantigi
Kelompok Tani Sea Green	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Sejahtera Mangrove	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Sidum Jaya	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Sigra Mongso	Waki, Kiper	Brondong	Pasekan
Kelompok Tani Sinar Jaya Mangrove	Bangsal & Keci	Pasekan	Pasekan
Kelompok Tani Terumbu Karang	Jangin	Cangkring	Cantigi
Kelompok Tani Tumbuh Hijau	Jangin	Cangkring	Cantigi
Kelompok Tani Tunas Jaya	Bangsal	Pagirikan	Pasekan
Kelompok THP Nandur Jaya	Sawah Laut	Pabean Ilir	Pasekan
Kelompok THP Sumber Urip	Sawah Laut	Pabean Ilir	Pasekan
Kelompok THP Tumbuh Jaya	Perlat	Karanganyar	Pasekan
Kelompok Tunas Lestari	Payang	Pabean Ilir	Pasekan

Commented [AM15]: Why? Please provide more information regarding it!

Kelompok Usaha Bersama Tiris Berseri	Tegur Baru	Pabean Ilir	Pasekan
Kelompok Pantai Lestari*)	Karangsong**)	Karangsong	Indramayu
LSM Siklus	Pabean Udik	Pabean Udik	Indramayu

Source: PT. Pertamina RU VI, Indramayu (year?). *) Manager of Karangsong Mangrove area. ** Karangsong mangrove area

Table 2. Institutions involved in mangrove plantation in ~~north~~ the North coast of Indramayu District and infrastructure development at Karangsong mangrove area.

Institutions	Contribution	Local Counterpart	Site
Kementerian Kelautan dan Perikanan	Planting, Infrastructure	Kelompok Pantai Lestari	Pabean Udik dan Brondong
Balai Besar Wilayah Sungai Cimanuk-Cisanggarung, Kementerian Pekerjaan Umum	Planting, Infrastructure	Kelompok Pantai Lestari	Karangsong
Balai Pengelolaan Hutan Mangrove Wilayah I Bali, Kementerian Lingkungan Hidup dan Kehutanan	Nursery	Kelompok Pantai Lestari	Karangsong
Dinas Perikanan dan Kelautan Prov. Jawa Barat	Planting	Kelompok Pantai Lestari, LSM SIKLUS	Karangsong, Pabean Udik
Dinas Perikanan dan Kelautan Kab. Indramayu	Planting	Kelompok Pantai Lestari	Karangsong
PSL IPB Program Magister Tahun 2014	Planting	Kelompok Pantai Lestari	Karangsong
Alumni Fahutan IPB (Angkatan E.27)	Planting	Kelompok Pantai Lestari	Karangsong
PT. BioFarma Bandung	Planting	LSM SIKLUS	Pabean Udik
PT. PLN	Planting	LSM SIKLUS	Pabean Udik
PT. Traktor Nusantara Jakarta	Planting	Kelompok Pantai Lestari	Karangsong
PT. Pertamina RU VI – Balongan, Indramayu	Planting, Infrastructure	Kelompok Pantai Lestari	Karangsong
MFF Indonesia (Mangrove For Future – UNDP)	Planting	Kelompok Pantai Lestari	Pabean Udik dan Karangsong
Yayasan KEHATI Jakarta	Planting	Kelompok Pantai Lestari	Karangsong

~~Sources:~~ Source: PT. Pertamina RU VI, Indramayu (Year?).

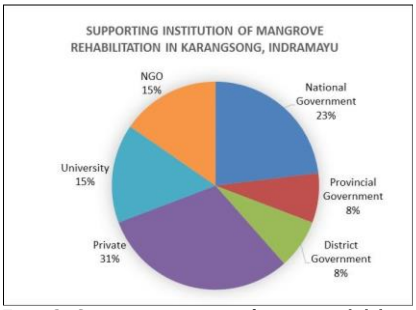

Figure 3. Supporting institutions of mangrove rehabilitation at Karangsong Village, Indramaayu District.

The extent of ~~the~~ rehabilitated mangrove area ~~is~~ has been increasing from ~~year~~ 2008 to 2016~~year~~ in Karangsong Village (Figure 4). ~~There has been a particularly~~A significant increase occurred from 2014 to 2016. In the first semester ~~of~~ 2016, the extent of mangrove revegetation in the ~~north~~ North shoreline of Indramayu District has covered ±69.08 hectares ~~.~~ Karangsong Village in Sub District of Indramayu has the largest area of mangrove revegetation. Mangrove revegetation has been also implemented in other sub districts i.e. Balongan (….heactares), Cantigi (…hecatares) and Pasekan …(hectares) . The cumulative extent ~~of green belt of~~ mangrove revegetation in ~~shoreline of~~ Indramayu District is estimated 103.19 hectares. This increase was triggered by national and international events such as the International Forest Day, Conservation Day, Environment Day, Tree Planting Day, One Billion Trees Program and One Man One Tree conducted at Karangsong and surroundings.

Commented [AM16]: Due to you provided data per year (2008-2016) (fig 4.) I think the significance increase occurred only from 2014 to 2015 not include 2016, right?

Commented [AM17]: It is confused! In fig 4. You showed the extent of mangrove revegetation in Karangsong from 2008-2016 and in first semester 2016 has covered 69.08 ha.

Commented [AM18]: Please provide data from other areas such as Balongan, Cantigi and Pasekan to support the statement that “Karangsong is the largest area of mangrove revegetation”.

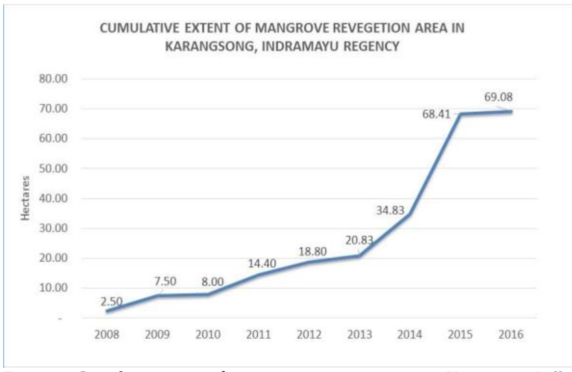

Figure 4. Cumulative extent of mangrove revegetation area at Karangsong Village, Indramayu District.

The increase in the extent of rehabilitated area has been accompanied by an increase in the population of mangrove species (Figure 5). *Rhizophora mucronata* is dominating the plantation (68.85%), followed by *R. stylosa* (18.33 %) and *R. apiculata* (9.53%) (Figure 6). The number of species has also increased from three species in 2008 to nine species in 2016, which consisted of six species of mangrove and three species of coastal vegetation trees (Table 3 and Figure 7). Compared with natural mangrove in Indonesia which consists of trees (at least 47 species), shrubs (5 species), herbs and grasses (9 species), and parasites (2 species) (Kusmana 2011), revegetation at Karangsong still needs to be diversified in terms of the range of species generated in the plantation areas. Increasing the species richness is critical to providing heterogeneous habitat for faunal diversity. The majority of studies have found a positive correlation between habitat heterogeneity/diversity and animal species diversity, although ecological effects of habitat heterogeneity may vary considerably between species groups depending on whether structural attributes are perceived as heterogeneity or fragmentation. Moreover, the effect of habitat heterogeneity for one species group may differ in relation to the spatial scale (Tews et al. 2004).

Although the population number of each species is increasing, the composition is not evenly distributed. This is indicated by the values for diversity and evenness indices. Figure 8 shows the change in values of diversity and evenness indices of mangrove during the period of 2008-2016. The indices have not been continuously increasing. In particular, the mass planting in 2014 – 2016 resulted in a decline in the diversity index as well as evenness index.

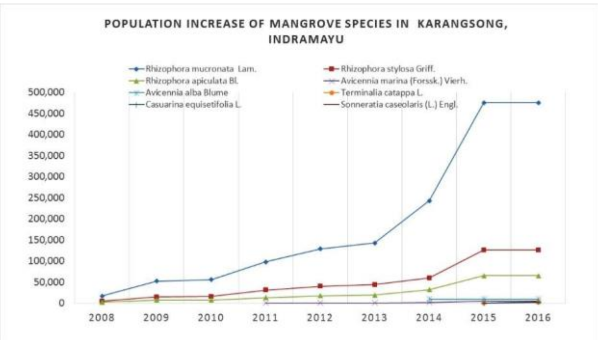

Figure 5. Population increase of mangrove and coastal species at Karangsong Village, Indramayu District.

Commented [AM19]: Please consistent to use the word "District"

This fig. just showed the extent of mangrove revegetation per year from 2008-2016, but not covered the cumulative extent. So please change the title of the fig.

Commented [AM20]: I suggest the discussion here provide the information why these Rhizopora sp is dominated here and even in Southeast Asia? You could use paper from Malik et al. (2015) Mangrove Exploitation Effects on Biodiversity and Ecosystem Services. *Biodiversity and Conservation 24: 3543-3557* and Ellison AM (2000) Mangrove restoration: do we know enough? Restor Ecol 8:219–229 as your references.

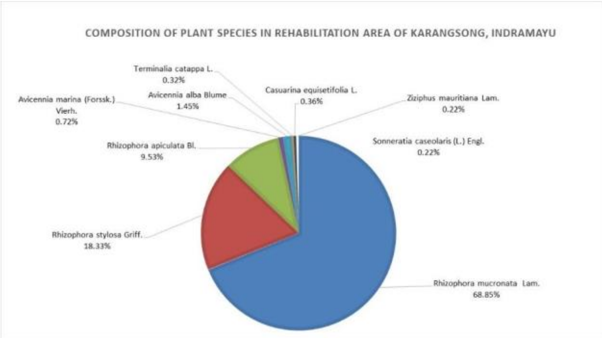

Figure 6. Composition of plant species in the rehabilitation area of Karangsong, Indramayu.

Table 3. List of species at Karangsong rehabilitation area.

Local Name	Botanic Name	Family	IUCN Red List Category	Habitat
Bakau hitam	*Rhizophora mucronata* Lam.	Rhizophoraceae	LC (ver 3.1)	Mangrove
Bakau kecil	*Rhizophora stylosa* Griff.	Rhizophoraceae	LC (ver 3.1)	Mangrove
Bakau minyak	*Rhizophora apiculata* Blume	Rhizophoraceae	LC (ver 3.1)	Mangrove
Api-api	*Avicennia marina* (Forssk.) Vierh.	Acanthaceae	LC (ver 3.1)	Mangrove
Api-api	*Avicennia alba* Blume	Acanthaceae	LC (ver 3.1)	Mangrove
Pidada	*Sonneratia caseolaris* (L.) Engl.	Lythraceae	LC (ver 3.1)	Mangrove
Ketapang	*Terminalia catappa* L.	Combretaceae	LR/nt (ver 2.3)	Coastal
Cemara laut	*Casuarina equisetifolia* L.	Casuarinaceae	NE (ver 3.1)	Coastal
Bidara	*Ziziphus mauritiana* Lam.	Rhamnaceae	NE (ver 3.1)	Coastal

Enrichment planting is critically important to increase the diversity of mangrove in order to enhance quality and heterogeneity of habitats for promoting fauna diversity. Azlan et al. (2015) stressed the importance of diversity and quality of habitat in encouraging the diversity and density of birds in mangroves. Bird species composition in mangroves was closely associated with both plant species composition and configuration of the vegetation structure (Azlan et al 2015). Habitat structure and floristic characteristics is also closely related to species richness and diversity of birds. Larger areas tend to have more diverse habitats, both structurally and floristically, which bird species can occupy, resulting in greater bird diversity (MacArthur & Wilson 1967; Woinarski et al. 2001). Besides being an important factor in contributing to the increase of species richness and diversity, habitat structure is also an important determinant influencing habitat selection and distribution of species, especially in complex habitats such as tropical forest (Watson et al. 2004). Habitat heterogeneity in mangrove is less pronounced and may limit the number of coexisting species (Ford 1982).

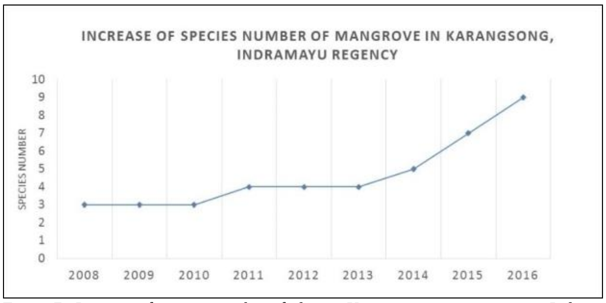

Figure 7. Increase of species number of plant at Karangsong mangrove area, Indramayu.

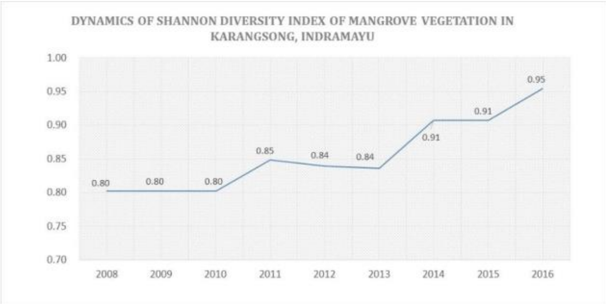

Figure 8. Dynamics of species diversity index of vegetation at Karangsong mangrove area, Indramayu.

Enrichment planting should include an increase in species number and a balancing of the proportions among the species, so that the evenness index increases. Some species of mangrove that could be added to enrich the Karangsong mangrove area are Tanjang (*Bruguiera* sp.), Nyirih (*Xylocarpus* sp.), Tengar (*Ceriops* sp.) and Buta-buta *(Excoecaria* sp.) These have not been planted yet in Karangsong. Sandy coastal habitat should also be enriched with coastal species such as Butun (*Barringtonia asiatica* (L.) Kurz.), Nyamplung (*Calophyllum inophyllum* L.), Bintaro *(Cerbera manghas* L.), Ketapang (*Terminalia catappa* L.), Kampis cina (*Hernandia peltata* Meisn.), Waru (*Hibiscus tiliaceus* L.), Waru laut (*Thespesia populnea* (L.) Sol. Ex Correa), Kepuh (*Sterculia foetida* L.), Dungun (*Heritiera littoralis* Aiton), and Malapari (*Pongamia pinnata* (L.) Pierre).

Impact of Mangrove Revegetation

The presence of mangrove revegetation in the ~~north~~ North coast of Karangsong Village has gradually encouraged birds and other faunas. Twelve families of birds consisting of twenty species were found in mangrove and coastal vegetation ~~at~~ of Karangsong (Table 4). Eight species of water birds were found in the mangrove habitat. These birds are a very common presence in the mangrove of Karangsong and some of them are temporary residents. The area of the North coast of Java still having mangrove is essential habitat for migrant birds. In the N~~n~~orth coast of Indramayu, Iskandar and Karlina (2004) reported 15 species of migrant birds and ~~. S~~some of them ~~migrant birds~~ are consumed and sold by local people for additional income (Iskandar & Karlina 2004). The role of mangrove as habitat of wildlife was also demonstrated by Gunawan (2002). ~~Gunawan (2002)~~He found 77 species of wildlife, consisting of three mammals, six reptiles and 68 birds that directly interacted with the mangrove vegetation in Rawa Aopa Watumohai National Park (RAWNP) Southeast Sulawesi. The mangrove of RAWNP is a secure home for endangered species that depend on mangroves and is a main transit habitat for many seasonally migrant birds.

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Table 4. List of birds species found at Karangsong mangrove area.

Local Name	Latin Name	Family	IUCN Red List Category Ver.3.1
Cekakak sungai	*Todirhampus chloris* Boddaert	Alcedinidae	Least Concern (LC)
Meninting	*Alcedo meninting Horfield*	Alcedinidae	Least Concern (LC)
Walet sapi	*Collocalia esculenta* Linnaeus	Apodidae	Least Concern (LC)
Walet linchi	*Collocalia linchi* Horsfield & Moore	Apodidae	Least Concern (LC)
Kuntul kerbau	*Bubulcus ibis* Linnaeus	Ardeidae	Least Concern (LC)
Kuntul karang	*Egretta sacra* Gmelin	Ardeidae	Least Concern (LC)
Kuntul kecil	*Egretta garzetta* Linnaeus	Ardeidae	Least Concern (LC)
Kuntul perak	*Egretta intermedia* Wagler	Ardeidae	Not Evaluated (NE)
Blekok sawah	*Ardeola speciosa* Horsfield	Ardeidae	Least Concern (LC)
Kokokan laut	*Butorides striata* Linnaeus	Ardeidae	Least Concern (LC)
Cinenen pisang	*Orthotomus sutorius* Pennant	Cisticolide	Least Concern (LC)
Tekukur biasa	*Streptopelia chinensis* Scopoli	Columbidae	Least Concern (LC)
Wiwik kelabu	*Cacomantis merulinus* Scopoli	Cuculidae	Least Concern (LC)
Bondol peking	*Lonchura punctulata* Linnaeus	Estrildidae	Least Concern (LC)
Layang-layang	*Hirundo tahtica* Gmelin	Hirundinidae	Least Concern (LC)
Bentet kelabu	*Lanius schach* Linnaeus	Laniidae	Least Concern (LC)
Gereja erasia	*Passer montanus* Linnaeus	Passeridae	Least Concern (LC)
Cucak kutilang	*Pycnonotus aurigaster* Vieillot	Pycnonotidae	Least Concern (LC)
Kacamata biasa	*Zosterops palpebrosus* Temminck	Zosteropidae	Least Concern (LC)
Kacamata laut	*Zosterops chloris* Bonaparte	Zosteropidae	Least Concern (LC)

The number of mangrove species planted in Karangsong has increased from three in 2008 to nine in 2016, consisting of six species of mangrove and three species of coastal vegetation. The population of each species is increasing, with the dominant species *Rhizophora mucronata* (68.85%), followed by *R. stylosa* (18.33 %) and *R. apiculata* (9.53%). The Shannon's species diversity index was fluctuated but tends to be increase from 0.80 to 0.95. The success of mangrove revegetation depends on the participation of local people and community groups as well as on contributions from the private sectors with support from government at national and local levels. The presence of mangrove has provided habitat for a diversity of fauna, especially for the bird community. Enrichment planting is still needed to increase the diversity of mangrove, which impacts on the diversity of fauna.

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Dynamics of mangrove community in revegetation area of Karangsong, north coast of Indramayu District, West Java, Indonesia

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Abstract. Gunawan H, Sugiarti, Iskandar S. *2017. Dynamics of mangrove community in revegetation area of Karangsong, north coast of Indramayu District, West Java, Indonesia. Biodiversitas 18: 659-665.* Mangrove along the north coast of Java is heavily degraded due to the conversion of land into fish ponds and human settlement areas. A revegetation program has been initiated by the local community of Karangsong Village, Indramayu District, West Java, Indonesia, supported by PT. Pertamina RU VI Indramayu. Our research aimed to study the population dynamics of the mangrove revegetation in Karangsong. Secondary data was collected from the Fishery and Maritime Services of Indramayu and PT. Pertamina. We carried out on-location field observations and we interviewed key respondents. Data was analyzed to describe trends in the diversity index and population dynamics of the mangrove. It was observed that the revegetation effort in the shoreline of Karangsong had covered ± 69.08 hectares which consisting of six species of mangrove and three tree species of coastal vegetation i.e. *Rhizophora mucronata* Lam., *Rhizophora stylosa* Griff., *Rhizophora apiculata* Blume, *Avicennia marina* (Forssk.) Vierh., *Avicennia alba* Blume, *Sonneratia caseolaris* (L.) Engl, *Terminalia catappa* L., *Casuarina equisetifolia* L., and *Ziziphus mauritiana* Lam. The mangrove population increased dramatically, from estimated 25,000 individuals in 2008 to 690,835 individuals in 2016. *Rhizophora mucronata* was the most dominant species (68.85%), followed by *Rhizophora stylosa* (18.33%) *and Rhizophora apiculata* (9.53%). The Shannon diversity index was fluctuated but tend to be increased from 0.80 to 0.95.

Keywords: Karangsong, mangrove, north coast, re-vegetation

INTRODUCTION

There are roughly 166,876 km^2 of mangrove along the shorelines of the world, with the largest proportion of mangrove occurring in Asia (77,169 km^2) and the Americas (43,161 km^2) (Valiela et al. 2001). Countries with the largest area of mangroves are Indonesia (4.25 x 10^4 km^2) (Spalding et al. 1997), followed by Brazil (1.34 x 10^4 km^2) (Spalding et al. 1997), Nigeria (1.05 x 10^4 km^2) (Saenger and Bellan 1995), and Australia (1.00 x 10^4 km^2) (Robertson and Duke 1990).

Globally, the area of mangrove area is declining rapidly as it is cleared and converted to mariculture, agriculture, urban development, logged timber concessions, and fuel production areas (Fortes 1988; Marshall 1994; Primavera 1995; Twilley 1998; Polidoro et al. 2010). At least 35% of the world's mangrove forest area has been lost in the past two decades (Valiela et al. 2001). It is apparent that maricultural practices are responsible for the bulk of the increasing loss of mangrove worldwide. For example, pond culture has been reported to be responsible for 50-80% of the loss of mangrove in Southeast Asia (Wolanski et al. 2000). Most of the damage is attributable to the direct loss of habitat from the conversion of "cheap" mangrove land to "valuable" shrimp, prawn, and fish ponds (Valiela et al. 2001).

In 1999, Indonesia's mangrove forest covered 8.6 million hectares which consisted of 3.8 million hectares of forest area and 4.8 million hectares of nonforest area. Degradation of mangrove in forest area is 1.7 million hectares (44.73%) and in nonforest area is 4.2 million hectares (87.50%) (Gunawan and Anwar 2005). Indonesia has lost 40% of its mangrove in the last three decades (FAO 2007). The deforestation rate for mangrove in Indonesia is estimated to be 6% or 0.05 million hectares of the total annual forest loss (Margono et al 2014; Ministry of Forestry Republic of Indonesia 2014). The Ministry of Forestry has reported that only 31% of the remaining mangrove is in an intact condition and the rest (69%) is heavily degraded (Ministry of Forestry 2007). FAO (2007) reported that mangrove forest in Indonesia is 3,062,300 hectares or 19% of the world's mangrove and still the largest in the world, followed by Australia and Brazil.

Mangrove forest in Java Island is decreasing as the impact of conversion to mariculture, human settlement and other uses worsens. This impact is due to limited understanding and awareness by surrounding communities of the ecological importance of mangrove and uncertainty about land status (Said and Smith, 1997). In 2011, mangrove in West Java Province was estimated as covering 40,130 hectares which were distributed between forest area 32,314 ha (80.52%) and non-forest area, 7,816 ha (19.48%), including 13 regencies (Forestry Service of West Java Province 2013). The degraded mangrove in this province is 15,276 hectares (38.06%), with the largest occurring in Karawang District 13,181ha (32.85%) followed by Bekasi 10,481ha, Indramayu 8,720ha, Subang 7,346 ha, Cirebon 190 ha, Ciamis 170 ha, Garut 32 ha

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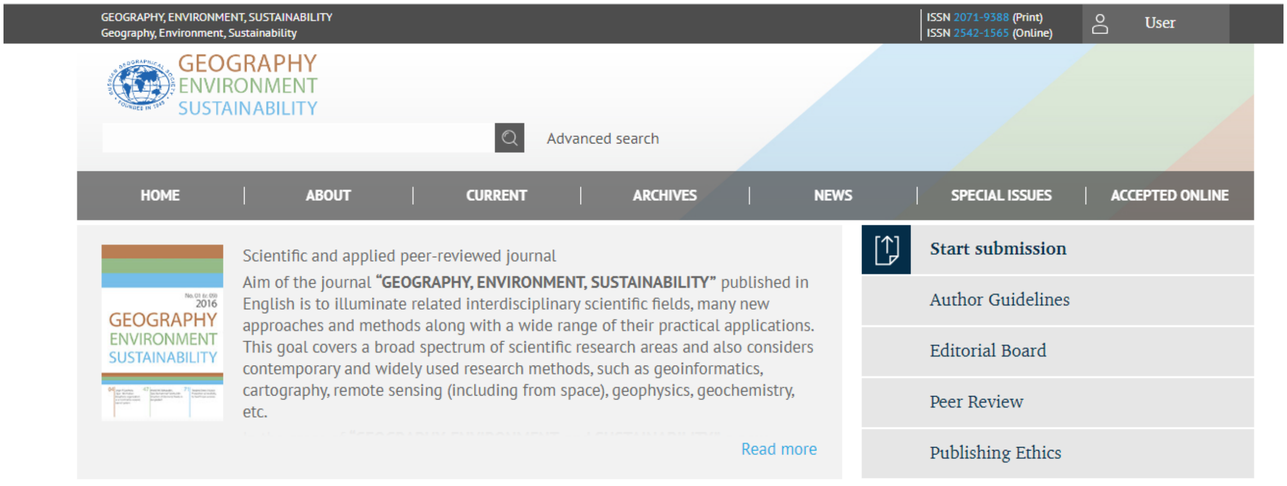

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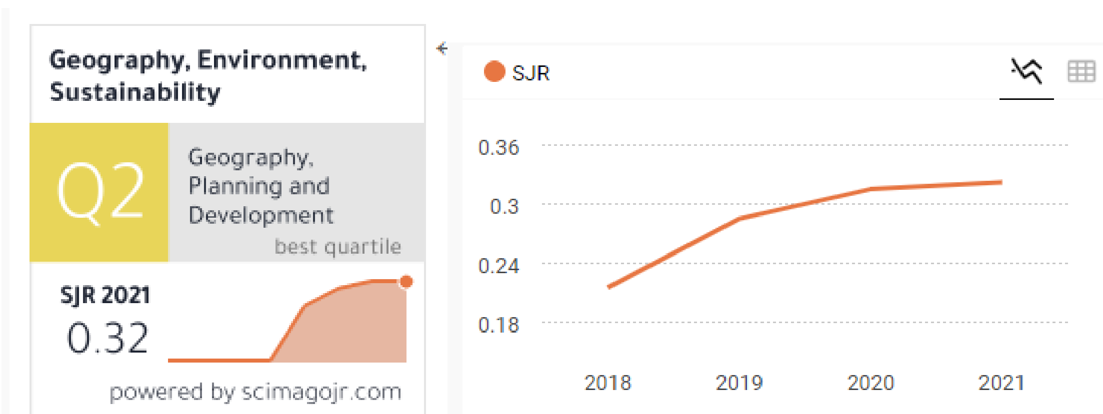

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1 message

Dr. Alexey A. Maslakov <no-reply@subs.elpub.science> Thu, Jan 13, 2022 at 11:36 PM
Reply-To: "Dr. Alexey A. Maslakov" <ges-journal@geogr.msu.ru>
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

We have received the following manuscript to be considered for publication in the Geography, Environment, Sustainability journal:

"Spatial Distribution of Carbon Stock in Southern Bali"

Abstract

Climate change occurs due to an increase in greenhouse gases that accumulate in the atmosphere. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. This study aims to produce a regression model between the vegetation index using NDVI and the carbon stock of vegetation so that carbon stock can be identified easily from Sentinel 2-A satellite imagery and analyze their spatial distribution in Southern Bali. The distribution of carbon stocks was analyzed using a combination of the vegetation index approach and statistical regression analysis. The vegetation index used is NDVI obtained from processing the Sentinel 2-A satellite imagery in 2015 and 2021. The value of vegetation biomass values is derived from allometric equations. After getting the amount of biomass, a regression model was built with the vegetation index. The model with the highest level of accuracy is used to estimate the distribution of carbon stocks in Southern Bali. The results of this study indicate that the best regression model for predicting the value of carbon stock is a quadratic regression model with the NDVI vegetation index variable. The spatial distribution of carbon stocks in southern Bali is in line with the value of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region.

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Nina Komova <no-reply@reg.elpub.science> Mon, Mar 28, 2022 at 11:52 PM
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To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik!

Thank you for completing the review of the submission "Spatial Distribution of Carbon Stock in Southern Bali," (ID 2209) for GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY.

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Research Paper

Spatial Distribution of Carbon Stock in Southern Bali

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Muhammad Dimyati[1], Winda Cantika Putri[2], Astrid Damayanti[3]

[1,2,3]Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, 16424, Depok, Indonesia

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ABSTRACT. Climate change occurs due to an increase in greenhouse gases that accumulate in the atmosphere. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. This study aims to produce a regression model between the vegetation index using NDVI and the carbon stock of vegetation so that carbon stock can be identified easily from Sentinel 2-A satellite imagery and analyze their spatial distribution in Southern Bali. The distribution of carbon stocks was analyzed using a combination of the vegetation index approach and statistical regression analysis. The vegetation index used is NDVI obtained from processing the Sentinel 2-A satellite imagery in 2015 and 2021. The value of vegetation biomass values is derived from allometric equations. After getting the amount of biomass, a regression model was built with the vegetation index. The model with the highest level of accuracy is used to estimate the distribution of carbon stocks in Southern Bali. The results of this study indicate that the best regression model for predicting the value of carbon stock is a quadratic regression model with the NDVI vegetation index variable. The spatial distribution of carbon stocks in southern Bali is in line with the value of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region.

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KEYWORDS:

carbon stock

NDVI

regression model

remote sensing

Sentinel 2-A

ACKNOWLEDGEMENTS

We are grateful to the Ministry of Research and Technology/National Research and Innovation Agency for support and research funding through SIMLITABMAS (Management Information Systems for Research and Community Participation) with the contract number NKB-2649/UN2.RST/HKP.05.00/2020. We also thank the members of the Department of Geography, Universitas Indonesia, for their encouragement.

CONFLICTS OF INTEREST

"The authors reported no potential conflicts of interest."

INTRODUCTION

In the last few decades, environmental issues regarding global warming have become an issue and the center of public attention. Global warming is a threat to the survival of various ecosystems on earth (Abdullah, 2009). Global warming is a form of ecosystem imbalance characterized by an increase in the temperature of the atmosphere, sea, and land (Hasan, 2016). Climate change occurs due to an increase of greenhouse gases that accumulate in the atmosphere (Griggs, 2002). The greenhouse effect keeps the earth's temperature higher than direct heating by the sun (Kweku, et al, 2017). Mitigation of greenhouse gas emissions is carried out as an effort to reduce the negative impact of global warming (Wahyudi, 2016). Various efforts to mitigate climate change have been carried out. Vegetation has an important role in reducing the impact of greenhouse gases as a carbon sink. Carbon sequestration is needed to reduce greenhouse gases in the atmosphere. Increased carbon stocks can reduce the impact of climate change (Nugroho, et al, 2012). On the other hand, the depletion of carbon stocks in an area causes an increase in greenhouse gas emissions (Setiawan, et al, 2020).

Plants absorb carbon and store it in the form of biomass, so increasing carbon stocks value can be done by planting trees and keeping the land vegetated (Zikri, 2015). Monitoring of vegetated land needs to be done to determine carbon stocks in an area. Southern Bali, is in a strategic location, which is at the center of business and tourism growth, so this condition has a major impact on vegetated land in the four districts (Kurniawan, 2019). The conversion of land into built-up lands such as settlements, recreation, and tourism areas, trade and shopping centers, and industrial centers is increasing, especially in urban areas (Sinaga, et al, 2018). The spatial description of land use change in Bali Province shows that the areas experiencing the largest land use changes are the central to southern regions of Bali Province (As-syakur, 2011). In this study, the researcher used remote sensing methods to estimate the distribution of carbon stocks in Southern Bali. Remote

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Sensing together with Geography Information System applications can provide quantitative information to determine the spatial distribution of vegetation (Giri, et al, 2008). To calculate the biomass estimation using remote sensing, it is done by connecting the biomass value obtained from the results of field measurements with the transformation of the vegetation index in the image (Nabila, 2019). The researcher uses the non-harvesting data collection method to collect vegetation biomass data and uses remote sensing and regression analysis to calculate the estimated carbon stock value because it is considered a potential method and also a practical method (Heumann, 2011).

Several previous studies related to carbon stock estimation were used as a reference in this study. Allometric equations for each type of vegetation were obtained in the research of (Marwah, et al, 2008) and (Nabila, 2019). Comparison of Landsat 8 OLI and Sentinel 2-A images for carbon stock estimation by (Astriani, et al, 2017). Research on forest carbon stock estimation was conducted by Widhi in Tesso Nilo National Park, Riau using Landsat 8 Imagery (Widhi, et al, 2014). Research by Simarmata, Elyza, & Vatiady in 2019 to examine the use of SPOT 7 imagery to estimate carbon stocks in mangrove forests as an effort to mitigate climate change in South Lampung (Simarmata, et al, 2019). Research by Suhardiman & Mardiyatmoko in 2017 to estimate carbon stocks in the Tenggarong urban area using the NDVI method on Sentinel Image 2-A (Suhardiman, et al, 2017). Research by Frananda, Hartono, & Jatmiko in 2015 in comparing the vegetation index for the estimated carbon stock of mangrove forests in Alas Purwo National Park Banyuwangi, East Java (Frananda, et al, 2015). Research by Pambudhi, Murti, & Zuharnen to estimate forest carbon stock in Long Pahangai District, West Kutai Regency using Alos Avnir-2 Image in 2012 (Pambudhi, et al, 2012). Research conducted by Nabila is also related to carbon stock estimation by using Sentinel 2-A imagery for the development of a model for estimating carbon stocks in vegetation stands in Kendari City (Nabila, 2019). The difference between this research with the previous researches in the previous researches just researched the distribution of carbon stocks in a region with a high accuracy model but did not research further to see carbon stock changes, so that in this study technically usability the geography information system was able to explain spatial phenomena that occurred in the research area.

The aims of this study are: (1) determine the best regression model in estimating carbon stocks with the highest level of accuracy, and (2) map the distribution of carbon stocks in southern Bali. The difference in this study with previous research is the combination of the use of 2-A sentinel data statistical analysis to estimate carbon stocks and research about the carbon stock changes, so that this study technically use the geographic information system to explain the spatial phenomena

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Commented [AM9]: The aims of the study should be improving to “detect of biomass carbon stock changes in Southern Bali from 2015 to 2021” that occurred in the research area. The NDVI vegetation index data (Normalized Difference Vegetation Index) is used as the main input to estimate carbon stock by applying statistical regression for Southern Bali.

MATERIALS AND METHODS

Study Area and Variable

The research location was conducted in Southern Bali which included Badung Regency, Gianyar, Tabanan, and Denpasar City. Geographically, the province of Bali is located on the island of Bali at114° 25' 53" - 115° 42' 40" BT dan 8° 3' 40" - 8° 50' 48" LS. The province of Bali consists of 8 districts and 1 city, named Tabanan, Badung, Gianyar, Jembrana, Klungkung, Bangli, Buleleng, Karangasem Regency, and Denpasar City (BPS, 2016). The satellite image data used in this study is the 2-A sentinel image obtained from USGS in March 2015 and 2021. The 2-A sentinel image has a wavelength ranging from 443 Nm to 2190 nm. These satellites are equipped with multi-spectral instrument sensors (MSI) to measure a reflection of 13 spectral bands (Adini, 2018).

Mapping land cover and vegetation density in Southern Bali

Land cover classification is processed using the supervised classification method and maximum likelihood analysis. Supervised classification was chosen because it is considered to be easier to recognize particular objects. This classification technique is done using several pixel sampling methods for each class or object, so it gets the characteristics of pixels in each class or object. All pixels that are not used as samples will be grouped with pixel values of sample characteristics by applying statistical calculations (Kiefer & Lillesand, 1990). The classification of land cover is divided into 5 classification classes, which are waters, built area, forests, bare land, and agriculture (Badan Standardisasi Nasional, 2012).

To process the land cover classification using supervised classification, the steps taken are to make the data training set become a classification reference. In this study, researchers took 30 points of land cover training in each classification class with even distributions in Southern Bali. After classification, validation by comparing data training sets with 50-point accuracy test data divided into each classification class with even distribution. To map the vegetation density in Southern Bali, NDVI is the algorithm that used in this study to transform the vegetation index. NDVI is a signal processing algorithm used to observe the state of vegetation. Every vegetation density found a collection of varying individuals that cover the surface of the land [26]. NDVI has a value ranging from -1.0 to 1.0 (Arhatin, 2007). The transformation of the NDVI vegetation index is carried out by entering the formula or algorithm and calculated using Google Earth Engine. The results of the calculation of the NDVI value will then be used for regression analysis in determining the model that has high accuracy and is used to estimate the value of carbon stock in southern Bali. The NDVI vegetation index is calculated on each pixel based on the difference between Band 4 (Red) and band 8 (NIR). The calculation of the NDVI formula can be seen in equation 3 (Khoirunnisa, et al, 2020).

NDVI = (NIR-R)/(NIR+R) (3)

NIR: near-infrared band; and R: red band

To analyze the health of vegetation and density, the vegetation density class is divided into 5 classes as in Table 1, which is non-vegetated area, very low, low, medium, high (Vision of Technology (VITO), 2017). The calculation of the NDVI formula can be seen in equation 3 (Khoirunnisa, et al, 2020).

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Table 1. Vegetation Density Class

Class	Density Class	NDVI Value	Land Cover
1	Non-Vegetated Area	-0,79 – 0,12	Waters, Bare Land
2	Very Low	0,12 – 0,22	Built Area
3	Low	0,22 – 0,42	Agriculture
4	Medium	0,42 – 0,72	Agriculture
5	High	0,72 - 1	Forest

Source: *Vision of Technology* (VITO), 2017

Data Normality Test

The data normality test in this study needs to be done before making carbon stock distribution maps. It aims to see normality in field data obtained as a condition before conducting regression analysis. Regression analysis can be done if the data is normally distributed (Sukestiyarno, 2017). The normality test is used in this study to find out the variables that will be tested, namely the NDVI vegetation index and field carbon stocks are normally distributed or not. The normality test was carried out using the 5% test rate ($\alpha = 0.05$) (Jonatan, 2018). The normality test is done by KS Test (Kolmogorov-Smirnov) using the SPSS application. The Kolmogorov-Smirnov test was used in this study due to the more appropriate Kolmogorov-Smirnov test used for samples of more than 50 (Dahlan, 2009). This equation uses a hypothesis, namely, Ho is rejected or the data is not normally distributed if the P-value <0.05, while Ho is accepted if p-value> 0.05 or normal distribution data (Faradiba, 2020). Tests are carried out using the Kolmogorov Smirnov test with a formula in equation 4.

KS = |Fn (Yi-1) – Fo (yi)| (4)

KS: The value of Kolmogorov-Smirnov; Fn (Yi-1): The frequency of the percentage of cumulative at the time before I; and Fo (yi): frequency of normal distribution data at the time i.

Carbon Stock Modelling

Carbon stock models are carried out using regression analysis. The simple regression model was used in this study because this study only has one independent variable (x) (Hijriani, 2017). This regression model is used to express functional relationships between one or several independent variables (predictors) of one bound variable (response) (Imran, 2014). In regression analysis, estimates the parameters automatically estimate the regression model (Tarno, 2007). Some regression methods used for estimates are as follows (Hartono, 2011):

a. Linear model

y = a.x + b (5)

b. Exponential model

y = a.eb.x (6)

c. Logarithmic model

y = a + b In(x) (7)

d. Quadratic model

y = ax2+bx+c (8)

The regression model was chosen by Karnea assumed that there was a linear connection between carbon stocks and the vegetation index. The four regression models were chosen to be used in this study because the four models were previously studied in research related to the appropriate regression method for forecasting studied by Hermanto & Rizqika, 2019. The formation of the regression model is carried out using the SPSS (statistical product and service solutions) application. The model of carbon stock value is built using the NDVI pixel value. The selection of the regression model is best tested based on the R2 value obtained with equation 9 and the accuracy test with RMSE (Root Mean Standard Error) in equation 10. The regression method selected from this method is the regression method that produces the largest R2 value and the smallest RMSE value which will be used for the estimation of biomass and carbon stock in this study.

$$R^2 = \frac{Number\ of\ quadratic\ regression}{Number\ of\ Quadratic\ Regression} \text{ x } 100\% \quad (9)$$

Accuracy Test and Mapping of Carbon Stock

The model accuracy test is done by comparing the measurement data from field data samples with predictive data or regression models. Carbon stock field data is calculated using the allometric model to calculate plant biomass, and then the biomass value is converted into the carbon stock value. The RMSE value is obtained by conducting a validation test to determine the irregularities of the carbon value estimated based on the four regression models built with carbon stocks in the

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field. A validation test is done to find out the model that has the best accuracy of all the models that have been built. The validation test is carried out with the RMSE test (Root Mean Standard Error), which is calculated using the formula in equation 10 (Syariz, 2015).

$$\text{RMSE} = \sqrt{\frac{(y - y')^2}{n - 2}} \qquad (10)$$

y: field carbon stock; y ': carbon stock model; and n: sample point number.

After the accuracy test is carried out, the regression model that has the smallest RMSE value will be used to map the distribution of carbon stocks in southern Bali. The distribution of carbon stocks in southern Bali is obtained by entering the best regression equation (Wijaya, 2017). This calculation was carried out with a 2-A sentinel satellite image in the 2015 research year and 2021.

RESULTS AND DISCUSSION

Vegetation Indices Classification

The results of Sentinel-2A image processing with NDVI algorithm calculations produce pixel values ranging from 0 to 1. **Fig. 1.** shows that the Southern Bali region is dominated by medium to high vegetation density that dominates in the southern and north of the research area. Whereas the class of very low and low density dominates in the central part of the research area which includes Denpasar City and Central Badung Regency which covers Kuta District. The low-density class is also spread in the southern part of Badung Regency which includes South Kuta District and the southern part of Gianyar Regency.

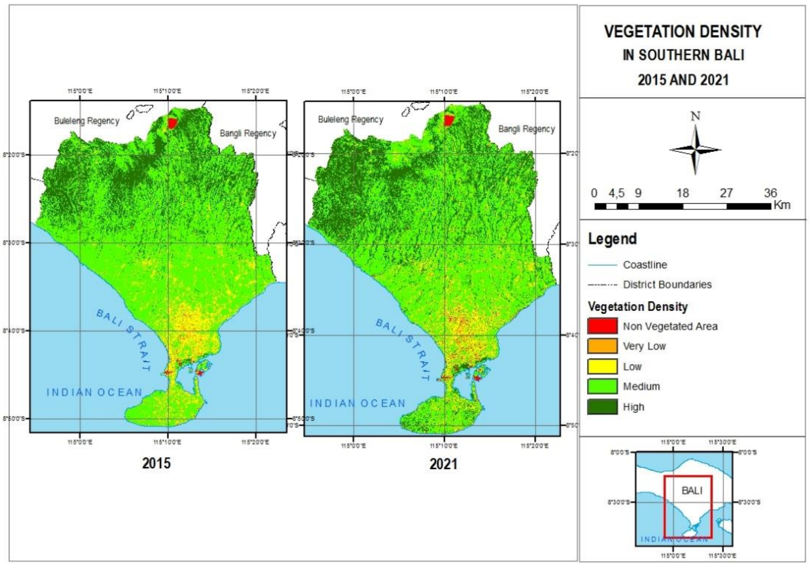

Fig. 1. Classification of Vegetation Density with NDVI

Data Normality Test

Based on **Table 2**, it is known that the significance in the KS test is 0.200 and the SW test is 0.564 which means greater than 0.05, so it can be said that the data is normally distributed with a significance value of more than 0.05. After the data used is known to be normally distributed, it can use the regression model.

Table 2. Normality Test

. Item	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	0,064	100	0,200*	0,989	100	0,564
Note: *. This is a lower bound of the true significance; and a. Lilliefors Significance Correction						

Carbon Stock Modelling by Vegetation Indices

The regression model was formed using the pixel values of the NDVI vegetation index. The models formed are as many as 4 models, namely linear, logarithmic, quadratic, and exponential models**. Fig. 2.a** shows the regression model between carbon stock and NDVI value using linear regression has an R^2 value of 0.854. Meanwhile, **Fig. 2.b** shows the logarithmic regression between carbon stock and the NDVI value has an R^2 of 0.825. **Fig. 2.c** shows the quadratic regression between carbon stock and NDVI value, which has an R^2 value of 0.854. **Fig. 2.d** shows the regression model between carbon stock and NDVI value using exponential regression has an R^2 value of 0.844. Based on this regression model, the linear and quadratic regression models have the highest R^2 value between the other models.

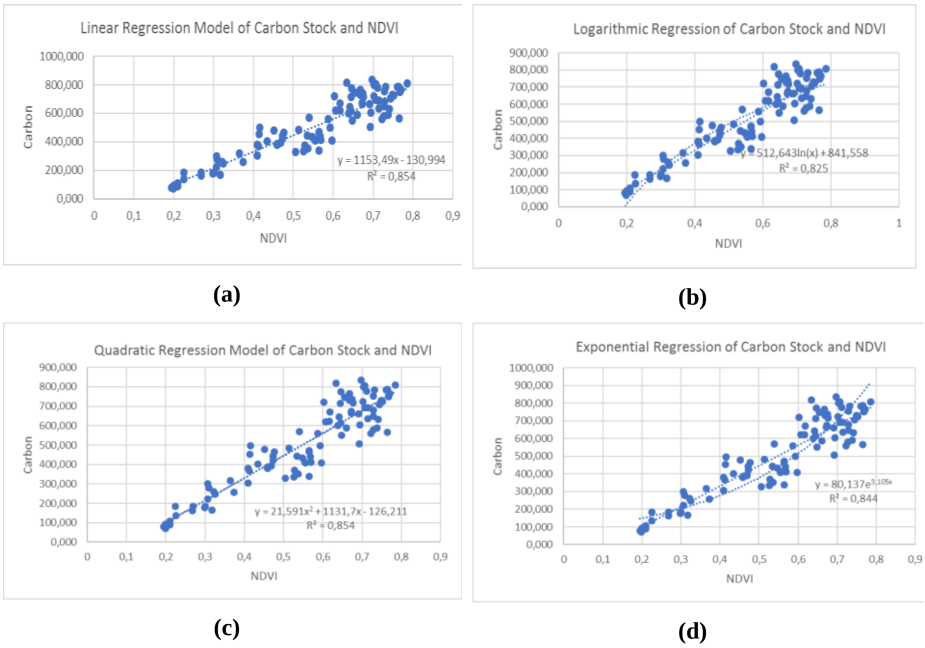

Fig. 2. (a) Linear Regression Model, (b) Logarithmic Regression Model, (c) Quadratic Regression Model, and (d) Exponential Regression Model

Accuracy Test

Table 3 shows the results of the RMSE calculation of the carbon stock regression model. The four models each have an RMSE value which is 81.58 for the linear regression model, 88.79 for the logarithmic regression model, 81.28 for the quadratic regression model, and 99.20 for the exponential regression model. Based on the RMSE calculation between the 4 regression models and the field carbon stock, the lowest RMSE value was found in the quadratic regression model which is 81.28. This value indicates that each carbon stock produced by the model has an average value difference of 81.28 or equal to 81.28 kg per 100 m^2 in 1 plot size.

The results of this data processing indicate that the best regression model for mapping the distribution of carbon stocks in Southern Bali is quadratic regression analysis with the model equation $y = 21.591x^2 + 1131.7x - 126.211$. This regression analysis has a coefficient of determination (R^2) of 0.854 and has the smallest RMSE value compared to the other three models, which is 81.28.

Table 3. RMSE Calculation of Carbon Stock Regression Model

No.	Regression Model	Model	RMSE
1.	Linear	$y = 1153{,}49x - 130{,}994$	81,58
2.	Logarithmic	$y = 512{,}643\ln(x) + 841{,}558$	88,79
3.	Quadratic	$y = 21{,}591x^2 + 1131{,}7x - 126{,}211$	81,28
4.	Exponential	$y = 80{,}137e^{3{,}105}$	99,20

Source: Data processing, 2021

Distribution of Carbon Stock in Southern Bali

Based on the calculation of carbon stock using a raster calculator on Sentinel 2-A images that have been transformed into Vegetation Density Class (NDVI) in Southern Bali 2015 and 2021, the carbon stock values range from 0 to more than 700 kg/pixel. The map of the carbon stocks distribution in Southern Bali 2015 (Figure 3) shows that carbon stocks in the range of 0-100 kg to 200-300 kg dominate in Denpasar City and Central Badung Regency which includes Kuta District. Carbon stocks in the range of 200-300 kg and 300-400 kg are scattered in the southern part of Badung Regency which includes Kuta and Mengwi Districts, and in the southern part of Gianyar Regency. Carbon stocks in the range of 400-500 kg dominate in the southern part of Badung Regency, the eastern part of Badung Regency, and the southern part of Gianyar Regency. Carbon stocks in the range of 500-600 are scattered in the southern part of Badung Regency which includes South Kuta and Mengwi Districts, the eastern part of Tabanan Regency, and the southern part of Gianyar Regency. Carbon stock in the range of 600-700 to >700 dominates in the western and northern parts of Tabanan Regency, the northern part of Badung Regency, and northern part of Gianyar Regency.

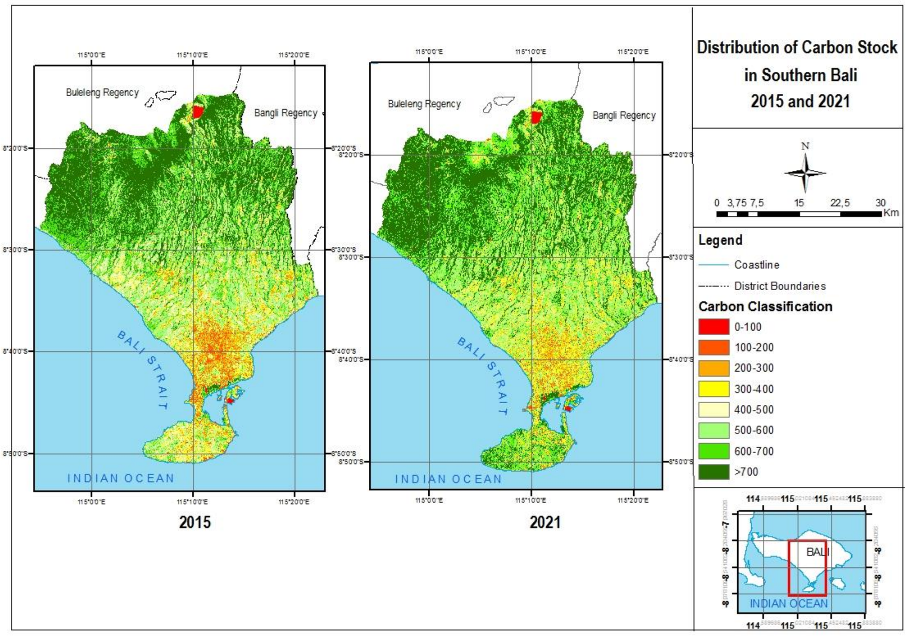

Fig. 3. Carbon Stock Distribution of Southern Bali in 2015 and 2021

Source: Data Processing, 2021

The map of the carbon stocks distribution in Southern Bali 2021 shows an increase of the carbon stocks value in Southern Bali which is marked by changes in light yellow and light green colors to green and dark green in the southern part of Badung Regency, decreasing dark orange and red colors to orange, light and yellow in Denpasar City, and a light yellow color change to light green in the eastern part of Tabanan Regency and the southern part of Gianyar Regency. The increase in carbon stock is also seen in the mangrove forest area in Benoa Bay which changes its color from green to dark green.

Table 4. Area of Carbon Stock Classification in 2015 and 2021

Carbon Stock (Kg)	Area (Ha)		Area (%)	
	2015	2021	2015	2021
0-100	527,13	535,66	0,30	0,30
100-200	3930,11	2331,71	2,23	1,32
200-300	8982,87	6277,65	5,09	3,56
300-400	13047,43	12165,183	7,39	6,89
400-500	23237,89	21541,49	13,16	12,20
500-600	36383,62	32469,02	20,61	18,39
600-700	35737,44	37308	20,24	21,13
>700	54692,133	63916,23	30,98	36,20
Total	176538,623	176544,943	100	100

Source: Data Processing, 2021

The area of carbon stocks in 2015 and 2021 is shown in **Table 4**. The table shows a very visible dominance in the range of carbon stock values of more than 700 kg. Based on these data, this shows that the classification of carbon stocks that experienced changes in the area was mostly experienced in the range of >700 kg which increased by 5.22% of the total area of the study area.

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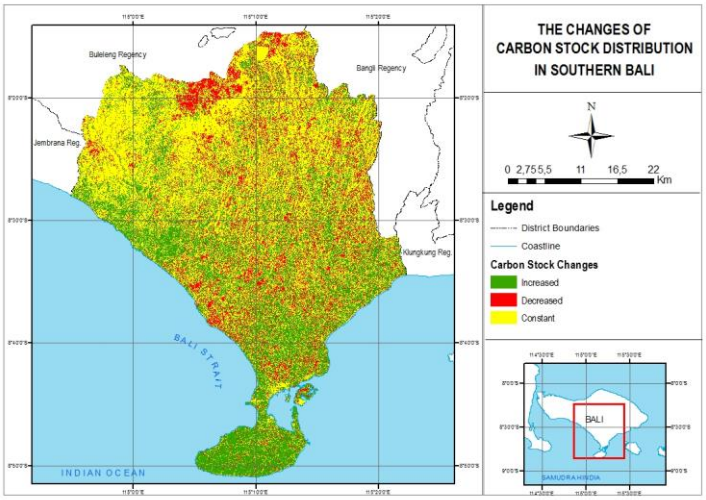

Fig. 4. Changes of Carbon Stock Distribution in Southern Bali 2015 and 2021

Source: Data Processing, 2021

The changes in Carbon Stock Distribution value in Southern Bali are classified into 3 classification classes, namely increasing, constant, and decreasing (**Fig. 4.**). Changes in carbon stocks that have increased are found in the southern part of Badung Regency which includes South Kuta District, the southern part of Tabanan Regency, the southern part of Gianyar, and northern part of Denpasar City. Changes in carbon stocks that have decreased are found in the southern and eastern parts of Denpasar City, the northern part of Tabanan Regency, and spread in the northern part of Badung Regency, and the central to the northern part of Gianyar Regency. Data analysis using the overlay technique to see changes in carbon stocks is an advantage of this study, in previous studies conducted by Nabila [13]; Mardiyatmoko & Suhardiman [19]; Frananda, Hartono, Jatmiko [20] were only to map the distribution of carbon stocks in areas with high accuracy models but did not investigate further to see changes in carbon stocks so that in this study the technical use of Geographic Information Systems can explain spatial phenomena that occur in the research area.

Table 5. Area of Carbon Stock Changes in 2015 and 2021

Changes of Carbon Stock	**Area (Ha)**
Increased	59455,42
Decreased	19247,34
Constant	87454,78

Source: Data Processing, 2021

Overall, the results of processing data (**Table 5**) on the change of carbon stocks distribution shows that Southern Bali has a carbon stock that tends to increase. Carbon stocks that experience a constant value also tend to increase, this is because, under normal conditions, the age of vegetation will increase every year so that carbon stocks will continue to increase. The increase in carbon stock is in line with changes in the vegetation index from low to high, as shown in **Figure 1**.

CONCLUSIONS

The best regression model to predict the value of carbon stock is a quadratic regression model with NDVI vegetation index variable. The regression model produces good predictive power and has good accuracy for estimating the spatial distribution of vegetation carbon stocks in Southern Bali. Overall, the carbon stocks value in Southern Bali tends to increase from 2015 to 2021 and the

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Many of previous findings stated the Diameter Breast High (DBH) size of trees have a great influence to carbon stocks. Also, dense of tree and anthropogenic activities can impact carbon stocks of tree.

spatial distribution of carbon stocks in Southern Bali is in line with the distribution of the vegetation index. The denser the vegetation index from 2015 to 2021, the higher the carbon stock in the region

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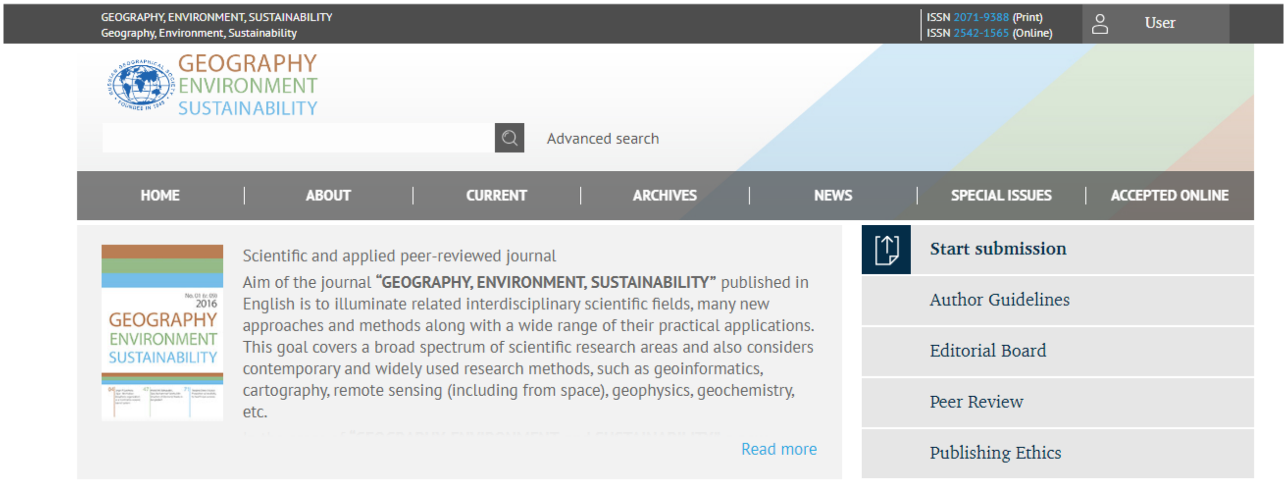
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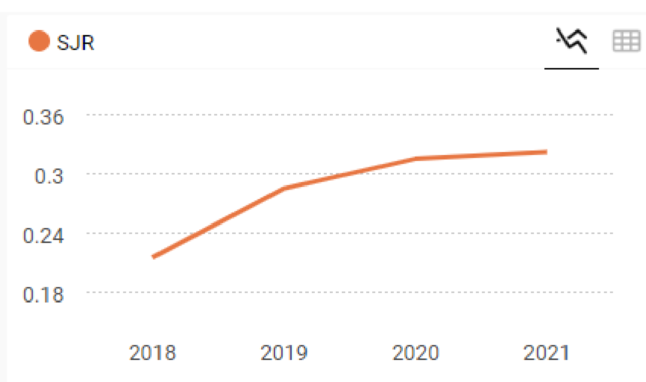

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"***CO2 UPTAKE IN ARTIFICIAL AND NATURAL MANGROVE FORESTS OF SOUTH VIETNAM***"

Abstract

Mangrove forests are one of the most productive and efficient long-term carbon sinks. Mangroves have experienced large-scale deforestation and conversion to other land uses, particularly in Southeast Asia. Present time the conservation of mangrove carbon stocks has been promoted in global climate negotiations due to their potential contribution to mitigating GHG emissions. However, uncertainty of estimating of CO2 fluxes remains recently due to geographical variability of mangrove forests and field data limitations. The paper presents the results of photosynthesis studies at the leaf level in-situ of seedlings of Rhizophora apiculata Blume, 1827 of natural and artificial origin. The research was carried out in a mangrove plantation located in the Can Gio Biosphere Reserve, located 50 km from Ho Chi Minh City (South Vietnam). The photosynthesis CO2 uptake was measured using a Portable Photosynthesis System LI-6800 (Li-Cor Inc., USA). The photosynthetic radiation is determining factor influencing the photosynthesis of the investigated seedlings of R. apiculata. Artificial seedlings growing in an open area had higher productivity and better photosynthetic performance. It was found that the obtained values of photosynthesis are distributed in three clearly marked zones, corresponding to the values of photosynthesis obtained in the pre-noon, noon and afternoon. The main inhibitory factor affecting the photosynthesis of R. apiculata is the disturbance of the water balance of the leaves. The optimum air temperature for the processes of photosynthesis in seedlings is (35 ± 2) °C. With an increase in the concentration of CO2 in the air, the intensity of photosynthesis also increases.

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Dear Abdul Malik!

Thank you for completing the review of the submission "*CO2 UPTAKE IN ARTIFICIAL AND NATURAL MANGROVE FORESTS OF SOUTH VIETNAM*," (ID 2515) for GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY.

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ABSTRACT. Mangrove forests are one of the most productive and efficient long-term carbon sinks. Mangroves have experienced large-scale deforestation and conversion to other land uses, particularly in Southeast Asia. ~~Present time~~Currently, the conservation of mangrove carbon stocks has been promoted in global climate negotiations due to their potential contribution to mitigating GHG emissions. However, the uncertainty of estimating ~~of~~ CO_2 fluxes remains recently due to the geographical variability of mangrove forests and field data limitations. The paper presents the results of photosynthesis studies at the leaf level in-situ ~~of~~ seedlings of *Rhizophora apiculata* Blume, 1827 of natural and artificial origin. The research was carried out in a mangrove plantation located in the Can Gio Biosphere Reserve, ~~located~~ 50 km from Ho Chi Minh City (South Vietnam). The photosynthesis CO_2 uptake was measured using a Portable Photosynthesis System LI-6800 (Li-Cor Inc., USA). ~~The p~~Photosynthetic radiation is determining factor influencing the photosynthesis of the investigated seedlings of R. *apiculata*. Artificial seedlings growing in an open area had higher productivity and better photosynthetic performance. It was found that the obtained ~~values of photosynthesi~~photosynthesis values are distributed in three clearly marked zones, corresponding to the values of photosynthesis obtained in the pre-noon, noon, and afternoon. The ~~reserves of water~~water reserves consumed in the midday time did not fully recover from the seedlings in the afternoon. The main inhibitory factor affecting the photosynthesis of R. apiculata (if we do not take into account PAR) is the disturbance of the water balance of the leaves. The optimum air temperature for the processes of photosynthesis in seedlings is (35 ± 2) °C. With an increase in the concentration of CO_2 in the air, the intensity of photosynthesis also increases.

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KEYWORDS: *Rhizophora apiculata*, air temperature, CO_2 concentration, diurnal dynamics, intensity of photosynthesis, light response curve

CONFLICTS OF INTEREST

The authors reported no potential conflicts of interest.

INTRODUCTION

Mangrove forests are one of the unique forest ecosystems. They are an important part of tropical coastal ecosystems. Being of great ecological importance, mangroves also fulfill protective and economic functions (Donato et al. 2011; Hogarth 2007; Hogarth 2008; Simard et al. 2019; Saintilan et al. 2020).

However, the degradation of mangrove ecosystems is currently being observed (Alongi 2002; Valiela et al. 2001; Nguyen 2000). This is due both to economic activity, which mainly consists of the deforestation of these forests (Luong 2014) and to the ongoing global warming (Desherevskaya et al. 2013), which results in both sea-level rise and the associated flooding of mangrove forests, as well as the drying up of individual mangrove ecotopes (FAO 2007; Simard et al. 2019).

Thus, the study of mangrove forests is of undoubted interest to scientists. One of the main directions of such research is research related to the study of the physiological characteristics of mangroves. The most significant of these are studies related to their gas exchange (Clough 1997). Nevertheless, despite sufficient knowledge in this area of research, many questions remain in the shadows. In particular, this applies to the mangroves of Vietnam.

According to our estimates, one of the most common tree species in the mangrove forests of South Vietnam is *Rhizophora apiculata* Blume, 1827. This species is widely used in reforestation activities (Hogarth 2007). Forming grandiose plantations due to its stilted roots, *R. apiculata* plays an important role in the ecology of mangrove forests (Thongjoo et al. 2018; Wenfang et al. 2020). Of undoubted interest is the fact that *R. apiculata* belongs to plants with C4 photosynthesis, which allows the plant to better adapt when growing in conditions of high temperatures and lack of water (Ehleringer and Björkman 1977; Slack and Hatch 1967). Therefore, it is not accidental that many researchers pay attention to this species (Christensen 1978; Ong et al. 1995).

Our previous studies carried out on mature *R. apiculata* trees showed that photosynthesis depression in these trees began to manifest itself at noon and was observed until the end of daylight hours (Đỗ Phong Lưu et al. 2021). In accordance with this, we put forward a hypothesis that the parameters characterizing the photosynthetic abilities of *R. apiculata* should differ at different times of the day. We did not find any studies confirming or refuting our assumption. We also assumed that the indicated parameters should also differ in plants growing in different conditions.

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In accordance with the hypothesis put forward, the purpose of the work was determined: to study the daily variability of the parameters of the photosynthetic ability of *R. apiculata* seedlings of artificial and natural origin.

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In accordance with the purpose of the work, the following tasks were set: to obtain daily dynamics of the intensity of photosynthesis for seedlings of artificial and natural origin, to model the response curves of photosynthesis to light according to the Michaelis-Munten equation (1), to obtain the dependence of photosynthesis on temperature and CO_2 concentration in the air, to conduct analysis of the obtained results.

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This article presents the results of our research related to the study of the photosynthetic exchange of CO_2 at the leaf level *in-situ* of seedlings of *R. apiculata* of natural and artificial origin. These results can be used to recalculate photosynthesis at the leaf level, down to the planting level. Also, the results obtained will contribute to predicting the growth of plants of this species both in the current period of time and in the future in connection with global climatic changes. In practice, the research results will be useful in the development of reforestation measures.

MATERIALS AND METHODS

Study site, plant material and growing conditions

The research was carried out in July 2020 in a mangrove plantation located in the Can Gio Biosphere Reserve, located 50 km from Ho Chi Minh City (10°28′36″N, 106°54′17″E) (South Vietnam). Seedlings of *Rhizophora apiculata* Blume, 1827, about 5 years old, of artificial and natural origin, were chosen as the test material.

Artificial seedlings grew in an open area and were intended for reforestation activities (Fig. 1a). The number of studied seedlings n = 27, their average height h = 57 cm (Standard Deviation, *SD* = 7 cm), the average number of leaves per seedling N = 35 (*SD* = 16).

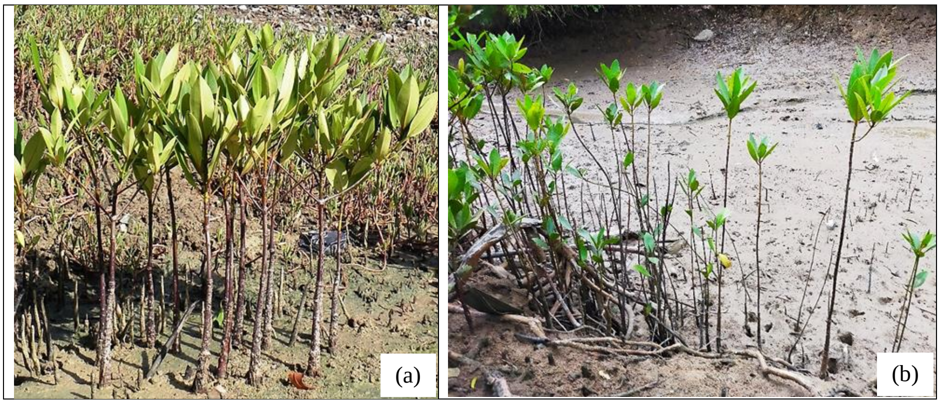

Fig. 1. Studied seedlings of *R. apiculata* of artificial (a) and natural (b) origins

Natural seedlings grew along the edge of the water channel on its northern side (Fig. 1b). The seedlings were formed as a result of the germination of floating fruits that were washed ashore. At noon, the seedlings were shaded by the trees and shrubs growing behind them. Seedling parameters: n = 14, h = 88 cm (*SD* = 8 cm), N = 10 (*SD* = 5).

Twice a day, both sites were flooded with water as a result of sea tides.

Measurement of photosynthetic gas exchange and experimental design

Photosynthesis processes were considered from the standpoint of CO_2 gas exchange. The rate of photosynthesis (photosynthesis) was measured using a Portable Photosynthesis System LI-6800 (Li-Cor Inc., USA). For artificial illumination of the investigated part of the sheet, a 3 × 3 cm light source was used, supplied by the LI-6800 manufacturer as an addition to the device. The emission spectrum of the light source consists of red (λ = 660 nm) and blue (λ = 453 nm) colors. When using it, the object was illuminated with light, consisting of red and blue colors in a ratio of 9: 1. During measurements under natural light, photosynthetically active radiation (PAR) was measured using a sensor located in the LI-6800 measuring chamber.

During measurements, the required microclimate parameters were set in the LI-6800 measuring chamber - object illumination, air temperature and humidity, and CO_2 concentration.

For the study, we used the formed intact leaves, as a rule, located on the penultimate node of the shoot. The measurements were carried out in the middle part of the leaf, bounded by the frame of the LI-6800 measuring chamber with an aperture of 3x3 cm. Current measurements of photosynthesis were carried out on 2-4 randomly selected seedlings. To construct the diurnal graphical dependencies, the average values of the measured values were used.

Studies of the dependence of photosynthesis on temperature were carried out on artificial seedlings. During measurements, the following microclimate parameters were set in the LI-6800 measuring chamber: illumination 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$, CO_2 concentration 400 $\mu mol \cdot mol^{-1}$, humidity ~ 60%. The measurements were carried out in an automatic mode in the temperature range from 24 to 46 °C.

Studies of the dependence of photosynthesis on CO_2 concentration were also carried out on artificial seedlings. During measurements, the following microclimate parameters were set in the LI-6800 measuring chamber: illumination 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$, temperature 30 °C, humidity ~ 70%. The measurements were carried out in an automatic mode in the CO_2 concentration range from 350 to 1000 $\mu mol \cdot mol^{-1}$ with a step of 50 $\mu mol \cdot mol^{-1}$.

The work used meteorological data ~~obtained from a meteorological station located on the territory of the reserve~~from a meteorological station located on the reserve's territory.

Diurnal curves of photosynthesis and PAR

The data for plotting the diurnal dynamics of photosynthesis and PAR were obtained over two days: July 4, 2020, from 15:00 to 19:00 and on July 27, 2020, from 05:00 to 14:30. The total solar radiation these days differed by 6% (the cloudiness on July 4, 2020, in the first half of the day was slightly higher). The average air temperature during the daylight hours on July 4, 2020, was 34 °C, on July 27, 2020 - 36 °C.

The measurements were carried out with an interval of ~20 min with the following microclimate parameters in the LI-6800 measuring chamber: CO_2 content 400 μmol·mol^{-1}, humidity ~65%, temperature ~32 °C.

Light-response curves

The mathematical description of the curves of the light response of photosynthesis was based on the Michaelis - Munten equation (Michaelis and Muenten 1913). We used this equation in a modified form (Kaipiainen 2009):

$$A=A_m \cdot Q/(Q+K_M)+A_d \quad (1),$$

where A is the intensity of photosynthesis, μmol·m^{-2}·s^{-1}; A_m - is the maximum intensity of photosynthesis, μmol·m^{-2}·s^{-1}; Q - PAR, μmol·m^{-2}·s^{-1}; A_d - respiration rate at $Q = 0$, μmol·m^{-2}·s^{-1}; K_M - Michaelis constant (K_M is numerically equal to PAR, at which the intensity of photosynthesis is half of the maximum $A = 0.5A_m$). The values of this constant are often used by researchers when comparing the physiological characteristics of plants (Hieke et al. 2002). According to (1), the light compensation point (*LCP*) was determined, μmol·m^{-2}·s^{-1}, which shows at what intensity of PAR photosynthesis becomes zero.

To assess the efficiency of photosynthesis, we propose to use the slope of the tangent *a* (italic font) to the function curve of (1) at the point corresponding to K_M. From a physical point of view, this coefficient reflects the rate of change in the intensity of photosynthesis with a change in PAR by one unit.

Statistical analysis

Data processing was carried out using the MS Excel "Descriptive statistics" package ($p < 0.05$). The degrees of association of the studied datasets were determined using Pearson's correlation coefficients, *k*. The parameters of equation (1) were selected using the MS Excel package "Parameters of the solution search" (the limiting number of iterations is 100, the relative error is 0.00001, the permissible deviation is 5%, the convergence is 0.0001). The slope *a* of the tangent, the coefficients of the equation for this tangent, as well as the extremum points of the graphical dependencies were determined using differentiation methods. The total values of the investigated quantities were determined by the integration method. Graphing was carried out using the MS Excel environment.

RESULTS

Diurnal dynamics of photosynthesis and PAR

Fig. 2 shows the daily dynamics of the intensity of photosynthesis and PAR, obtained as a result of measurements on seedlings of artificial origin.

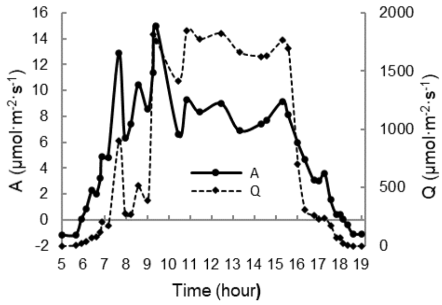

Fig. 2. Daily dynamics of the intensity of photosynthesis – *A*, and PAR – *Q*, of artificial seedlings

The dependences of photosynthesis and PAR for these seedlings are characterized by a good degree of the association during the day, k = 0.78. On the other hand, when analyzing the degree of association of these quantities in the pre-noon (from 06:00 to 09:30), noon (from 09:30 to 15:30), and afternoon (from 15:30 to 18:30), the following k values were obtained: 0.85, 0.50 and 0.87, respectively.

The total PAR for artificial seedlings was 46.9 ± 2.4 mol·m^{-2}. In the first half of the day (up to ~ 12 h), it was 24.2 ± 1.3 mol·m^{-2}, in the second - 22.8 ± 1.2 mol·m^{-2}.

The total CO_2 exchange for these seedlings was 0.304 ± 0.016 mol·m^{-2}. However, both in the first half of the day (up to ~ 12 h) and in the second, it was the same and amounted to 0.154 ± 0.008 and 0.151 ± 0.008 mol·m^{-2}, respectively.

Fig. 3 shows the daily dynamics of the intensity of photosynthesis and PAR, obtained as a result of measurements on seedlings of natural origin.

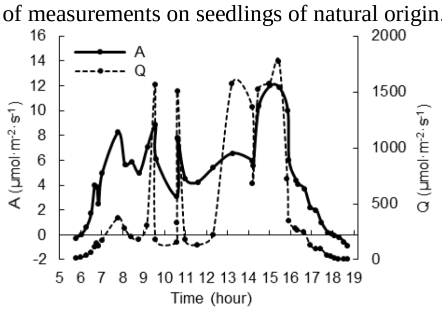

Fig. 3. Daily dynamics of the intensity of photosynthesis - *A*, and PAR - *Q*, seedlings of natural origin

The dependences of photosynthesis and PAR for these seedlings are also characterized by a good degree of the association during the day, k = 0.78. When analyzing the degree of association of these dependencies in the pre-noon, noon, and afternoon hours, the following k values were obtained: 0.96, 0.77, and 0.90, respectively.

The total PAR for seedlings of natural origin was 24.2 ± 1.3 mol·m^{-2}. In the first half of the day (up to ~ 12 h), it was 5.8 ± 0.3 mol·m^{-2}, in the second - 18.4 ± 1.0 mol·m^{-2}.

The total CO_2 exchange for these seedlings was 0.241 ± 0.013 mol·m^{-2}. In the first half of the day (up to ~ 12 h), it was 0.103 ± 0.006, in the second - 0.138 ± 0.007 mol·m^{-2}.

Light-response curves

Figure 4 shows the values of photosynthesis depending on PAR, measured on seedlings of artificial (Fig. 4a) and natural (Fig. 4b) origin. The figures also show the curves approximating these values, constructed according to (1) for the values obtained in the pre-noon (curves 1) and in the afternoon (curves 2) and tangents to these curves at the points corresponding to the K_M values. Photosynthesis values obtained in the pre-noon time are indicated by markers in the form of circles, at noon - in the form of triangles, in the afternoon - in the form of open circles.

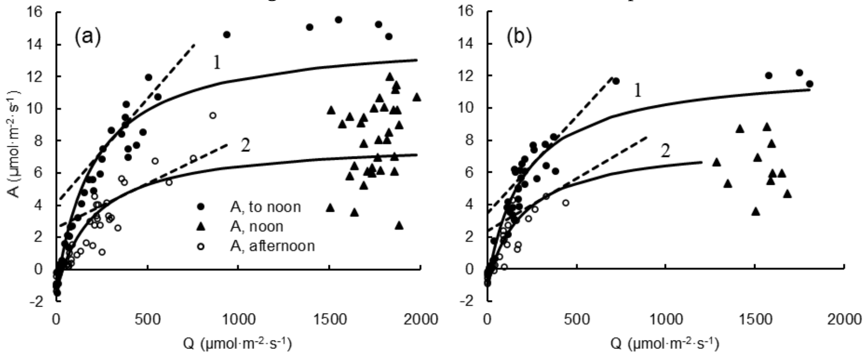

Fig. 4. Dependences of the intensity of photosynthesis - *A*, on PAR - *Q*, obtained on seedlings of artificial (a) and natural (b) origins. These figures also show the curves approximating these values, constructed according to (Equation 1) for the values obtained in the pre-noon (curves 1) and in the afternoon (curves 2) and tangents to these curves at the points corresponding to the K_M values

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The indicators characterizing the photosynthetic characteristics of seedlings obtained according to (1), as well as the R^2 values for the curves plotted and the number of measurements n, are summarized in Table 1.

Table 1. Indicators characterizing photosynthetic characteristics of seedlings.

Index	Seedlings of artificial origin		Seedlings of natural origin	
	Pre-noon time	Afternoon time	Pre-noon time	Afternoon time
R^2	0.97	0,90	0.95	0,89
n	124		94	
A_m, µmol·m^{-2}·s^{-1}	16.0	9.5	13.5	8.9
a	0.013	0.006	0.012	0.007
K_M	202.5	202.7	204.2	204.6
A_d, µmol·m^{-2}·s^{-1}	-1.5		-1.0	
LCP, µmol·m^{-2}·s^{-1}	21.0	38.0	16.3	25.9

Dependence of photosynthesis on temperature and CO_2 concentration

The obtained values of the intensity of photosynthesis for seedlings of artificial origin, as a function of the temperature T of the air surrounding the leaf, are approximated by a quadratic equation (R^2=0.97, n=20):

$$A(T) = -0.0889T^2+6.2453T-100.84 \quad (2).$$

The extremum of this function corresponds to a value of T = 35 °C. Therefore, taking into account measurement errors, the optimal temperature for photosynthesis of *R. apiculata* seedlings is T_{opt} = (35 ± 2) °C.

The dependence of the intensity of photosynthesis of seedlings on the concentration of CO_2 in the air is described by a linear equation (R^2=0.95, n=13):

$$A(CO_2) = 0.0056CO_2+2.62 \quad (3).$$

DISCUSSION

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Effect of PAR on photosynthesis

The diurnal dynamics of the intensity of photosynthesis of seedlings of artificial origin (Fig. 2) show the following distinctive patterns:

1) an increase in photosynthesis to maximum values in the pre-noon time, up to 09:30, in proportion to an increase in PAR (k = 0.85);

2) a decline in photosynthesis from maximum values to values corresponding on average to 8.0 μmol·m^{-2}·s^{-1} (SD = 2.4 μmol·m^{-2}·s^{-1}), and the exit of the photosynthesis curve to a kind of plateau at noon, from 09:30 to 15:30, with a weak dependence of photosynthesis on PAR (k = 0.50);

3) a decline in photosynthesis in the afternoon, from 15:30, in proportion to a decrease in PAR (k = 0.87);

4) negative values, indicating the processes of respiration occurring in the leaf, at night.

It is interesting to note that the same diurnal dynamic was obtained for the light leaves of *Rhizophora mucronata* Poir. growing in Indian red mangroves (Kumar et al. 2017).

In order to give a more detailed interpretation of the listed patterns, let us turn to the dependences of photosynthesis on PAR (Fig. 4a) and indicators characterizing the photosynthetic characteristics of seedlings (Table 1).

As can be seen from Fig. 4a, the markers representing the obtained photosynthesis values are distributed in three clearly marked zones: 1 - in the zone corresponding to the photosynthesis values obtained in the pre-noon (markers in the form of circles); 2 - in the zone corresponding to the values obtained at noontime (triangular markers); 3 - in the zone corresponding to the values obtained in the afternoon (markers in the form of open circles).

The curves plotted according to (1) for the photosynthesis values obtained in the pre-noon and afternoon (Fig. 4a) have a high degree of association (Table 1). The K_M coefficients characterizing the physiological characteristics of plants are approximately the same, which is obvious since we examined plants of the same type. However, the maximum intensity of photosynthesis, A_m, in seedlings in the pre-noon time was significantly higher than in the afternoon. The same applies to the slopes a. Thus, in artificial seedlings, the efficiency of photosynthesis in the pre-noon time was 2.2 times higher than in the afternoon.

On the other hand, the *LCP* for these seedlings in the afternoon was 1.8 times higher than that in the pre-noon. That is, in the afternoon, at a PAR of 38.0 μmol·m^{-2}·s^{-1}, the absorption of CO_2 by the leaf was compensated by its release. Such processes are caused by respiration, as a rule, associated with metabolic processes occurring in the leaf.

In addition to the above, it can be noted that, according to Figures 2 and 4a, the saturation of photosynthesis for these seedlings occurs when the PAR is about 1800 μmol·m^{-2}·s^{-1}.

A similar pattern in the dynamics of photosynthesis, indicating its different behavior in the pre-noon and afternoon, was not identified by the authors of this work in similar studies. However, it should be noted that the authors of the work (Ball et al. 1997), when conducting similar studies, noted a very large scatter of data. In our studies, with the exception of midday measurements, this was not noted.

The daily dynamics of photosynthesis in seedlings of natural origin (Fig. 3), in general, is characterized by the same regularities as in seedlings of artificial origin. Distinctive features of this dynamics are somewhat large values of *k* obtained before and afternoon (0.96 and 0.90), as well as the presence of a relationship between photosynthesis and PAR at noon (*k* = 0.77).

A similar situation emerges when analyzing the features of photosynthesis of seedlings according to Figure 4b - the obtained values of photosynthesis are also distributed in the three zones indicated above.

The plotted curves (1) for the values of photosynthesis obtained before and afternoon also have a high degree of association (Table 1). The K_M coefficients are approximately the same. The maximum intensity of photosynthesis, A_m, in seedlings in the pre-noon time is significantly higher than in the afternoon. The same applies to the slopes *a*. Thus, in seedlings of natural origin, the efficiency of photosynthesis in the pre-noon time was 1.7 times higher than in the afternoon. The *LCP* for these seedlings in the afternoon was 1.6 times higher than that in the pre-noon time. In the afternoon, *LCP* was 25.9 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Summarizing what has been said, we can present a comparative analysis of the characteristics of the growth of seedlings of artificial and natural origin.

On the one hand, these seedlings have similar characteristics. Thus, the diurnal dynamics of seedlings is characterized by an increase in photosynthesis in the pre-noon and a decrease in photosynthesis in the afternoon, with strong degrees of connection with PAR (Fig. 2, 3). The obtained values of photosynthesis are distributed in three clearly marked zones, corresponding to the values of photosynthesis obtained in the pre-noon, noon and afternoon (Fig. 4a, 4b). Photosynthesis values obtained in the pre and afternoon time are described with a high degree of association (1).

Slope coefficients *a* obtained for seedlings during pre-noon and during the afternoon are identical (Table 1). Accordingly, the efficiency of photosynthesis during pre-noon and during the afternoon is approximately the same and during pre-noon, it is higher than during the afternoon. K_M coefficients for seedlings are approximately the same. *LCP* for seedlings in the afternoon was higher than that during pre-noon.

On the other hand, the seedlings under consideration also have distinctive characteristics. So, at noon, photosynthesis in seedlings of artificial origin was more stochastic, while in seedlings of natural origin, there is a connection between photosynthesis and PAR. Further, the maximum values of photosynthesis, A_m, for seedlings of artificial origin, both during pre-noon and afternoon, were significantly higher than those of seedlings of natural origin. This is primarily due to different lighting conditions of seedlings: the total PAR for artificial seedlings was 46.9 ± 2.4 $mol \cdot m^{-2}$ (in the first and second half of the day it was on 23.5 ± 1.3 $mol \cdot m^{-2}$), while for seedlings natural origin - 24.2 ± 1.3 $mol \cdot m^{-2}$ (in the first half of the day it was 5.8 ± 0.3 $mol \cdot m^{-2}$, in the second - 18.4 ± 1.0 $mol \cdot m^{-2}$).

Accordingly, the total CO_2 gas exchange for artificial seedlings was 0.304 ± 0.016 $mol \cdot m^{-2}$ (in the first and second half of the day it was the same and amounted to on 0.153 ± 0.008 mol m^{-2}), whereas, for seedlings of natural origin, the total CO2 exchange was 0.241 ± 0.013 $mol \cdot m^{-2}$ (in the first half of the day it was 0.103 ± 0.006, in the second - 0.138 ± 0.007 $mol \cdot m^{-2}$).

The saturation of photosynthesis for these seedlings (Fig. 3 and 4b) occurs when PAR equals about 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

It should be noted here that the saturation values of photosynthesis obtained by us, both for artificial seedlings and for seedlings of natural origin, are fundamentally different from those presented in (Ball et al. 1997) that was amounting to about 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Thus, seedlings of artificial origin had higher productivity, and this was determined, first of all, by the amount of PAR supplied to the plants. Higher metabolic processes occurring in the leaves of plants of seedlings of artificial origin are also indicated by higher values of *LCP* and A_d (Table 1).

Naturally, the considered physiological parameters affected the morphological characteristics of the seedlings. Thus, the average number of leaves on a seedling of artificial origin is N = 35 (SD = 16), while on a seedling of natural origin - N = 10 (SD = 5). However, such a significant difference in the number of leaves on seedlings was to some extent compensated by the height - seedlings of natural origin were 1.5 times higher.

Effect of temperature and CO_2 concentration on photosynthesis

Analysis (2) showed that the optimal air temperature for photosynthesis of *R. apiculata* is T_{opt} = (35 ± 2) °C. It can be noted here that our similar studies on an adult tree *R. apiculata* of natural origin gave the same result (Đỗ Phong Lưu et al. 2021). According to (Ball et al. 1997), this figure is approximately 38 °C. However, the authors noted a large scatter of data and, unfortunately, do not indicate the amount of error in the determined value. In another work (Okimoto et al. 2013), two values of this temperature are given: 33 °C and 26 °C. Because the authors used similar equipment to carry out their studies, taking into account the error, we can say that the first temperature coincides with T_{opt}. Thus, the deviation of the air temperature from T_{opt}, both to a lower and to a higher side, causes a decrease in photosynthesis in *R. apiculata* (Sage and Kubien 2007).

The average air temperature during measurements at noon was 37.2 °C (SD = 1.0 °C). However, such temperatures could cause a decrease in photosynthesis by only 0.1%. On the other hand, we did not measure the temperature of the leaves, which, as a result of exposure to direct solar radiation (Fig. 1a and 2), could be quite high. High leaf temperatures inhibit photosynthesis. In addition, plants could experience a water shortage. For example, our studies related to the moisture content of leaves in relation to their absolutely dry weight on an adult *R. apiculata* tree showed that from 08:50 to 15:20 the leaves were losing 34% of moisture.

It is possible that in different leaves of seedlings, water deficiency manifested itself in different ways with corresponding changes in photosynthesis. At least, this hypothesis can explain the stochastic distribution of the values of photosynthesis in artificial seedlings at noon.

In contrast to this, in seedlings of natural origin, the presence of a connection between photosynthesis and PAR was noted at noon. This is due to the fact that these seedlings in the midday time were shadowed by the trees and shrubs growing behind them (Fig. 1b and 3). As a result, the leaves of these seedlings were exposed to significantly less overheating and so experienced less water deficit.

Based on what has been said, we can make the following assumption. In the studied seedlings, the water consumed during midday time was not completely restored afterwards. This can explain the significantly lower photosynthetic parameters observed in seedlings during afternoon (Table 1) than during pre-noon. This assumption is confirmed by the conclusions made in the work (Kumar et al. 2017).

The dependence of the intensity of photosynthesis of *R. apiculata* on the concentration of CO_2 in the air is described by (3). It follows from this equation that with an increase in CO_2 concentration, photosynthesis naturally increases. An increase in the growth of *R. apiculata* seedlings at increased CO_2 concentration in the air is noted in in (Eong et al. 1997; Kumar et al. 2017).

The presented dependences of photosynthesis on temperature and CO_2 concentration find their confirmation also in a number of works related to the study of the effect of elevated temperature and CO_2 concentration, simulating global warming, on photosynthesis of C4 plants (Alberto et al. 1996; Ghannoum et al. 2000; Read and Morgan 1996; Morgan et al. 1994). In our case, for example, if we consider the most optimistic forecasts associated with an increase in the concentration of CO_2 in the air in the next decade from 412 ppm to 460 ppm (and this concentration is already observed over cities), then the intensity of photosynthesis in the studied seedlings will increase by about 6%. This trend will be one of the tools for stabilizing the climate on Earth.

CONCLUSIONS

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1. The determining factor influencing the photosynthesis of the investigated seedlings of *R. apiculata* is PAR. This determines the higher productivity of artificial seedlings in comparison with natural seedlings.

2. The obtained photosynthesis values are distributed in three clearly marked zones, corresponding to the photosynthetic values obtained in the pre-noon, noon and afternoon.

3. In the studied seedlings, the water consumed in the midday time was not completely restored afterwards. As a result, the photosynthetic parameters of the seedlings in the pre-noon were significantly higher than in the afternoon.

4. The main inhibiting factor affecting the photosynthesis of *R. apiculata* (if we do not take into account PAR) is the disturbance of the water balance of the leaves (lack of water).

5. The optimum air temperature for the processes of photosynthesis in *R. apiculata* seedlings is (35 ± 2) °C.

6. With an increase in the concentration of CO_2 in the air, the intensity of photosynthesis in *R. apiculata* naturally increases.

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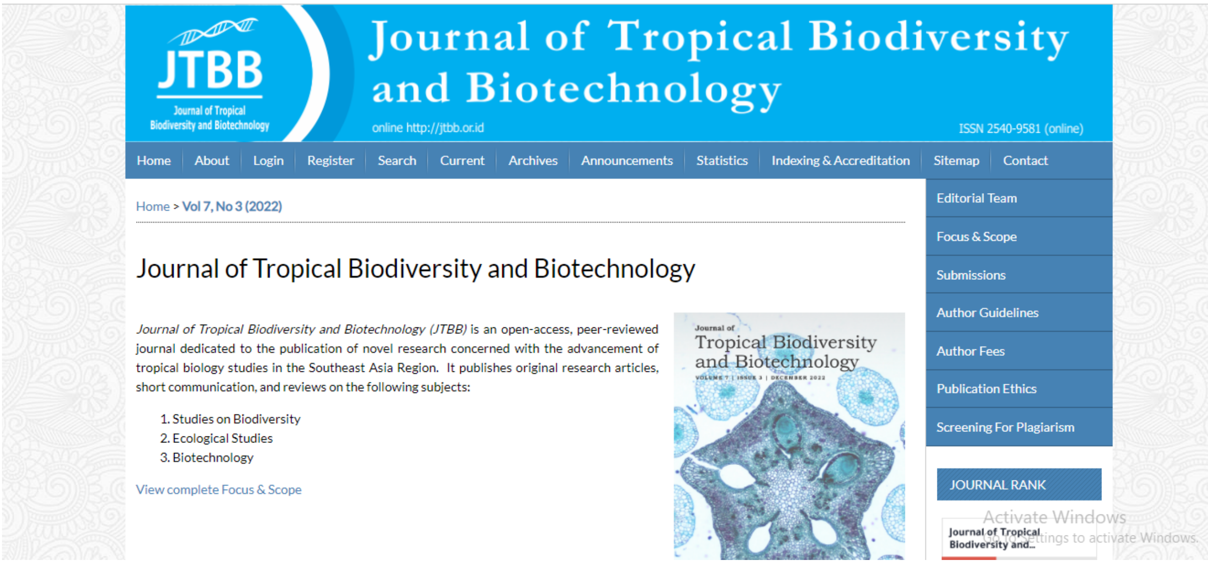

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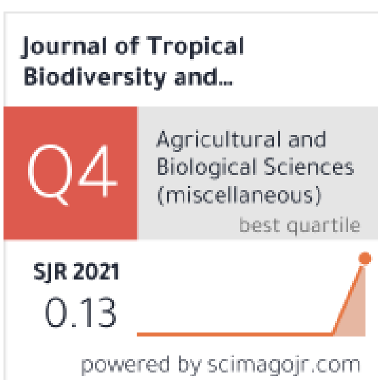

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Abdul Malik <abdulmalik@unm.ac.id>

[JTBB] Article Review Request

Liya Audinah <liyaaudinah15@gmail.com> Fri, Sep 30, 2022 at 11:08 PM
To: Abdul Malik <abdulmalik@unm.ac.id>

Dear Abdul Malik,

I believe that you would serve as an excellent reviewer of the manuscript, "Combining moderate and high resolution of satellite images for characterizing suitable habitat for vegetation and wildlife," which has been submitted to Journal of Tropical Biodiversity and Biotechnology. The submission's abstract is inserted below, and I hope that you will consider undertaking this important task for us.

Please log into the journal web site by 2022-10-07 to indicate whether you will undertake the review or not, as well as to access the submission and to record your review and recommendation.

The review itself is due 2022-10-14.

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Thank you for considering this request.

Liya Audinah
Faculty of Biology, Universitas Gadjah Mada
liyaaudinah15@gmail.com

"Combining moderate and high resolution of satellite images for characterizing suitable habitat for vegetation and wildlife"

Abstract

Combining different resolution of remote sensing satellites become a unique approach for vegetation and wildlife habitat assessment study. Remote sensing technology can reach land and water on the Earth's surface, and it can interpret signals from spectral responses. When these techniques are combined with Geographical Information Systems (GIS), land can be monitored in a variety of ways. WorldView-2 and GeoEye-1 satellite image were pre-processes, processes, and classified to produce land use indicator in Sabah Softwoods Tree Plantation majoring Eucalyptus spp. tree planted in Tawau, Sabah. Net Primary Productivity at monthly scale was also calculated and ranked the productivity for the suitability mapping. Climatic condition based on monthly precipitation and seasonality derived from ASEAN Specialized Meteorological Centre (ASMC) was employed for ranking its suitability value. In this study, natural forest and oil palm plantation is tested to developed suitability map for vegetation and wildlife habitat to live with. All indicators were ranked 10 to 40 presenting benefit and usefulness of the indicator to vegetation and wildlife in the study area. Then, final classification was made from accumulation of those indicators into 0 to 200 (Not suitable to Highly suitable). The results showed 59.9% of the area classified as moderately

suitable, 36.9% highly suitable, 3.2% least suitable and no area was classified as not suitable. This type of study assists forest managers and policymakers for better managing of their forests for better life of trees and wildlife under their management.

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Abdul Malik <abdulmalik@unm.ac.id>

[JTBB] Article Review Acknowledgement

Liya Audinah <liyaaudinah15@gmail.com>
To: Abdul Malik <abdulmalik@unm.ac.id>

Thu, Nov 10, 2022 at 11:08 PM

Dear Abdul Malik,

Thank you for completing the review of the submission, "Combining moderate and high resolution of satellite images for characterizing suitable habitat for vegetation and wildlife," for Journal of Tropical Biodiversity and Biotechnology. We appreciate your contribution to the quality of the work that we publish.

In addition, Journal of Tropical Biodiversity and Biotechnology is a partner of Publons; a company works with researchers, publishers, and research institutions to speed up science and research by harnessing the power of peer review. We encourage you to check our page in Publons (https://publons.com/journal/59779/journal-of-tropical-biodiversity-and-biotechnology) and add reviews that you have done for us.

Sincerely yours,

Liya Audinah
Faculty of Biology, Universitas Gadjah Mada
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This is presented to

Abdul Malik, S.T., M.Si., Ph.D.

for contributing as a reviewer for the Journal of Tropical Biodiversity and Biotechnology in volume 7 issue 3 December 2022

Dr. Miftahul Ilmi

Editor in Chief

Journal of Tropical Biodiversity and Biotechnology

Combining moderate and ~~high~~ high-resolution ~~of~~ satellite images ~~for characterizing~~to characterize suitable habitats for vegetation and wildlife

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Abstract

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Combining different resolutions of remote sensing satellites become~~ a unique approach for vegetation and wildlife habitat assessment study~~s a unique approach to studying vegetation and wildlife habitat. Remote sensing technology can reach land and water on the Earth's surface~~,~~ ~~and it can~~ and interpret signals from spectral responses. When these techniques are combined with Geographical Information Systems (GIS), land can be monitored in a variety of ways. Meanwhile, changes in land use led to changes in vegetation on the ground, with natural vegetation being removed from natural forests, leaving a degraded forest. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) are derived from a mathematical equation ~~able to demonstrate intensity of greenness of~~demonstrating the intensity of green vegetation ~~green vegetation~~ in a particular area and time; and soil moisture availability~~availability of soil moisture~~, respectively. WorldView-2 and GeoEye-1 satellite images were pre-process~~se~~sed, process~~se~~sed, and classified to produce land use indicators in Sabah Softwoods Tree Plantation majoring Eucalyptus spp. tree planted in Tawau, Sabah. Net Primary Productivity at a monthly scale was also calculated and ranked the productivity for the suitability mapping. Climatic condition based on monthly precipitation and seasonality derived from ASEAN Specialized Meteorological Centre (ASMC) was employed for ranking its suitability value. In this study, natural forest and oil palm plantation is tested to develop~~ed~~ a suitability map for vegetation and wildlife habitat to live with. All indicators were ranked 10 to 40, presenting the benefit and usefulness of the indicator to vegetation and wildlife in the study area. Then, the final classification was made from the accumulation of those indicators into 0 to 200 (Not suitable to Highly suitable). The results

showed that 59.9% of the area was classified as moderately suitable, 36.9% as highly suitable, 3.2% as least suitable, and no area was classified as ~~not~~ unsuitable. This type of study assists forest managers and policymakers ~~for~~ manage~~better managing~~ ~~of~~ their forests for the better life of trees and wildlife under their management.

Keywords: High resolution satellite image, wildlife habitat, NDVI

1. Introduction

Remote sensing technology enable acquisition of satellite image for land monitoring based on different satellite resolution. For example, Landsat TM and Worldview satellite that carried 30-meter and 1.8 -meter multispectral image. In a recent study, the indices as indicator of vegetation productivity estimation as discovered by a study by (O'Neil et al., 2020) that can be derived by various satellite resolution. At global level, more study using a land cover change model to detect vegetation changes caused by human factor in China pasture, located in Wulagai River Basin (Chen et al., 2021). NDWI is as a significant index in forest fire study and found have good relationship in drought study as demonstrated in (Bowyer and Danson 2004 & Mohd Razali et al., 2015).

Therefore, there is a need in estimating land area with vegetation for wildlife human-conflicts translocation. Suitable land characteristics need to identify as a major criterion in ensuring security of the wildlife and sufficient land for live. This is important to solve the above problem by merging different satellite sensor resolution data and climatic data.

Managing human and wildlife conflict is a tough task. Sabah Softwoods Berhad (SSB) a company that was experienced in mitigating human wildlife conflicts (Nathan 2016). In 2016, the report stated that the company primary activity are oil palm and tree plantation that make it about 60,000 hectares of land. The company adopt 7,000 of that area as reserve land for conservation, meanwhile about 3,000 hectares were earmarked for housing and infrastructure. With the allocation, the company was one of the earliest companies obtained certification for its palm oil operation for Malaysian Sustainable Palm Oil (MSPO) (MPOCC 2022). They managed to handle human-elephant conflicts

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with estimated two thousand Pygmy elephants that roam the landscape. The elephants get into human activities and the company using translocation and fencing the plantation.

2. Materials and methods

2.1. Study area

To test the site suitability, we examined a Sabah Softwoods Berhad plantation at Brumas, Tawau, Sabah. The site located at latitude 4°35'36" and longitude 117°45'31" retrieved from Google Map (Google 2022) (Figure 1). The plantation is located at 200 to 600 m elevation above sea level. The plantation area is approximately 18,000 hectares planted with *Eucalyptus pellita* and *F. moluccana* tree species. The *F. moluccana* tree species are planted in the conservation area in the plantation. The whole plantation area is characterized as Tanjung Lipat type (clay texture 25 percent to 35 percent) of soil type and also Kumansi type (>40 percent clay). Rivers of Sungai Umas, Sungai Landau, Sungai Indit and Sungai Umas-Umas are in the plantation, serves as source water to the plantation. The monthly mean temperature in Tawau in 2016 was a minimum of 24ºC, a maximum of 31ºC, and a mean of 28ºC collected from www.worldweatheronline.com. Data for monthly precipitation referred from (Markos et al. 2018) was recorded as 50 mm in 2014. In the meantime, annual precipitation was collected from Malaysia Meteorological Station as shown in Figure 2.

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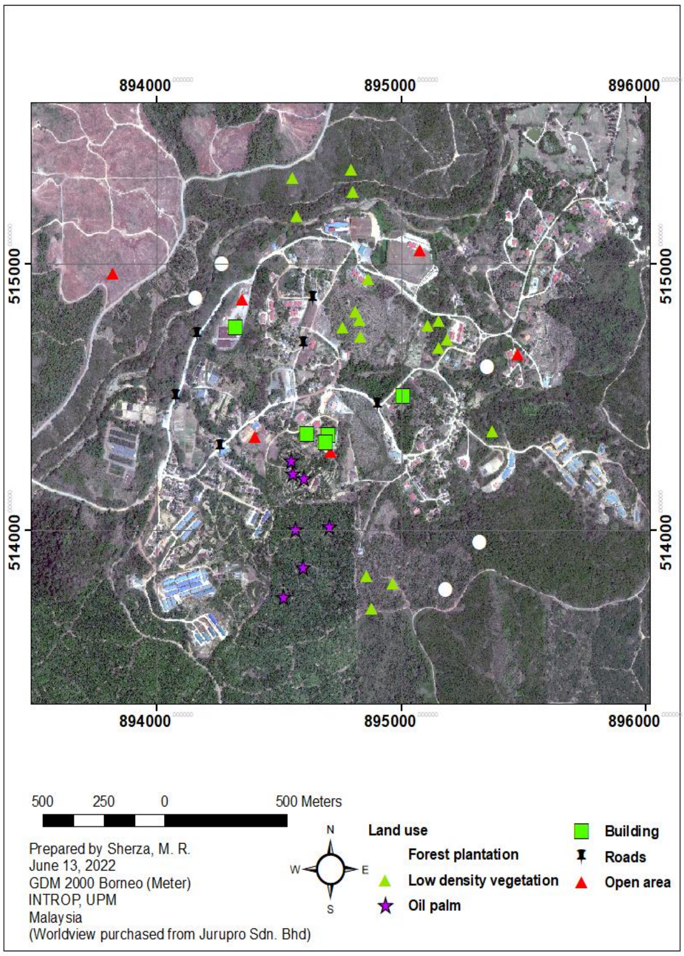

Figure 1. Map of the study area with location of various land use and land cover.

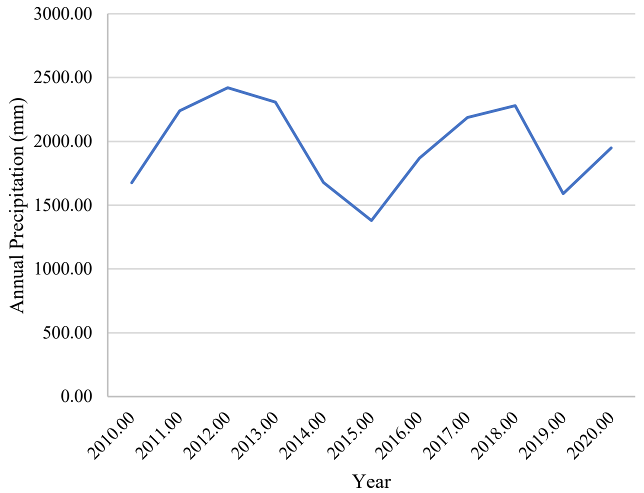

Figure 2. Annual precipitation of Tawau based on data from Malaysia Meteorological Department for 2010 – 2020.

2.2. Methods

The Sentinel and Landsat 8 data was obtained from Land viewer application purchased online. Before that, the image was atmospherically corrected using atmospheric correction wizard, which allows users to execute a variety of atmospheric corrections in the simplest and fastest method possible. The wizard automatically in most of the required parameters using image information and walks the user through each key step. The software's focus application was used to prepare data, and then ATCOR ground reflectance tools were used to analyse atmospheric correction.

The NDVI and NDWI data was run a year time series analysis. Inclusion of dry and wet season in Sabah. NDVI and NDWI was calculated for both of the satellites. Based on theory, NDVI was calculated based on the approach that, using the index vegetation status can be identify as healthy and full vegetation coverage of from higher that 0.5 to 0.9. The index very suitable to be used in tropical area, which a study by (Braswell et al., 2003) found NDVI not to use in too dry condition like Iran and other area with similar condition. In the meantime, a study by (Pujiono et al., 2013) employed NDVI for monitoring mangrove forest in Indonesia. Continuously, a year after that (Darmawan and Sofan 2012) using Enhanced Vegetation Index (EVI) and NDVI to detect changes in tropical forest in Indonesia. Elsewhere, many years ago (Bhuiyan, Singh, and Kogan 2006) used NDVI for assessing vegetation stress in vegetative and agriculture land in India. NDVI showed increasing trend of vegetation change which caused by anthropogenic factor (Chen et al., 2021). The equation for the index was as referenced to the study by (Rouse et al., 1973):

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$$NDVI = (\rho NIR - \rho Red) / (\rho NIR + \rho Red) \ \ldots(1)$$

Meanwhile, NDWI was found very applicable to use in detection of water-stress forest such as in mangrove (Vidhya et al. 2014). Again it was applied by (Mohd Razali et al., 2015) in monitoring vegetation drought in West Malaysia. NDWI measured sensitivity to changes in liquid water content (Gao 1996). NDWI showed a good relationship with plant stress, which was used by a study of (Vidhya et al. 2014) in classification of mangrove heath status. A recent study of (Caturegli et al. 2020) tested NIR at two wavelength of 1240 µm and 2130 µm. The study tested NDWI without water on Bermuda grass in Italy. Based on theory, the index was calculated based on below equation (Gao 1996):

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$$NDWI = (\rho NIR - \rho SWIR3) / (\rho NIR + \rho SWIR3) \ \ldots(2)$$

In details, the time series started from June 2017 until April 2022. About 39 samples were collected between the time frames. The study hypothesized that the distribution of

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Sentinel and Landsat for NDVI and NDWI indices were similar across categories of wet season influenced by Northeast monsoon in Sabah region.

Worldview satellite image for 2016 was derived to calculate NDVI as comparison with the 2021 and 2011 NDVI data. Inadequate spectral properties in Worldview image of shortwave to calculate NDWI for the comparison. This is because the availability for comparison make use of previous data for related study (Razali and Lion 2021). Overall flowchart of the study is presented below (Figure 3).

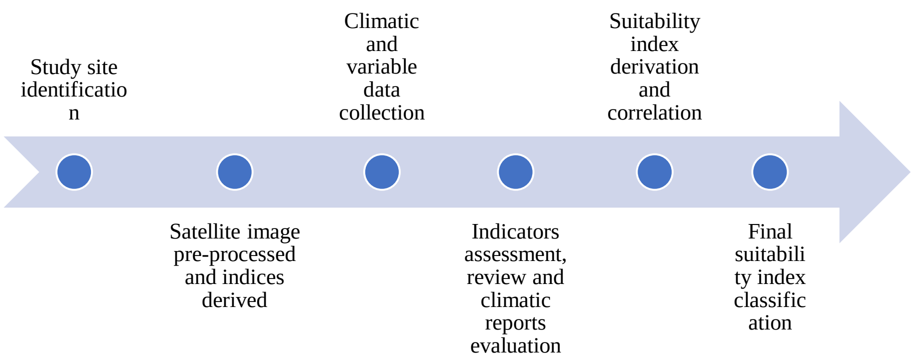

Figure 3. Overall flowchart of the study.

2.2.1. Land use mapping

The study employed PCI for mapping the land use. Land use map was developed by using object-based image analysis (OBIA) using Catalyst Professional software, formerly known as PCI Geomatics. Worldview 2 satellite image was pre-processed the process employed Atmospheric Correction wizard (ATCOR), which allows users to execute a variety of atmospheric corrections in the simplest and fastest method offer (PCI Geomatics Enterprise 2021). The focus of the application was to prepare data, and then ATCOR ground reflectance tools were analysed the atmospheric correction. Overall flow of the land use mapping is shown in figure below (Figure 4).

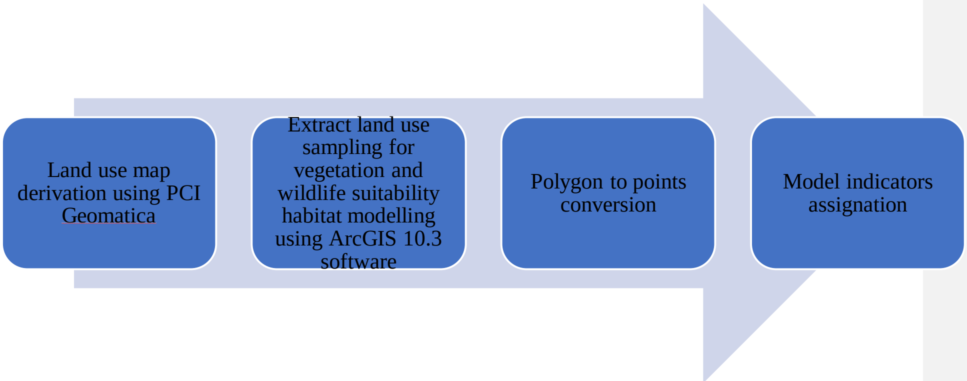

Figure 4. Overall flowchart of land use mapping.

2.2.2. NPP estimation

In this study, the NPP was derived from GPP that was based on (Xiao et al., 2004). This is because GPP is the rate of CO_2 fixation by photosynthesis in the forest canopy. Therefore, GPP is calculated as below:

$$GPP = fAPAR \times PAR = \varepsilon \times APAR \ldots (1)$$

Where, the ε is Light Use Efficiency (ε), that LUE have known as an important element of the radiation regime for tree growth, incoming photosynthetically active radiation (PAR) ($gMJ^{-1}\ m^{-2}$), and the fraction of PAR intercepted by foliage (Fraction of photosynthetically active radiation of fAPAR).

Moreover, this study estimated PAR from 50% of incoming solar radiation as a results of solar radiation data collected from (Sukarno et al., 2017) study. Instruments were allocated

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in top-roof of building in Universiti Malaysia Sabah (UMS), Kota Kinabalu, Sabah on 17 March 2016. The study derived the value for absorbed fraction of photosynthetically active radiation (APAR) (gMJ^{-1}) by multiplying the two most important elements of radiation, fAPAR and PAR (Coops et al., 2010). In this study, to calculate the LUE, [18] equation was referred to as:

$$LUE = 0.8932 + TMonth + 0.0015(PRECIPMonth) - 0.002(GDD) \quad ..(2)$$

Meanwhile, fAPAR was based on of a study by [21], which is derived as:

$$fAPAR = 1.25 \times NDVI - 0.025 \quad ...(5)$$

The NDVI was derived by using two bands in the satellite image as shown below, as referenced to the study by [23]:

$$NDVI = (\rho NIR - \rho Red) / (\rho NIR + \rho Red) \quad ...(6)$$

Where, ρNIR is the reflectance of the WorldView image at 0.77 – 0.895 nm (Near-infrared band) and ρRed is the reflectance of the satellite image at 0.63 – 0.690 nm (red band). The NPP (gCM^{-2} $month^{-1}$) was therefore, derived by applying 50% of GPP.

3. Results and Discussion

3.1 Vegetation of water-stress

The study conduct correlation scatter plots for NDVI and NDWI of the Sentinel and Landsat satellite. Figure 6 shows the comparative analysis of the Brumas plantation features from April 2-21 to April 2022. From R^2 values, the NDVI in Sentinel was 0.95, whereas R^2 for Landsat was 0.99. These results, showed that the NDVI had a good indicator to predict forest

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productivity, assessing forest health and biomass changes over time. It is potential for drought and post-fire recovery in Eucalyptus forest such as demonstarted by (Caccamo et al., 2011, 2015).

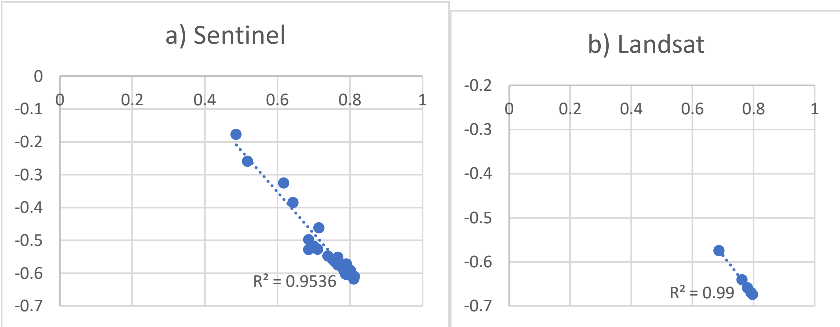

Figure 5. Correlation between NDVI and NDWI (a) Sentinel and (b) Landsat.

It can be seen, based on the two indices, that the NDVI very useful for application in vegetation community is broadleaved and evergreen. Changes on the season scale was also anticipated that higher NDVI values, pursue NDWI to be lower, due to plant capability to maintain water supply for biomass accumulation, hence no water stress was recorded. Some studies define NDWI as Land Surface Water Index (LSWI), whereby as the LSWI served similar indicator. The study showed the fortnightly percentage increase of LSWI and NDVI from the previous fortnight for 2002 and 2005, for a few typical districts of Andhra Pradesh (Chandrasekar et al., 2010). In (Penuelas et al., 1997), Water Index (WI) have good agreement with NDVI (NDVI vs WI, $R^2 = 0.66$) and improved when rationing WI with NDVI (WI/NDVI=0.71).

3.2 Vegetation and wildlife habitat indicator

NDVI for 2016 that was overlaid with land use map showed NDVI > 0.8 is located on Eucalyptus plantation area. Whereas NDVI of > 0.7 is located on mostly on oil palm plantation.

Meanwhile, NDVI > 0.6 can be found located in Eucalyptus forest plantation but with presence of oil palms features (light green). The oil palm features have a high agreement with ground data with 100% of accuracy assessment, however, is very uncertain to found oil palm features in Eucalyptus plantation. The features could be misclassified with low growth in the forest plantation. This making forest plantation have lower NDVI than found in full covered forest. NDVI scale for the analysis is tabulated as in Table 1.

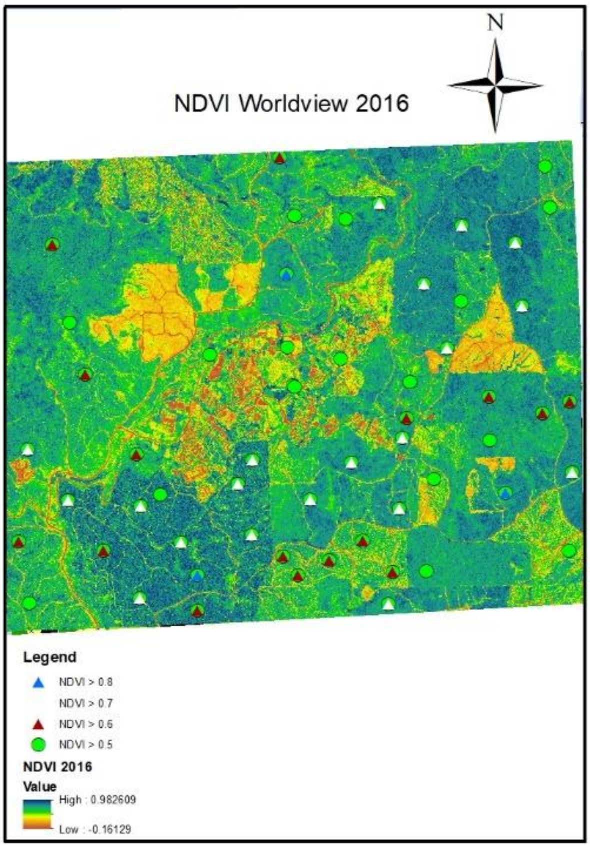

Figure 5. NDVI of the study area.

Table 1. NDVI scale and suitability index value for analysis.

NDVI scale	Suitability index
NDVI > 0.8	40
NDVI > 0.7	30
NDVI > 0.6	20
NDVI > 0.5	10

3.3 Land use

The land use accuracy was:

- Producer's accuracy for Eucalyptus plantation, buildings, low-density vegetation, oil palm, open area and roads were, 100%, 81.25%, 94.12%, 100%, 100% and finally 25%, respectively.
- User's accuracy was, 94.12%, 61.90%, 100%, 76.92% and finally 80%, respectively.

Each of the class was rank according to its priority for wildlife to live within the removal of forest to a forest plantation. Higher forest coverage is ranked higher whereas lower forest cover or vegetation cover is ranked as lower (Table 2).

Table 2. Land use type and suitability index.

Land use	Suitability index
Forest plantation	40
Oil palm	30
Low density vegetation	20
Open area/Buildings/Roads	10

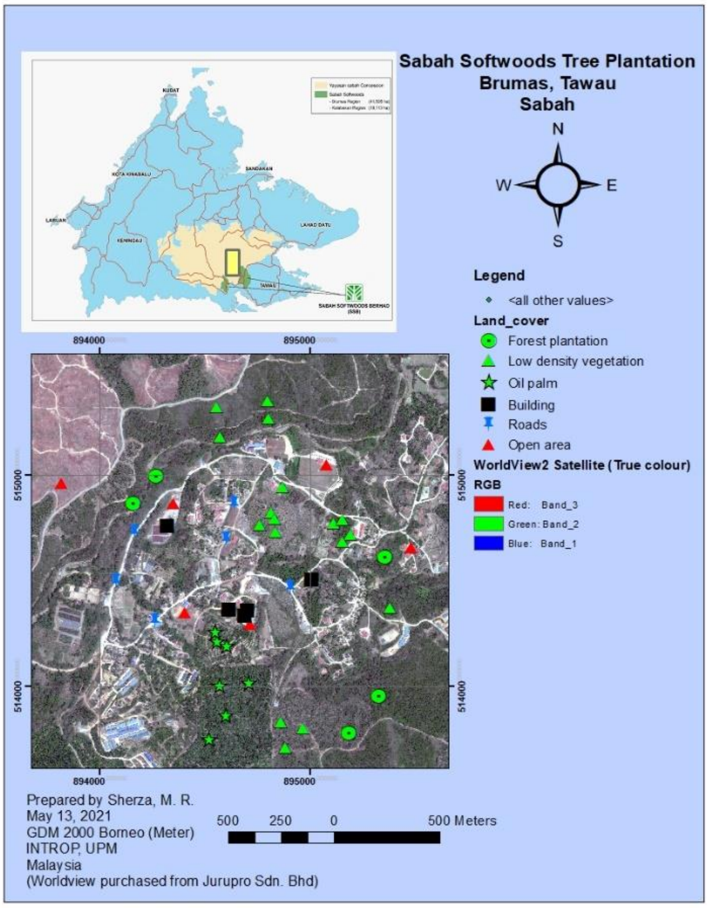

Figure 6. Land use produces from the land use mapping.

3.4 Precipitation

In general, Sabah and Sarawak are influenced by Northeast monsoon which November to April approximately bringing heavy rain to east coast area, that including Tawau area. In 2015, a study by (Ng et al. 2019) found Tawau recorded 207.0 mm ±92.98 of monthly precipitation. This making Tawau is the highest precipitation than districts of Sabah, namely, Kota Kinabalu,

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Beufort, Kudat and Keningau. For additional information the value similarly recorded by Sandakan area which is located far much northern area. Finally, precipitation rank is shown in Table 3.0.

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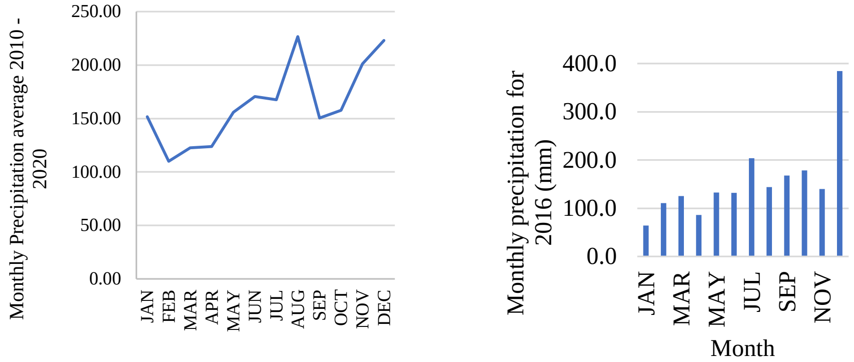

(a) (b)

Figure 7. Monthly (a) and annual precipitation for the study area (b).

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Table 3. Mean monthly precipitation and suitability index.

Mean monthly precipitation (mm) of Year 2016, Tawau, Sabah	Suitability index
0 – 80	40
80 – 160	30
160 – 280	20
280 – 340	10

3.5 Seasonal

Seasonal data was assessed based on ASEAN Specialized Meteorological centre (ASMC) report. The comprehensive report comprising data of ASEAN information on haze situation which rank as in Table 4.0.

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Table 4. Indication of seasonal parameters derived from ASMC report and suitability index.

ASEAN Specialized Meteorological Centre (ASMC) based on Worldview satellite image acquired March 2016	Suitability index
March to May 2020	40
December – January 2016 – 2017	30
September - November 2020	20
Unidentified	10

3.6 NPP productivity

Using the tools in ArcGIS Spatial Analyst, the NPP was interpolated to map the distribution of NPP on ground data, as depicted in Figure 7.

3.7 Final suitability index

The final index was developed based on accumulation of all indicators suitability index value that was calculated using ArcGIS 10.8 software attribute table. Table 5 showed overall indicators that employed for the index based on below equation:

$$\text{Habitat Wildlife Indicator} = \text{VEG} + \text{LU} + \text{NPP} + \text{PREP} + \text{SEAS}$$

Vegetation and wildlife habitat indicator = VEG

Land use indicator = LU

Net Primary Productivity = NPP

Precipitation indicator = PREP

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Season = SEAS

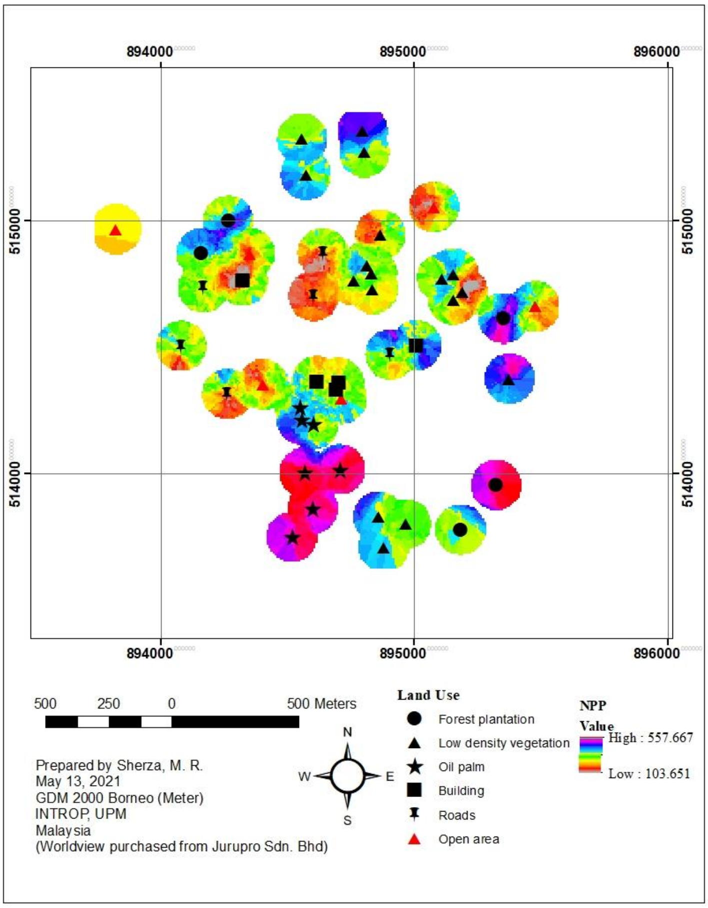

Figure 7. Overall NPP value interpolated on land use layer with points marked showed major area of the land use type.

Table 5. Indication of NPP scale and rank value.

NPP scale (650 gCm-2 month-1)	Suitability index
NPP > 500	40

NPP > 300	30
NPP > 200	20
NPP > 100	10

Table 6. Indication of accumulation of vegetation and wildlife habitat suitability index.

No.	Indicator/Scale	Description	Suitability index	Source of References
1.	Vegetation and wildlife habitat indicator			Rock/Sand/Snow: Value approaching zero, 0.1 <
	Biomass			X < 0.1
	NDVI > 0.8	Adequate biomass	40	Greenness/Vegetation:
	NDVI > 0.7	Moderate biomass	30	Value low positive, 0.1 <
	NDVI > 0.6	Low biomass	20	*X* < 0.4
	NDVI > 0.5	Inadequate biomass	10	Tropical rainforest value approaching 1, X→1
				Hanset et al., (2017)
2.	Land use indicator			
	Habitat			
	Forest plantation	Natural habitat	40	
	Oil palm	Plantation	30	Field observation and
	Low density vegetation	Degraded land	20	author experienced

	Open area/Buildings/Roads	Infrastructure and non-vegetated land	10	
3.	Net Primary Productivity			NPP evaluated for the plantation is 650 gCm-2 month-1 (Sheriza et al., 2022). NPP from WorldView-2 particularly valuable if applied to temporal NDVI data to assess the monthly NDVI for the study area (Sheriza et al., 2022)
	NPP > 500	Adequate biomass	40	
	NPP > 300	Moderate adequacy biomass	30	
	NPP > 200	Low adequacy biomass	20	
	NPP > 100	Inadequate biomass	10	
4.	Precipitation indicator			
	Mean monthly precipitation (mm)			200 mm during June and July 350 mm in November and December (climateknowldegeportal.worldbank.org)
	280 – 340	High	40	
	160 – 280	Moderate	30	
	80 – 160	Low	20	
	0 – 80	Very low	10	
5.	Seasonal indicator			
	ASEAN Specialized Meteorological Centre (ASMC)			

September - November 2020	Wetter	40	ASEAN Specialized Meteorological Centre (ASMC) report (2016)
December – January 2016 - 2017	Wetter than average	30	
March - May 2020	Wetter and drier effects are averaged	20	
Unidentified	Unidentified	10	

The study was successfully mapping suitability index for vegetation and habitat in Sabah Brumas, Tawau Eucalyptus and oil palm plantation. Habitat and vegetation classification derived after each of the pixels accumulated based on its suitability index. An index approaching 200 classified and highly suitable for the wildlife and vegetation to live and sustain its live for a long term. A value less than 50 indicate not suitable habitat for wildlife and vegetation to be in the area (Table 7).

Table 7. Indication of vegetation and wildlife habitat classification for the study.

Rank	Suitability Index	Habitat & Vegetation classification
1	150 - 200	Highly suitable
2	100 - 150	Moderately suitable
3	50 - 100	Least suitable
4	0 - 50	Not suitable

Area of the habitat and vegetation classification pixels were classified based on Equal interval and Natural Breaks classifier. Based on the methods, percentage of the area classification derived and shown in Figure 8.

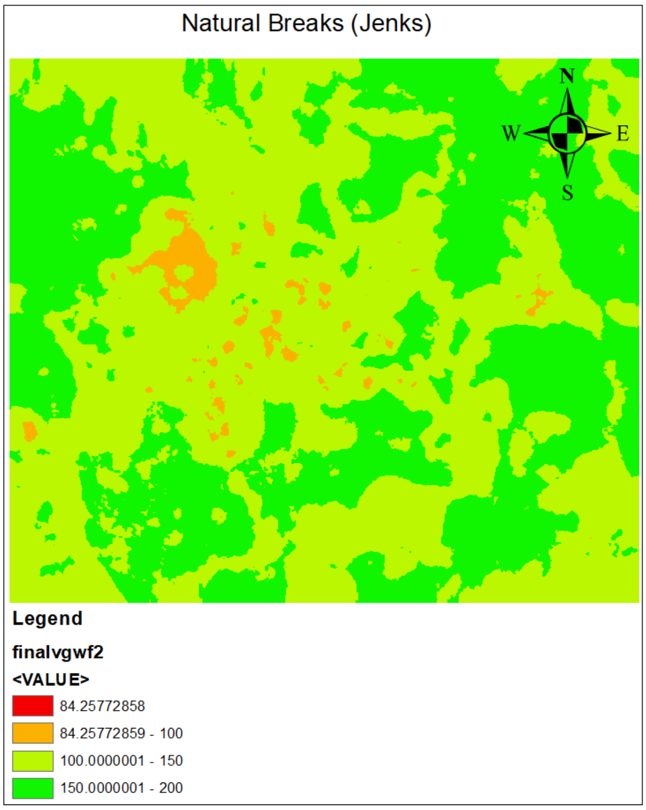

Figure 8. Final index classification for the study area.

4. Conclusion

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Most of the study area which is about 59.9% was under moderately suitable habitat for vegetation and wildlife. The variable employed for the study covered land use, climatic condition presented by precipitation, NPP and seasonal variation of the study area showed overview of year 2016 condition of the study area. The condition of the study area as plantation area is very suitable for natural habitat to live.

Author contribution

Sheriza Mohd Razali design the methods and employed ArcGIS for all the analysis. Whereas Zaiton Samdin provides research materials and research allocation. Marryanna Lion improve the manuscript write up.

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Conflict of Interest

There are no conflicts of interests.

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