International Journal of Development and Sustainability
ISSN: 2186-8662 – www.isdsnet.com/ijds
Volume 6 Number 11 (2017): Pages 1835-1847
ISDS Article ID: IJDS17101605

A tropical case study of tree diversity and productivity relationships in mixed species plantations in protected areas

Md. Afzarul Islam [1], Muha Abdullah Al Pavel [2,3], Mohammad Belal Uddin [1], Md Abdullah Al Mamun [4], Syed Ajijur Rahman [5*], Amanda Sarah Mathys [5,6], Karlina Indraswari [7], Simone Bianchi [8], Kazuhiro Harada [9], Terry Sunderland [5,10]

[1] *Department of Forestry & Environmental Science, Shahjalal University of Science and Technology, Sylhet, Bangladesh*
[2] *Department of Land, Environment, Agriculture and Forestry (TeSAF), School of Agriculture and Veterinary Medicine, University of Padova, Viale dell'Università, Legnaro (PD), Italy*
[3] *Sustainable Forest Management Research Institute, University of Valladolid-INIA, Palencia, Spain*
[4] *Department of Folklore, Faculty of Social Science, University of Rajshahi, Rajshahi, Bangladesh*
[5] *Center for International Forestry Research (CIFOR), Bogor Barat, Indonesia*
[6] *Department of Forest Resource Management, 2424 Main Mall, University of British Columbia, Vancouver, Canada*
[7] *Science and Engineering Faculty, Queensland University of Technology, Queensland, Australia*
[8] *School of Environment, Natural Resources and Geography, Bangor University, UK*
[9] *Department of Biosphere Resources Science, Graduate School of Bioagricultural Sciences, Nagoya University, Nagoya, Japan*
[10] *University of British Columbia, Faculty of Forestry, Forest Sciences Centre, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada*

Abstract

Degradation of tropical forest is considered as one of the greatest threats to biodiversity conservation. Such losses are mainly due to agricultural expansion and overharvesting of economically important trees. To enhance scientific understanding, this paper investigates the relationship between tree diversity and productivity in 58 mixed species plantations in protected tropical areas as a case study. We measured overall diversity using species richness and productivity using stand basal area and mean annual increment of stand basal area. Our research shows a negative relationship between tree diversity and productivity. These findings suggest that mixed species plantations should not be implemented if the main purpose is to consider the productivity of forest stands.

Keywords: Plant Diversity; Stand Basal Area; Productivity; Conservation; Folk Community

* Corresponding author. *E-mail address:* sumonsociology@yahoo.com

Cite this article as: Islam, M.A., Al Pavel, M.A., Belal Uddin, M., Al Mamun, M.A., Rahman, S.A., Mathys, A.S., Indraswari, K., Bianchi, S., Harada, K. and Sunderland, T. (2017), "A tropical case study of tree diversity and productivity relationships in mixed species plantations in protected areas", *International Journal of Development and Sustainability*, Vol. 6 No. 11, pp. 1835-1847.

1. Introduction

Tropical forests are the most species rich terrestrial ecosystems, therefore loss of tropical forests is considered one of the greatest threats to biodiversity conservation (Rahman et al., 2012a; Mukul et al., 2008). According to Earth observation satellite data tropical forest loss occurred at a rate of 2101 square kilometers per year from 2000 to 2012 (Hansen et al., 2013). The main causes of forest loss are caused by conversion to agriculture and overharvesting of economically important trees (Babigumira et al., 2014; Mukul, 2007). The continuous harvesting of economically important trees has resulted in the need of reforestation road maps for timber production and implementation of sustainable forest management strategies (Nguyen et al., 2012; Rahman et al., 2007). Therefore, the establishment of tree plantations has been used extensively in the tropics to reforest large areas of cleared and degraded land, while aiming to meet the demands of local communities for timber and income generation (Rahman et al., 2012b).

This paper focused on the relationship between tree diversity and productivity in 58 mixed species plantations in the Lawachara National Park, Bangladesh as a case study. These mixed plantations consist of economically important species that are grown together with local tree species. In Bangladesh, these mixed plantations have the potential to supply considerable amount of timber and generate income for folk communities while conserving local biodiversity. However, this potential is currently not being optimally utilized as high timber demand leads to overharvesting in the plantations. Overharvesting has caused a decrease in diversity and is detrimental in a long run for both economic productivity and the plantations' ecosystem functioning.

Over the past decades, researchers have paid considerable attention to the relationship between tree diversity and productivity (Zhang et al., 2012), and generated a variety of results. A recent analysis of herbaceous dominated communities from five continents, found no consistent relationship between productivity and species richness (Adler et al., 2011). This study investigates the relationship between tree diversity and productivity to show a consistent result that can be used as a reliable scientific document for mixed species planations in protected areas.

2. Material and methods

2.1. Study site

This study was conducted in the Lawachara National Park (LNP) of Maulovibazar wildlife range in Bangladesh, which is one of the oldest protected areas of Bangladesh (Figure 1) and appropriate to get information required for the study. The park covers an area of about 1,250 ha (12.5 km^2), lies between 24º30´ to 24º32´ N and 91º37´

to 91º47´ E (Mukul et al., 2014). The climate of the region is warm and humid during the summer and cool and mild during winter. The temperature ranges from 26.8ºC in February to 36.1ºC in June. Humidity is high throughout the year, ranging from 74% in March to 89% in July. There is heavy dew during winter when rainfall is low. The study area has an annual rainfall of approx. 4,000 mm (Mukul 2008), and maximum rainfall is during June to September caused by the Southwest monsoon. Geographically, the area undulates with gentle slopes and has an elevation ranging between 0–50 m (Mukul et al., 2014). The forest soil is a brown sandy loam and slightly to strongly acidic (NSP, 2006).

2.2. Data collection

Field work was conducted from February to March 2013 in mixed tree plantations aged between 5-50 years at LNP, comprised of 58 tree species. A total of 43 plots were sampled to represent mixed-species diversity in all 1,250 ha of the study area. Each plot was 0.01ha (10m x 10m) in size and selected to contain at least two different planted species (tree dbh>5cm and height >3m). The area covered by the sample plots represents 2% of the total study area. Information about age, area, range, map of the mixed-species plantations were obtained from the office of LNP.

2.3. Data analysis

Tree diversity was calculated using the Species Richness Index (R) and Shannon Diversity Index (H) (Rahman et al., 2013; Nguyen et al., 2012; Margalaf, 1958). Measurements of the Stand Basal Area (SBA) and Mean Annual Increment of Stand Basal Area (MAISBA) were undertaken to represent tree productivity. SBA and MASIBA are highly correlated with tree volume and biomass and has been also used as the index of plantation productivity in many studies (e.g. Waring et al., 2014; Nguyen et al., 2012). SBA was calculated using the following formula:

$$SBA = \pi r^2/p = \pi (d/2)^2/p = \pi d^2/4p$$

where d = diameter at breast height and p = plot size (0.01 ha).

Species rank-abundance curves and species accumulation curves were also derived to assess tree diversity in the study area. This was undertaken by using average pooled species richness and species accumulation curves followed by a method where different combinations had a different species richness. The Biodiversity-R 1.4.2 (Vegan 1.17-4 package) was used with Software R (version 2.10.1) for the analysis to obtain the Shannon diversity index (Kindt and Coe, 2005) followed by a series of simple linear regression analysis to determine the relationship between species diversity and productivity using SPSS 18 software.

Figure 1. Study area (marked in red)

3. Results

3.1. Species richness and abundance

The rank-abundance curve in Figure 2 shows the order of species abundance of the 58 species recorded on 43 plots (Figure 2, Appendix 1). The most abundant species were found to be economically important commercial trees, mainly used for timber supply. The three top ranking species were *Tectona grandis* (Teak), *Swietenia mahagoni* (Mahagoni) and *Lagerstroemia speciosa* (Jarul). *Tectona grandis*, a broadly dispersed, deciduous species, was the most abundant species with 31 individuals. The second most abundant tree was *Swietenia mahagoni* with a total of 23 individuals and the third *Lagerstroemia speciosa* with 20 individuals. These two economically important species are also less dispersed compared to *Tectona grandis*. It is not a surprise that these are the abundant species, concerning that the study site has mixed plantations and the highest ranking trees are economically important trees which are planted for harvesting purposes and to benefit folk people.

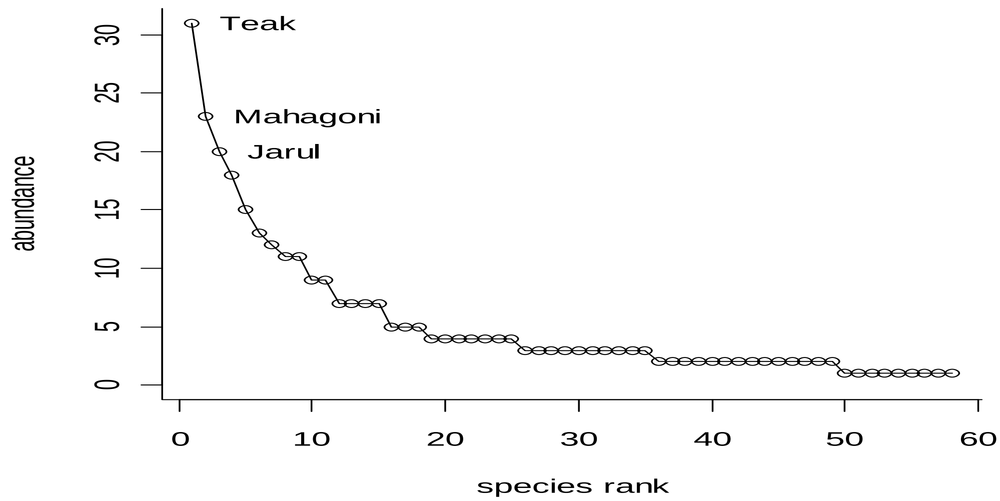

Figure 2. Species rank abundance curve in the study site

3.2. Species richness and composition

The species accumulation curve demonstrates an increase in the number of species with an increase in sampled sites (Figure 3). The rate of increase in species richness levels off until it reaches an asymptote where it no longer increases with number of observed sites. The standard deviation based on our observation shows that certain sites contain a small number of species, while other sites contain a large number.

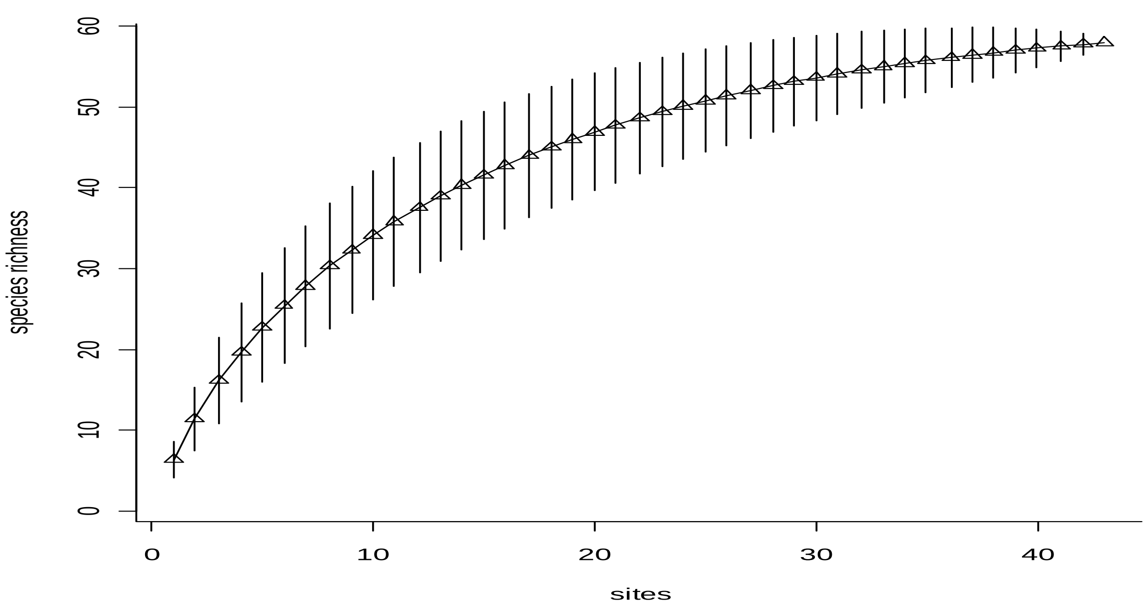

Figure 3. Species accumulation curve based on the increase in the number of observed sites (the bars indicate standard deviations)

This can also be seen in the results of the average species richness for all possible sites combinations. We found that the average species richness is 36.13 in 14 sites, whereas it was 40.07 for all possible combinations of the 17 sites.

3.3. Average value of different variables

The average calculated value of Stand Basal Area (SBA), Mean Annual Increment of Stand Basal Area (MAISBA), and the Stand age is listed in the Table 1 along with the calculated value of Shannon Diversity Index (H) and the Species Richness Index (R).

Table 1. Average calculated value of different variables

Variable	Mean	Standard Deviation
SBA (m2/0.01ha)	5.41	5.03
MAISBA (m2/0.01ha/year)	0.23	0.12
H	1.27	0.41
R	4.23	1.46
Stand Age (year)	21.44	11.27

3.4. Relationship between biodiversity and productivity variables

The dependent (SBA and MAISBA) and independent (H and R) variables were found to have a significantly negative relationship ($p<0.0001$) when measuring the impacts of diversity on productivity (Table 2). Our result showed that diversity has an influence on productivity, although it only explains 65% of the total variance. Thereafter, stand basal area was also correlated with species richness index to examine the impact of diversity on productivity. A linear regression model showed a significant negative relationship ($p<0.0001$) between Species Richness Index (R) and Stand Basal Area (SBA). However, this linear regression model explained less variance and had a weaker relationship with SBA compared to the Shannon Wiener Index (Figure 4). Species richness calculated the number of observed species, while Shannon Wiener calculated the number of species and distribution of the number of individuals of these species within the sampling plots, which could be the reason why Shannon Wiener explains more of its variation (Table 2).

Table 2. Linear regression analysis of Shannon Diversity Index (H), Species Richness Index (R) vs. Stand Basal Area (SBA), Mean Annual Increment of Stand Basal Area (MAISBA)

Parameter Estimates		Variable			
Independent	Dependent	Coefficient	Constant	R Square	Sig.
H	*SBA (m^2/0.01ha)*	-11.23	20.68	0.66	<0.0001
R	*SBA (m^2/0.01ha)*	-3.11	19.42	0.63	<0.0001
H	*MAISBA(m^2/0.01ha/year)*	-0.23	0.55	0.50	<0.0001
R	*MAISBA(m^2/0.01ha/year)*	-0.07	0.53	0.51	<0.0001

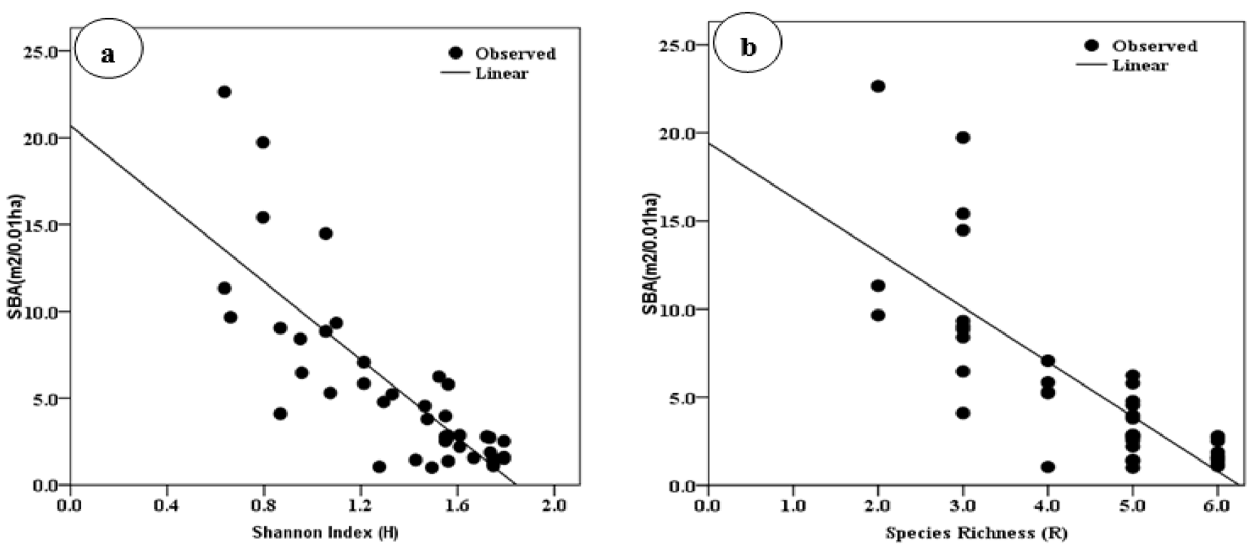

Figure 4. (a) impact of Shannon diversity index on stand basal area (SBA); (b) species richness index (R) on stand basal area (SBA)

This study shows a linear regression between H and Mean Annual Increment of Stand Basal Area (MAISBA) which has a significant negative relationship (Figure 5). The relationship between R and MAISBA was also analyzed to further assess the relationship between diversity and productivity, and found to be significantly negative.

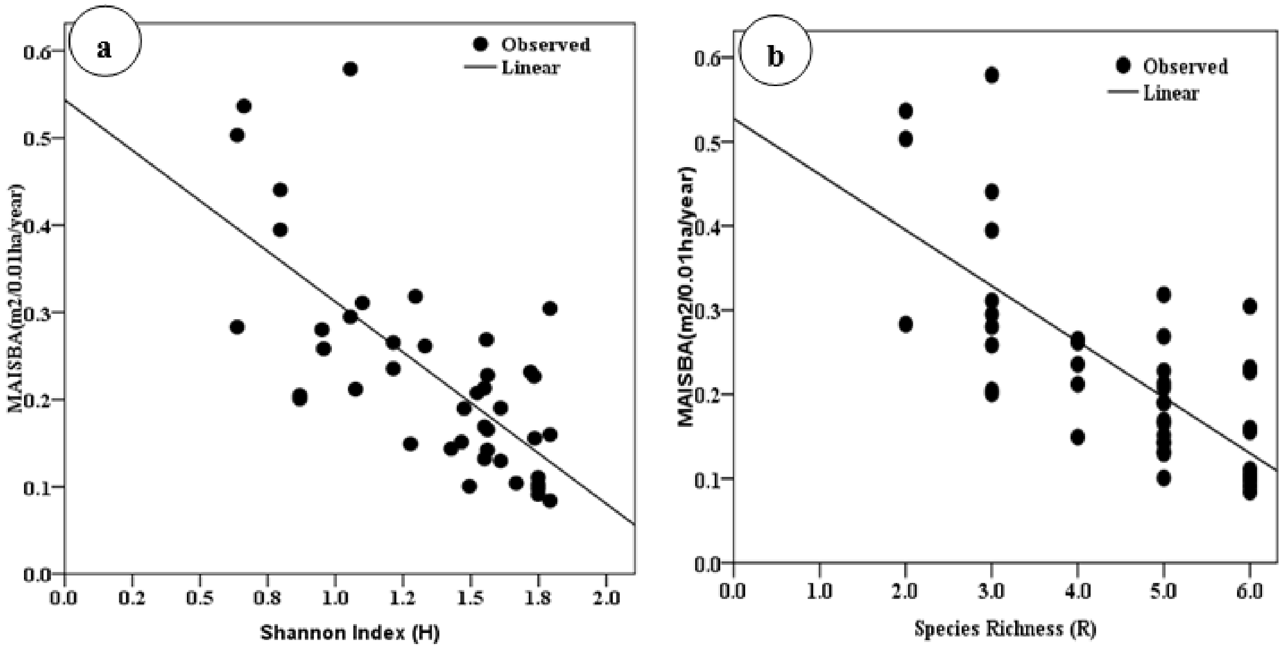

Figure 5. (a) impact of Shannon diversity index (H) on mean annual increment of stand basal area (MAISBA); (b) species richness index(R) on mean annual increment of stand basal area (MAISBA)

4. Discussion

The sample plots in this study recorded a total of 58 species and showed that the most abundant trees are economically important species. This indicates the main purpose of the mixed species plantations is to produce economically important products beneficial to local communities. *Swietenia mahagoni* was one of the most abundant species of this study and is commercially planted for both its timber, oil, and insecticidal properties. In addition, its bark, leaves and roots are extracted for anti-tumor properties as an important folk medicine. The leaves of *Lagerstroemia speciosa* is also useful for diabetes and kidney related diseases. The diversity of the plantations increased with sample size and the species accumulation plot appeared to reach an asymptote as well. This indicates that this study did not record all existing species in the area and that the increase in sample size also increases the number of species records (Gotelli and Colwell, 2011).

Regression analysis showed a negative relationship between tree diversity (R and H) and productivity (SBA and MAISBA) in the study area (Figure 4 and 5). Tree diversity (H and R) only explained a very small fraction of the variance and other environmental variables excluded from this study likely played an important role as well. Productivity in the form of Stand Basal Area and Mean Annual Increment of Stand Basal Area are also known to be influenced by climatic factors (Waring et al., 2014; Hooper et al., 2005).

Nonetheless our results indicate that an increase in treediversity leads to a decrease in productivity. In agreement with our study, Jacob et al. (2010) found a decline of wood and total aboveground productivity with an increase of diversity of tree genera. The negative relationship between productivity and diversity is most probably due to the problem of space and niche availability. Some species may work in their way around this limitation by employing different adaptation strategies, such as a accelerated growth or a more efficient utilization of the available time and space. When different functional groups are present, they would be able to occupy different ecological niches, and as a result diversity may be positively correlated with stand productivity (Nguyen et al., 2012). Moreover, the negative relationship between diversity and SBA may simply be explained by the ageing of the plantation, which causes suppression of species less tolerant to competition and productivity, and better explained by MAISBA. Therefore, a well-managed forest can sustain the positive relationship between tree diversity and productivity (Rosenzweig and Abramsky, 1993).

5. Conclusion

In general mixed species plantations can be considered to meet the increasing demand of wood and to restore degraded land. However, this work showed that tree diversity and productivity in mixed species plantations had a negative relationship in the study area. The relationship between SBA and diversity may explain the suppression of less tolerant species when the plantation age increases. In fact, this is a matter which further needs to be address by the scientific world. Diversity should encouraged because it can change the pattern of the relationship between diversity and productivity (Balvanera and Aguirre, 2006). Results of this study could aid forest management decisions on whether to implement monoculture or mixed species plantations considering the livelihoods of folk people.

Acknowledgement

The authors are grateful to the number of scientists of the Department of Forestry & Environmental Science, Shahjalal University of Science and Technology; Department of Folklore, University of Rajshahi; and Lawachara National Park authority for their support and guidance. Many thanks are also extended to the people in the study sites where field investigation was undertaken, who share their precious time, thought and concerns.

References

Adler, P.B., Seabloom, E.W., Borer, E.T., Hillebrand, H., Hautier, Y., Hector, A., O'Halloran, L.R., Grace, J.B., Anderson, T.M., Bakker, J.D., Biederman, L.A., Brown, C.S. and Buckley, Y.M. (2011), "Productivity is a poor predictor of plant species richness", *Science*, Vol. 333, pp. 1750–1753.

Babigumira, R., Angelsen, A., Buis, M., Bauch, S., Sunderland, T. and Wunder, S. (2014), "Forest clearing in rural livelihoods: household-level global-comparative evidence", *World Development*, Vol. 64, pp. 67-79.

Balvanera, P. and Aguirre, E. (2006), "Tree diversity, environmental heterogeneity, and productivity in a Mexican tropical dry forest", *Biotropica,* Vol. 38, pp. 479–491.

Firn, J., Erskine, P.D. and Lamb, D. (2007), "Woody species diversity influences productivity and soil nutrient availability in tropical plantations", *Oecologia,* Vol. 154, pp. 521–533.

Gotelli, N.J. and Colwell, R.K. (2011), "Estimating species richness", in Magurran, A. E. and McGill, B. J. (Ed.), *Frontiers in Measuring Biodiversity*. Oxford University Press, New York, pp. 39–54.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O. and Townshend, J. R. G. (2013), "High-resolution global maps of 21st-century forest cover change", *Science,* Vol. 342 No. 6160, pp. 850-853.

Jacob, M., Leuschner, C. and Thomas, F.M. (2010), "Productivity of temperate broad-leaved forest stands differing in tree species diversity", *Annals Forest Science*, Vol.67 No. 5, pp.9.

Kindt, R. and Coe, R. (2005), *Tree Diversity Analysis: A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies,* World Agroforestry Centre (ICRAF), Nairobi.

Margalef, R. (1958), "Information theory in ecology", *General Systematics,* Vol. 3, pp. 36-71.

Mukul, S.A, Herbohn, J., Rashid, A.Z.M.M. and Uddin, M.B. (2014), "Comapring the effectiveness of forest law enforcement and economic incentive to prevent illegal logging in Bangladesh", *International Forest Review*, Vol. 16, pp. 363-375.

Mukul, S.A. (2007), "Biodiversity conservation strategies in bangladesh: the state of protected areas", *Tigerpaper,* Vol. 34 No. 3, pp. 28-32.

Mukul, S.A. (2008), "The role of traditional forest practices in enhanced conservation and improved livelihoods of indigenous communities: case study from Lawachara National Park, Bangladesh", in *1st international conference on 'Forest Related Traditional Knowledge and Culture in Asia*, Seoul 2008, Korea, pp. 24-28.

Mukul, S.A., Uddin, M.B., Uddin, M.S., Khan, M.A.S.A. and Marzan, B. (2008), "Protected areas of Bangladesh: current status and efficacy for biodiversity conservation", *Proceedings of the Pakistan Academy of Sciences*, Vol. 45, pp. 59-68.

Nguyen, H., Herbohn, J., Firn, J. and Lamb, D. (2012), "Biodiversity–productivity relationships in small-scale mixed-species plantations using native species in Leyte province, Philippine", *Forest Ecology and Management,* Vol. 274, pp. 81–90.

NSP. (2006), *Site Information Brochure: Satchari National Park*, Nishorgo Support Project, Bangladesh.

Rahman, S.A, Baldauf, C, Mollee, E.M., Pavel, M. A. A., Mamun, M.A.A., Toy, M.M. and Sunderland, T. (2013), "Cultivated plants in the diversified homegardens of local communities in Ganges valley, Bangladesh", *Science Journal of Agricultural Research & Management*, Vol. 2013, pp. 1-6.

Rahman, S.A., Imam, M.H., Snelder, D.J. and Sunderland, T. (2012b), "Agroforestry for livelihood security in agrarian landscapes of the Padma floodplain in Bangladesh", *Small-scale Forestry*, Vol. 11 No. 4, pp. 529-538.

Rahman, S.A., Rahman, M.F. and Sunderland, T. (2012a), "Causes and consequences of shifting cultivation and its alternative in the hill tracts of eastern Bangladesh", *Agroforestry Systems*, Vol. 84 No. 2, pp. 141-155.

Rahman, S.A., Rahman, M.F., Codilan, A.L. and Farhana, K.M. (2007), "Analysis of the economic benefits from systematic improvements to shifting cultivation and its evolution towards stable continuous agroforestry in the upland of eastern Bangladesh", *International Forestry Review*, Vol. 9 No. 1, pp. 536-547.

Rosenzweig, M.L. and Abramsky, Z. (1993), *How are Diversity and Productivity Related?*, The University of Chicago Press, Chicago.

Waring, R.H., Coops, N.C., Mathys, A., Hilder, T. and Latta, G. (2014), "Process-based modeling to assess the effects of recent climatic variation on site productivity and forest function across western North America", *Forests*, Vol. 5, pp. 518–534.

Zhang, Y., Chen, Y.H.H. and Reich, B.P. (2012), "Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis", *Journal of Ecology*, Vol. 100, pp. 742–749.

Appendix 1

Tree species present in the mixed species plantation at the Lawachara National Park.

Family	Local Name in Bengali	Scientific Name
Anacardiaceae	Amm	*Mangifera indica*
Aquifoliaceae	Ludh	*Llex godajam*
Leguminosae	Malakana koroi	*Paraserianthes falcataria*
	Mangium	*Acacia mangium*
	Akashmoni	*Acacia auriculiformis*
Bombacaceae	Shet Shimul	*Ceiba pentandra*
	Shimul	*Bombax buonopozense*
Lamiaceae	Teak	*Tectona grandis*
	Gamar	*Gmelina arborea*
	Awal	*Vitex pinnata*
Moraceae	Dumur	*Ficus hispida*
Moraceae	Kanthal	*Artocarpus heterophyllus*

	Chapalish	*Artocarpus chaplasha*
	Kakdumur	*Ficus hispida*
	Deoa	*Artocarpus lacucha*
	Jagadumur	*Ficus racemosa*
Dilleniaceae	Ekuish	*Dillenia scabrella*
	Bonchalta	*Dillenia Indica*
Caesalpiniaceae	Sada shingra	*Cynometra ramiflora*
Capparaceae	Bonak	*Crataeva nervosa*
Combretaceae	Arjun	*Terminalia arjuna*
	Bohera	*Terminalia belerica*
	Deshi Badam	*Terminalia catappa*
Apocynaceae	Chatian	*Alstonia scholaris*
Dipterocarpaceae	Garjan	*Dipterocarpus turbinatus*
	Telsur	*Hopea odorata*
	Sal	*Shorea robusta*
Euphorbiaceae	Bolos	*Sapium baccatum*
Elaeocarpaceae	Jalpai	*Elaeocarpus robustus*
Myrtaceae	Eucalyptus	*Eucalyptus citriodora*
Euphorbiaceae	Amloki	*Phyllanthus embelica*
	Latkan	*Baccaurea ramiflora*
	Pitali	*Trewia nudiflora*
Mimosaceae	Kala Koroi	*Albizia lebbeck*
Lecythidaceae	Khami	*Careya arborea*
Clusiaceae	Kau	*Garcinia cowa*
Fabaceae	Loha kath	*Xylia Dolabriformis*

Lauraceae	Kalo menda	*Litsea glutinosa*
	Ludijaylla	*Litsea lancifolia*
	Tejpata	*Cinnamomum tamala*
Lythraceae	Jarul	*Lagerstroemia speciosa*
Sterculiaceae	Jangli Badam	*Sterculia foetida*
Malvaceae	Paresh	*Thespesia populnea*
Meliaceae	Chikrashi	*Chukrasia tabularis*
Meliaceae	Mahogani	*Swietenia mahagoni*
Mimosaceae	Loha Siris	*Albizia procera*
Myrtaceae	Jam	*Syzygium cumini*
	Bottejam	*Syzygium operculatum*
Phyllanthaceae	Neur	*Phyllanthus Acidus*
Rutaceae	Pisli	*Micromelum minutum*
Rhizophoraceae	Lal kakra	*Bruguiera gymnorrhiza*
Anacardiaceae	Jhawa	*Holigarna longifolia*
Theaceae	Sagoler bori	*Eurya acuminate*
Unkown	Chercheri	*Unkown*
	Kaloti	*Unkown*
	Khaiwala	*Unkown*