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TREE SPECIES DIVERSITY AND PRODUCTIVITY RELATIONSHIP IN THE CENTRAL REGION OF BANGLADESH

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ABSTRACT
The diversity-productivity relationship has received considerable attention during the past two decades, largely because of the continuous loss of biodiversity. The positive relationship between species diversity and productivity is significant as a credible argument for the conservation of biodiversity. This research was conducted in the central region of Bangladesh to exemplify the relationship between tree species diversity and stand productivity at four mixed plantations. In total 112 sample plots (size - 0.09 ha/plot) of four different mixed species plantations were systematically selected for data collection. After that, regression analysis explained a significantly positive relationship between tree species diversity and productivity at four mixed plantations. This research suggests that having more tree species generally raises plantation productivity. Therefore, this result indicates that mixed species plantations could be the better choice in the degraded and fallow forest lands of Bangladesh.

Keywords: Species diversity, Stand productivity, *Acacia auriculiformis*, *Acacia mangium*, *Swietenia mahagoni*, *Gmelina arborea*, Mixed species plantations.

Contribution/ Originality

This study is important in terms the positive relationship between species diversity and productivity should be used for restoring degraded tropical forests and the conservation of biodiversity.

1. INTRODUCTION

Over the last twenty years, ecologists have focused on determining the nature of the relationship between biodiversity and ecosystem function, although Darwin [1] proposed more than a century ago that diverse plant communities were more productive, and at the present time,

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it has proven controversial as well as difficult to verify [2-5]. Previous empirical diversity-productivity relationship studies in forest ecosystems have reported positive [6] insignificant or even negative [7] hump-shaped and flat (non-significant) patterns effects of species diversity on productivity. The positive relationship between species richness and productivity has been used as a persuasive argument for the conservation of biodiversity. Nowhere is this argument more important than in the highly diverse tropical forests, which have been, and continue to be, significantly degraded by human activities [8]. At the local scale, variation in site quality is thought to determine whether mixed forests are more productive than mono-specific stands [9]. In the simplest case of two-species mixtures, the higher productivity of mixed-species stands compared with mono-specific stands would be expected whenever the two species are either more efficient or complementary in using limited resources or when there is facilitation between species. These mixed species plantations may also be more productive than monocultures for three theoretical reasons. The niche complementarity hypothesis proposes that species-rich communities are able to more efficiently access and utilize limited resources because they contain species with a diverse array of ecological attributes [9]. The ecosystem is thought to be more functionally complete because these species complement each other, allowing them to optimize the use of resources. As a consequence, more diverse ecosystems are also more productive and have also been described as having fewer nutrients available because, overall, the uptake is more efficient [10]. The facilitation hypothesis suggests that plantations that use combinations of species that improve the growing conditions (i.e. Nitrogen-fixing trees) for other species may facilitate increases in overall production of a mixed stand [11, 12]. On the other hand, the sampling effect hypothesis proposes that more biologically diverse communities have increased productivity because they are more likely to contain at least one species that is particularly efficient in resource usage. That is, only one or two species within the community may be largely responsible for most of the production [13].

Monocultures are perceived to have largely negative impacts on the local environment [14-15]. This does not mean that communities necessarily want to restore the original forests, but plantation systems with multiple species, using high-value local species appear to be attracting increasing interest in many parts of the tropical world. Mixed forests have been maintained for landscape aesthetics, conservation of wildlife, recreational purposes, a higher diversity of forest products, and the belief that they are more resistant to disease and disturbances such as wind or fire [13]. The research focuses on 10-20 years of mixed plantations in the Bhawal National Park. The objective of this research was to investigate the nature of the relationship between tree species diversity and productivity at different mixed species plantations across the region. We hypothesize that increases in both the species richness and Simpson's biodiversity index influence the diverse benefits of productivity.

2. MATERIAL AND METHODS

2.1. Site Description

The Bhawal Sal forest is situated 40 km north of Dhaka on the Madhupur tract in the central region of Bangladesh (Figure 1) and it lies between 24º 5´ 44.98´´ North latitude and 90º 24´ 14.4´´ East longitude. The fieldwork was conducted at the Bhawal National Park (BNP) on this forest that was established in 1982 comprising an area of 5,022 ha of reserved forests through the Bangladesh Wildlife (Preservation) Order, 1973. The park is a tropical, moist-deciduous forest that mainly originated from seedlings and coppices with Sal (*Shorea robusta*) as the dominant tree species [16-18]. Its forest of partial area planted of the different mixed species plantation includes *Acacia auriculiformis*, *Acacia mangium*, *Swietenia mahagoni*, *Gmelina arborea*, and so on. The soil belongs to the bio-ecological zone of Madhupur Sal Tract [19-20]. The soils have a moderate to strong acidic reaction [21]. The soils are also characterized by low organic matter and low fertility [22]. Climatic condition is moderate, with annual rainfall of 2030-2290 mm, annual temperature of 10-37°C, and humidity between 60 and 86% [23].

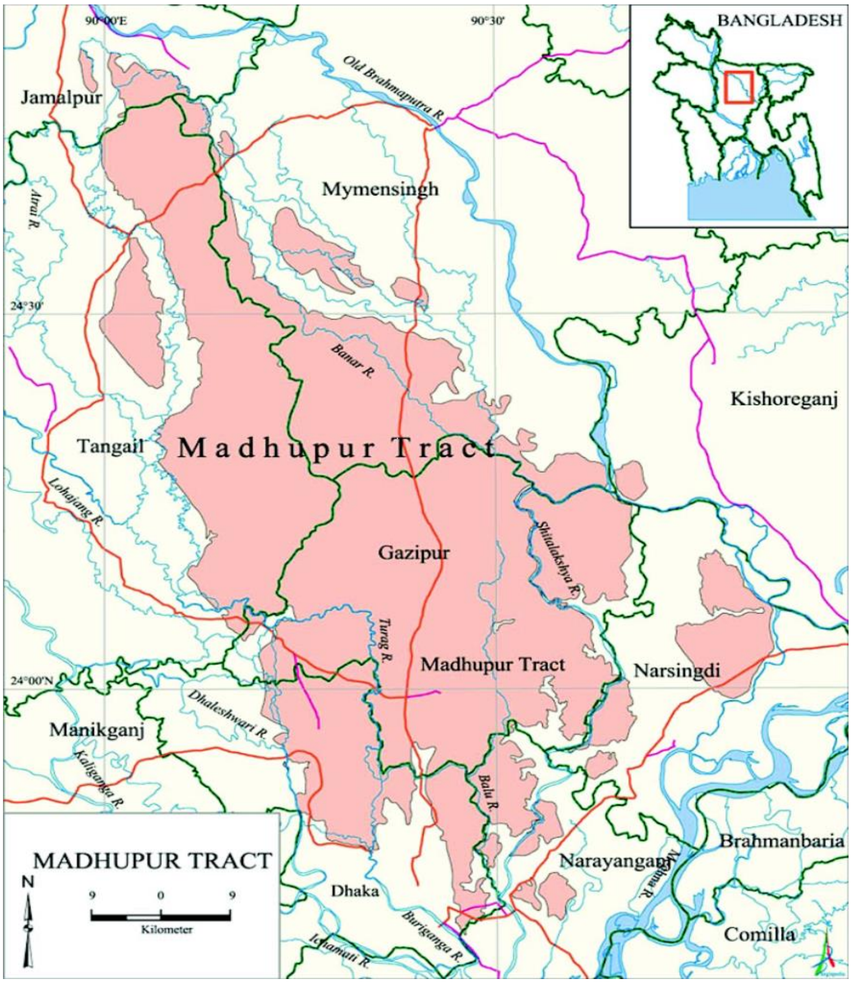

Figure 1. Study area in the central region of Bangladesh (Source: Banglapedia [16])

2.2. Sampling Design

The Bhawal National Park was selected on the basis of different mixed species plantation forests in this region. In total 112 sample plots (sample size – 30 m × 30 m) were systematically selected for data collection. Four different mixed plantations of *S. mahagoni* (1996 year planted), *A. auriculiformis* (1998 year planted), *G. arborea* (2000 year planted), *A. mangium* (2002 year planted) were selected in this research. Systematic sampling was adopted for selecting plots within these mixed plantations. Afterward, 28 sample plots of size 30 m × 30 m were established in each mixed species plantation.

2.3. Data Collection and Measurement

Standard forestry growth measurements were made on each plot with the following information recorded: tree species identity, diameter over bark at 1.3 m (breast height-DBH), and total height data from all sample plots (10.08 hectares). In each plot, all trees ≥7.6 cm in diameter at breast height (DBH) was identified and it was measured by *tree* calipers. These measurements were used to calculate biodiversity (as species richness and Simpson's biodiversity index) and production (calculated as basal area (m^2 ha^{-1}) [24]. Simpson's biodiversity index was used to represent biodiversity after testing found that it was closely related to both species richness and the Shannon–Weaver index. This choice is supported by Magurran [25] who, in a detailed analysis of different biodiversity indices, suggests that the Simpson's biodiversity index can be a more reliable measure than the Shannon–Weaver index or species richness. Therefore, accurate biomass estimates would have been problematic, so plantation productivity was measured by stand basal area, which were derived from DBH and plot measurements. Subsequently, nondestructive methods were found user-friendly, less expensive, and can give accurate different parts of tree productivity estimates [26-30]. Moreover, basal area is nevertheless highly correlated with tree volume and biomass [31] and is used as a measure of plantation productivity.

2.4. Data Analysis

The Regression analysis suggests the simplest expressions of linear relationship between species diversity and productivity (Table 2), were retained as the best models explaining variation in the data. We used R statistical software version 3 [32] for data analysis.

3. RESULTS AND DISCUSSION

Table 1 illustrates that average stand basal area, tree species diversity, average number of stems, and mean tree height are stated in different mixed species plantations i.e. 1996, 1998, 2000, and 2002 years plantations.

Table 1. Status of four mixed species plantations

Plantation type	Year planted	Size (ha)	Average stand basal area (m^2 ha^{-1})	Average no. of stems/ha (≥7. 6cm)	Average tree height (m)	Average Simpson's biodiversity index	Average species richness
Swietenia mahagoni	1996	61	37.197	374	24.8	0.79	5.6
Acacia auriculiformis	1998	147	33.457	395	22.76	0.71	4.6
Gmelina arborea	2000	54	22.192	442	17.78	0.56	3.8
Acacia mangium	2002	82	16.513	477	15.81	0.58	3.2

Relationship between species diversity and productivity was observed positive in four mixed species plantations. The subject species of *S. mahagoni* (1996 year planted), *A. auriculiformis* (1998 year planted), *G. arborea* (2000 year planted) and *A. mangium* (2002 year planted) comprised 32.6, 38.3, 27.4, 35.2 % correspondingly of their plantation stand basal area. After that, we also showed that the Simpson's biodiversity index of tree species was highly positive related to stand basal area than species richness in these plantations (Figure 2-5) in addition to the Simpson's biodiversity index explained around 45, 38, 34 and 26 % respectively of their variance (Table 2).

Table 2. Statistical analysis of stand productivity using the regression analysis

Species diversity	Plantation type	*a*	*b*	Residual standard error	*F*	*P* value	R^2	Adjusted R^2_a
Species richness	*Swietenia mahagoni*	25.255	2.107	5.14	15.24	0.001	0.3525	0.3294
	Acacia auriculiformis	22.493	2.349	4.446	8.005	0.01	0.2323	0.2146
	Gmelina arborea	13.792	2.211	3.981	8.264	0.01	0.2279	0.2003
	Acacia mangium	7.620	1.529	3.056	5.709	0.05	0.1693	0.1397
Simpson's biodiversity index	*Swietenia mahagoni*	-1.500	48.648	4.737	22.9	0.001	0.4499	0.4303
	Acacia auriculiformis	3.922	39.656	3.96	17.39	0.001	0.3832	0.3611
	Gmelina arborea	10.273	21.207	3.677	14.52	0.001	0.3415	0.3179
	Acacia mangium	4.254	14.170	2.894	9.606	0.01	0.2554	0.2289

The results of this research indicate a significant positive relationship between tree diversity and productivity at different mixed species plantations (Table 2 and Figure 2-5). Hence, the biodiversity-production balance was strongly related to the productivity of the mixed species plantations. There is observational evidence of a positive relationship between tree species richness and productivity at the regional and continental scale [33]. Caspersen and Pacala [34] and Vila, et al. [35] found a positive relationship between species richness and productivity in forest communities. They also found that on average forest plantations with mixed species were 30% more productive. Our results match species diversity–productivity patterns found in other parts of the world. For example, in Australia, Specht and Specht [36] showed a positive relationship between over storey species (trees and tall shrubs) richness and canopy annual shoot growth. After that, mixed stands are more productive than pure stands depends greatly on site conditions [37] and species composition [9, 38].

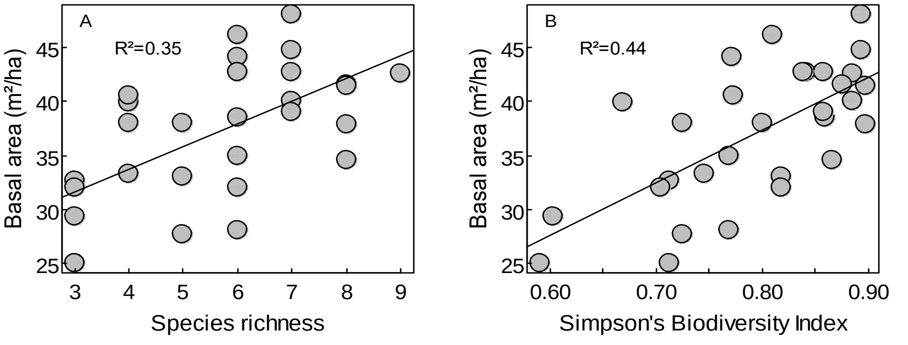

Figure 2. The relationship between tree species diversity and productivity in *Swietenia mahagoni* mixed species plantation. (A) Species richness and stand basal area (N=28, $R^2_a = 0.329$, $p<0.001$) and (B) Simpson's biodiversity index and stand basal area (N=28, $R^2_a = 0.43$, $p<0.001$)

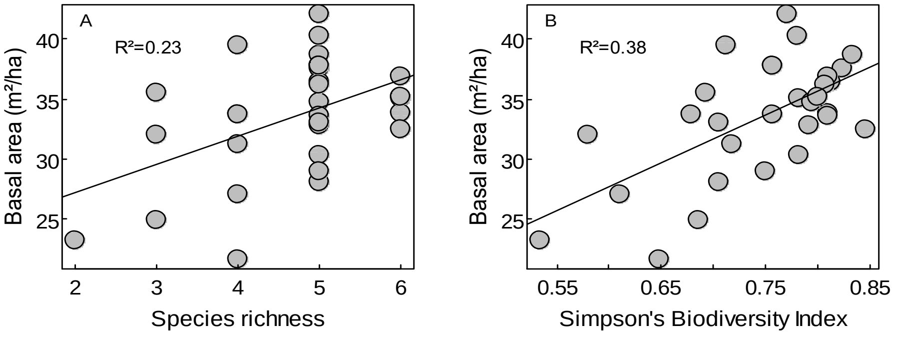

Figure 3. The relationship between tree species diversity and productivity in *Acacia auriculiformis* mixed species plantation. (A) Species richness and stand basal area (N=28, $R^2_a = 0.214$, $p<0.01$) and (B) Simpson's biodiversity index and stand basal area (N=28, $R^2_a = 0.361$, $p<0.001$)

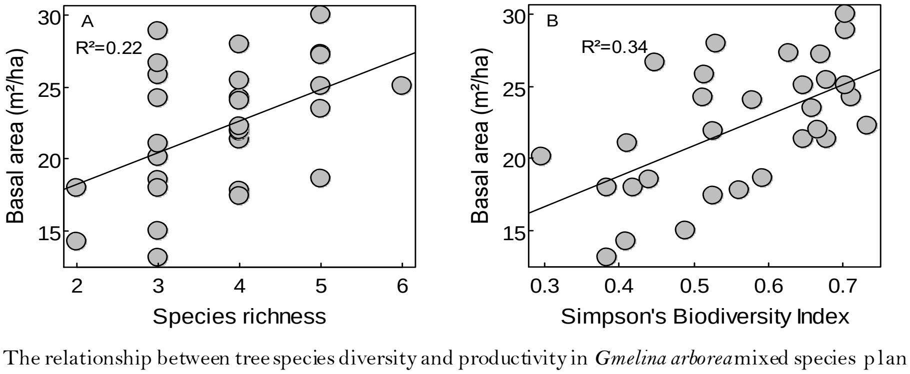

Figure 4. The relationship between tree species diversity and productivity in *Gmelina arborea* mixed species plantation. (A) Species richness and stand basal area (N=28, $R^2_a = 0.20$, $p<0.01$) and (B) Simpson's biodiversity index and stand basal area (N=28, $R^2_a = 0.317$, $p<0.001$)

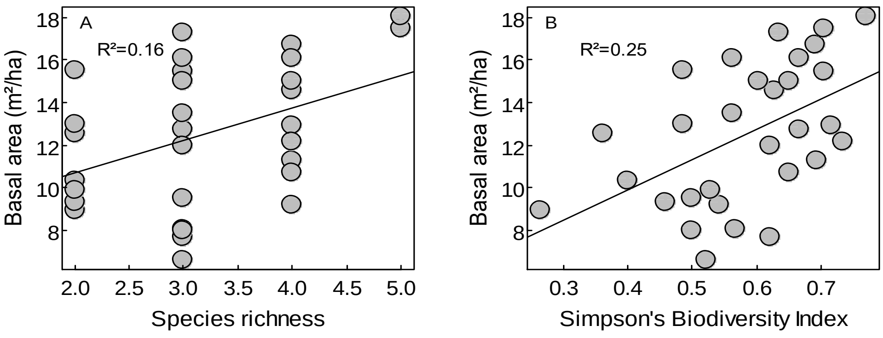

Figure 5. The relationship between tree species diversity and productivity in *Acacia mangium* mixed species plantation. (A) Species richness and stand basal area (N=28, $R^2_a = 0.139$, $p<0.05$) and (B) Simpson's biodiversity index and stand basal area (N=28, $R^2_a = 0.228$, $p<0.01$)

The productivity increase could be the result of a number of different mechanisms including complementary, facilitation, and the sampling effect. Although the plantations were not designed to rigorously test these mechanisms, some trends can be explored. Facilitation did not appear to be an important mechanism. The facilitation of growth by the fertilizing effect of nitrogen-fixing species [11] was tested in the correlation analysis and was found not to be a significant factor. On the other hand, the sampling effect could go some way to explaining the results. As a result, we showed the potentially influential role of the complementary mechanism in generating positive relationships, established within the mixed species plantations that are capable of more resourceful access and exploit inadequate supply. Followed by observational and experimental approaches (i.e. tree plantations) in forests should examine the relationship between species diversity and productivity while controlling for the effect of other co-varying factors such as environmental gradients and management practices that could underlie and confound the diversity–productivity relationships. However, based on this finding, the relationship between tree species diversity and stand productivity was straightforward as originally proposed by Darwin [1] and found in experimental community studies.

4. CONCLUSION

The consequences of this result showed that high species diversity usually raises productivity in mixed-species plantations. These results should encourage the planting of a wider variety of species across this region. Extensive research is also required to incorporate the management factors in the diversity-productivity research to surpass the effects of compounding factors. However, tropical mixed species plantations could be the better choice in the degraded and fallow forest lands in the central region of Bangladesh.

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