Teak Article for TRI News – Apr 16, 2001

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Title – *Understory Vegetation Characteristics along Teak (Tectona grandis) Plantation/ Natural Forest Ecotones in Costa Rica.*

Abstract –

Tree plantations often border natural forests. Plantations are generally acknowledged as a buffer zone option for these natural areas. However, their utility in maintaining understory diversity and site productivity as compared to the adjacent forests has not been well studied. One measure of the effectiveness of a buffer zone plantation could be understory plant cover and species diversity. To help understand interactions along a teak/forest ecotone, understory plants in 8 teak stands adjacent to forest parcels in the central Pacific Costa Rican lowlands were examined for cover and species composition. 20 m transects were established from the teak/forest edge into the teak with four 1x1 m. plots along each transect. Measurements were taken of several plantation attributes and the understory in order to estimate 1) best fits for linear regressions to explain vegetative cover and species diversity, and 2) differences in family composition at various distances from the edge. The aggregate of teak and forest tree basal area was the best single indicator for number of species per plot (r^2=.21), whereas distance from the teak edge was the best single indicator for understory cover (r^2=.12). Transformations of basal area, open canopy percentages, and the log of distance from the edge explained 24% of the variation in understory cover and 40% of the variation in the number of species from the forest/teak edge. Vegetation cover decreased from 50% at the teak/forest edge to 22% at 20 m, and species per plot decreased from 8.6 to 5.2 along the same line. Teak litter weight was not a significant indicator for understory cover or species per plot. The family *Papilionaceae* showed the most consistent presence along transects and had the highest average percent cover of any family. Specific families, genera, and species were noted as worth further consideration to enhance understory cover and diversity.

"The future of a significant portion of tropical biodiversity may depend on the way in which production forests are managed." - D. Delgado, 1999.

Introduction –

Teak (*Tectona grandis*) is a valuable timber species used for shipbuilding, furniture, and other carpentry (Weaver and Francis, 1990), for popular flooring and paneling, and even for specifics such as fixtures requiring a high resistance to acids (Chudnoff, 1984). As of the early 1990s, teak alone accounted for 14% of the total worldwide tropical plantations (Evans, 1992). Teak is also an increasingly popular plantation tree in parts of Central America. However, erosion and lack of understory growth beneath pure teak stands is a commonly acknowledged problem that makes teak management environmentally difficult for maintaining forest biodiversity and site productivity. Erosion is suspected to be the cause of much of the "pure teak problem," where teak experiences significantly reduced second rotation growth (Champion and Seth, 1968). Sometimes teak can suppress *all* ground vegetation (Evans, 1992). Yet, teak stands can have abundant understories. A continuous litter layer and undergrowth can practically eliminate erosion problems (Ibid). Maintaining healthy and diverse understories can also “increase the value of plantations for biodiversity conservation to a considerable extent” (Johns, 1997).

A significant portion of local plant biodiversity can be found in plantations (Keenan 1997). Plantations next to forest may help reduce adverse edge effects on the forest as well as provide additional habitat for some forest species (Johns, 1997). Studies have found that plantations can more quickly encourage forest succession processes on ecologically degraded sites by providing more suitable conditions for forest understory species from adjacent forest remnants (Parrotta et al, 1997; Lugo, 1997; Powers et al, 1997; Haggar et al, 1997). Most of these studies concentrate on woody vegetation. Allowing forest trees to re-grow is often not the aim of plantation managers, especially those anticipate a second rotation of a particular species, and so management often entails occasional ‘cleaning,’ leaving herbaceous and low-growing vegetation. Knowing the diversity and cover of this ‘default’ and mostly non-woody understory can help assess the biological conservation value of this form of management.

In a plantation, vegetation diversity appears to develop relatively quickly near the forest boundary (i.e. ecotone) but develops more slowly with increasing distance away from the forest (Parrotta, 1997b). As examples, colonizing tree species with larger seeds concentrate near edges (Ibid.), and frugivorous bats roosting on edge trees result in higher colonization rates (i.e. diversity) at plantation edges (Lugo, 1997). Though research has been done on teak understory in Indonesia and India for example, there is little data for teak understory and ecotones in Central America. If general teak plantation attributes relating to species diversity and cover differences along a teak/forest ecotone can be determined, this in turn can inform decisions to maintain adequate understory cover for erosion control, landscape diversity, animal passageways, plantation strip widths, and understory enrichment planting.

The objectives of this study were threefold: (1) Examine the relationship between teak litter and understory variables. One hypothesis about the lack of understory beneath teak is that the amount of teak litter suppresses understory vegetation. To test this, I investigated the relationship between teak litter weights and such variables as understory cover and plant diversity. (2) Obtain general regression models for understory species diversity and vegetation cover compared to plantation attributes in the teak/forest ecotone. This can reveal general correlated plantation variables for teak ecotone understory diversity and cover. (3) Examine the effects of forest edge distance on plant family diversity and cover, and determine various taxonomic trends. This will guide further research on certain plants or conditions to encourage under standard teak plantations for greater cover and plant diversity.

Site Description –

The research took place in the Parrita Valley in the foothills of the Cordillerra de Talamanca in Costa Rica near the town of Parrita – Latitude 9º31’ N, Longitude 84º18’W. (Average annual temperature 26º C: average annual rainfall ranges between 3000-3600 mm.) Sampling took place between June 13 and August 15, 2000. Seven teak stands ranging from ages 3-12 years and one stand of 49 years were sampled. All ranged between 10 and 200 m.a.s.l. Previous land uses on had been pasture and/or agriculture. The stands had all received a typical treatment of cutting back any vegetation both before planting and for roughly the first two years after until the teak canopy establishes and further cutting is generally unnecessary. Initial spacing for the teak was 2.5x3 to 3x3 m for all the stands. About a third of the plots were on slopes ≤3%, while the rest were typically on slopes 10-35%. In slopes ≤3%, soils were typically riparian Inceptisols. Soils on slopes >3% were mostly Ultisols. Several soil samples showed organic material ranging from 1.5-5.6% and pHs ranging from 5.3 to 6.4. The sampled stands did not have any evidence of grazing, nor of recent fires.

Methods –

Site Selection Criteria

Teak plantations were chosen with the following criteria: (1) Pure teak stands with a width of greater than 50 m, (2) stands 3 years or older, as this age begins to show a reduced understory, (3) contiguous edges 100+ m long with a swath of natural forest (at least 2 ha and typically over 10 ha) in order to include larger forest remnants which should have a fuller compliment of species able to adopt to teak understory conditions, (4) the adjacent forest canopy being nearly as tall or taller than the teak canopy to limit light differences along the ecotone, and (5) no thinning or weeding cuts within the past year to allow any vigorous resprouting plants time to establish. Most of the plots had only low-growing understory below 1.4 m of shrubs, vines, herbs, and grasses.

Experimental Design

Transects running from the forest/teak edge into the teak (perpendicular to the edge line) were established at random points 15 to 40 m apart along the forest/teak edge. At each transect, 1 x 1 meter plots were set at 0 m (underneath the forest/teak canopy line), 3 m, 9 m, and 20 m further into the teak stand. These distances were chosen after visiting several of the teak plantations and informally assessing that understory floristic and vegetative cover changes generally seemed concentrated in the first 10-15 meters from the edge. A total of 45 transects of four plots each were measured in 8 different stands. Four stands had only four transects each.

At each plot, the following measurements were taken: percent ground slope, basal area (BA) of the teak, BA of the forest trees, and open canopy percentage readings. An angle gauge was used to estimate BA in m^2/ha (BAF 1 m^2/ha). The teak and adjacent forest BA measurements were combined to create an aggregate BA estimate at each plot. Open canopy percentages were used as a proxy for light amounts. A concave spherical densiometer was read at 1 m above the ground facing outward at each plot corner, and the mean was calculated per plot. Within each plot, the following measurements were taken: (1) Teak litter weight was determined by weighing any identifiable teak leaf parts that had not yet decomposed into pieces less than ~3 cm. (2) Understory litter was weighed as leaf litter other than teak and any 'non-snapping' rotting branches less than 1 cm diameter. (3) The percentage of plant cover below 1.4 m was recorded using the Domin scale, a 0-100% range partitioned into 10 classes with smaller graduations for low percentages (Kent & Coker, 1992). (4) For each understory plant species, percent cover, aboveground biomass, and number of individuals were recorded. Grasses did not receive density counts. (5) Teak tree heights were taken to determine site indices. In several plots, soils were sampled to a 15 cm depth for pH and organic material, and measured for A-layer depths. Plant samples were mostly taken to the Institute of Biodiversity in Costa Rica for identification. In all, 1032 species counts were made in the various plots.

Data Analysis

Analyses of variance regressions were performed to find closely correlated variables. The number of species/m^2 was used to indicate species diversity. The percentage of understory cover and species/m^2 were considered the most closely correlated dependant variables to determine understory characteristics, as opposed to biomass, densities, or other litter weights. The most useful independent variables with the strongest correlations were the aggregate BA, slope percentages, open canopy percentages, and distance from the edge. The following measurements did not have correlations or explanatory power as strong to compare against other variables, and were thus not used for correlations: soil data, biomass within each plot, understory litter weights, individual species counts, individual species biomass, and site indices.

Results -

Teak Litter Weight Comparisons

Over all stands, teak litter weights were very weakly correlated with understory cover or species/m^2. Teak litter weight explained less than 2% of the variance of species per plot, and less than 1% of cover variance. BA, distance from the edge, and open canopy percentages also varied with teak litter weight by less than 1%. Yet, slope percentages showed a positive correlation of 23% with teak litter weight. Teak litter weights at various slope percentages are presented in Table 1. The steepest stand (63% slope ±18%) had a mean teak litter weight over twice the average weight of any other stands (1770 g ± 729). When only the 28 plots in the 3-year old stand were examined, teak litter was correlated to 31% of the vegetative cover and 18% of the species diversity. However, these correlations promptly diminished with the inclusion of 4- and 5-year old stand data.

Table 1: Teak litter weights at various slopes for 180 plots in the Parrita Valley, Costa Rica. (Standard errors in parentheses)

Percent slope	Teak litter weight	Plots
0 ≤ slope ≤ 3	385 (± 206) g.	63
3 < slope ≤ 10	738 (± 336)	28
10 < slope ≤ 25	744 (± 432)	42
25 < slope ≤ 40	912 (± 616)	19
40 < slope ≤ 100	1196 (± 737)	28

Regression Estimators for Understory Cover and Species Diversity

For general regression models, three variables had the strongest ability to predict understory cover and species/m^2: BA, open canopy percentages, and the distance from the teak/forest edge. Notable correlations are shown in Table 2. BA and distance were negatively associated with cover and species/m^2, while open canopy percentages were positively associated. Differences of r^2 values were minimal using either squared roots or log transformations of values of both BA and distance from the edge. Similarly, the r^2 values using the squared roots and the cubed roots of the open canopy percentages were nearly the same. The correlation coefficients for all of the models in Table 2 were P<.0001. Slope was a positive but weak indicator for understory cover with r^2=.02.

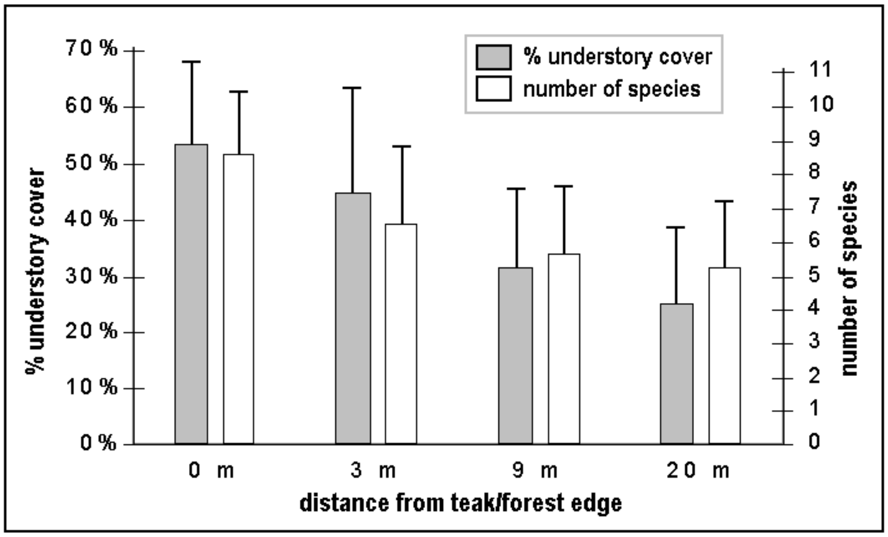
Table 2: Single and multiple regressions with number of species per m^2 and percent understory cover for 180 plots in the Parrita Valley, Costa Rica.

	Independent variable(s)	**r^2 (adj. r^2)**	**F value**
Species/m^2 versus:	$\sqrt{\text{BA}}$	.21	47.2
	$\sqrt{\text{distance from edge}}$	.17	37.5
	$\sqrt{\text{BA}}$ $\sqrt[3]{\text{\% open canopy}}$ log(distance from edge)	.39 (.38)	37.4
% understory cover versus:	log(distance from edge)	.13	26.8
	$\sqrt{\text{BA}}$ $\sqrt{\text{distance from edge}}$	.21 (.20)	23.6
	$\sqrt{\text{BA}}$ $\sqrt[3]{\text{\% open canopy}}$ $\sqrt{\text{distance from edge}}$	.23 (.22)	17.6

Effects of Distance from Teak/Forest Edge and Taxonomic Trends

Distance from the edge was only very weakly correlated with any other independent variable. BA and distance from the edge had almost no correlation (r^2=.002), and open canopy percentages and distance had a very slight negative correlation (r^2= .01). (BA and open canopy percentages had a much stronger negative correlation (r^2= .21).) Overall, the average percent understory cover per plot was 42% with a standard error of 10%, while the average number of species/m^2 was 6.9 with a standard error of 1.8, though the median was 7.6. Stand average differences across distances to the edge are shown in Figure 1. Across all plots, the mean BA reading was 11.4 m^2/ha (±4.5), the mean open canopy percentage was 10.4% (±5.3%), and mean slope was 19.4% (±22.9%).

Figure 1: Average percent understory cover per plot and number of species per plot along teak/forest ecotone over stand averages.



66 families and 132 genera were recorded. 94% of the species were identified to family, while 84% were identified to genera. 2.2% of the species counts were unidentified seedlings. Family data were compiled for different distances from the teak/forest edge using stand averages (Table 3). Subfamily *Papilionaceae* (*Leguminosae*) stood out as a clear presence in all the stands and across all edge distances, with about 7% average cover. Though *Amaranthaceae* and *Acanthaceae* covered 3.4% and 3.0% of the aggregated plots, they covered ≥0.5% in only three and five out of the eight stands, respectively. *Sapindaceae* and *Marantaceae* had a better distribution, being recorded as ≥0.5% in seven and six of the corresponding stands, but only had overall coverages of 2.6% and 2.0%. Amongst the families in Table 3, there were no clear differences in mean BA estimates, nor mean open canopy percentages, though with mean slope percentages, there were some notable differences. *Amaranthaceae* had a mean slope reading of 4% (SE 7%), *Piperaceae* had a mean of 29% (SE 26%), and *Rhamnaceae* had a mean of 36% (23%).

Certain genera and species within the 18 families were more prevalent. In the *Papilionaceae*, the genus *Machaerium* alone provided over half of the cover, and about half of the *Machaerium* was provided from one stand with very steep slopes (~50-80% typical) where grew *M. biovulatum* 'siete cuero,' and *M. acuminatum* and/or *M. pittieri* 'bejuco negro.' Plots in other stands often recorded instances of the genus *Lonchocarpus* 'chapierno,' and vines of *Desmodium* and *Centrosema* ('pega pega' named for their epizoic seeds). *Clitoria javitiensis* was encountered growing well as a thick shrub in steeper slopes of a 12-year-old stand that had undergone a hard thinning two years earlier. In all, at least 12 different *Papilionaceae* species were encountered, more than any other family, and *Papilionaceae* was the only family with a presence of >0.5% cover in every stand.

Table 3: Family percent cover over all stands at different transect distances in order of total percent cover over all stands. (Standard errors between stand averages at different distances included in parentheses.)

Family	Distance into Teak from Teak/Forest Edge: Canopy Edge (0 m)	3 m	9 m	20 m	Stand Transect Mean
No Understory Cover – 8 stands [1]	49.9 *(16.5)*	60.5 *(17.6)*	71.9 *(13.2)*	77.9*(14.1)*	65.1
Papilionaceae – 8	7.7 *(8.0)*	6.5 *(5.2)*	7.5 *(8.9)*	6.2 *13.4)*	7.0
Amaranthaceae – 3	2.6 *(8.1)*	6.5 *(36.7)*	2.7 *(15.1)*	1.8 *(8.9)*	3.4
Acanthaceae – 5	4.4 *(7.3)*	2.0 *(5.6)*	1.6 *(4.6)*	4.1 *(6.1)*	3.0
Sapindaceae – 7	4.1 *(4.5)*	3.7 *(4.6)*	1.9 *(3.3)*	0.8 *(1.3)*	2.6
Marantaceae – 6	2.2 *(2.5)*	3.3 *(6.1)*	1.9 *(3.6)*	0.4 *(1.3)*	2.0
Rubiaceae – 5	1.3 *(1.4)*	2.5 *(6.4)*	2.8 *(9.2)*	1.2 *(5.4)*	2.0
Piperaceae – 6	4.9 *(5.5)*	1.0 *(1.2)*	0.8 *(2.1)*	0.5 *(2.1)*	1.8
Stericulaceae – 6	1.7 *(1.1)*	1.4 *(5.8)*	1.5 *(1.8)*	0.9 *(2.5)*	1.4
Rhamnaceae – 6	2.3 *(3.3)*	1.9 *(1.8)*	0.3 *(na)*	0.6 *(2.5)*	1.3
Euphorbiaceae – 4	2.4 *(5.1)*	1.3 *(2.6)*	0.7 *(3.7)*	0.1 *(0.3)*	1.1
Vitaceae – 3	1.0 *(2.6)*	1.4 *(3.9)*	0.4 *(0.6)*	1.7 *(5.5)*	1.1
Poaceae – 6	2.0 *(3.5)*	1.0 *(1.9)*	0.6 *(0.9)*	0.5 *(0.7)*	1.0
Cyperaceae – 6	2.0 *(2.8)*	1.2 *(1.6)*	0.3 *(0.8)*	0.5 *(0.5)*	1.0
Asteraceae – 7	0.5 *(0.6)*	0.5 *(1.2)*	1.5 *(2.2)*	0.5 *(0.8)*	0.8
Cyclanthaceae – 1	1.7 *(na)*	0.5 *(na)*	0.3 *(na)*	0.0 *(na)*	0.6
Boraginaceae – 3	0.6 *(2.7)*	0.0 *(na)*	1.6 *(5.6)*	0.0 *(na)*	0.6
Palmae – 2	0.1 *(na)*	0.2 *(0.7)*	1.0 *(2.7)*	0.3 *(na)*	0.4
Solanaceae – 1	1.4 *(na)*	0.0 *(na)*	0.0 *(na)*	0.0 *(na)*	0.4
Unidentified – 4	1.0 *(1.0)*	1.2 *(2.9)*	0.1 *(na)*	0.1 *(0.2)*	0.6
Other Families [2] – 8	13.0 *(6.0)*	11.2 *(3.4)*	5.6 *(3.2)*	3.8 *(2.1)*	8.4
totals	*106.8*	*107.8*	*105.0*	*101.9*	*105.4*

Totals ≠ 100% due to plant overlap and rounding.

[1] indicates number of stands (out of 8) with family percent cover total >0.5%.

[2] Includes all other families with <1% average cover over any transect distance and family stand totals <0.5%

The *Amaranthaceae* family principally included species in the genera *Achyrathes* and *Cyanthula*, with over 90% of the total cover from a 49-year-old stand on flat ground. For the Most of the *Acanthaceae* family were found in younger stands with modest slopes (~10-30%) and in the 12-year-old stand that had been thinned two years earlier.

In the *Sapindaceae* family, the genera *Paullina* and *Serjania* accounted for most all of the cover. With the *Marantaceae* family, *Calathea* was the single genus recorded. The family *Rubiaceae* consisted mostly of *Psychotria* with around ¾ of that being *P. horizontals*, encountered in one 4-year-old stand with modest slopes (~5-35%). The *Piperaceae* were all *Piper* species, typically *P. marginatum* 'anicillo' where identified, though two stands also recorded *P. reticulatum* 'anicillo montaña.' In the *Stericulaceae*, nearly all the encountered plants were *Guazuma invira* or *G. ulmifolia* 'guacimo.'

Plants of the family *Rhamnaceae* were all identified as two or three viny *Gouania* species. With *Euphorbiaceae*, *Acalypha diversifolia* 'carnilla de mula' had the highest percent cover, accounting for over half of the *Euphorbiaceae* cover. In *Vitaceae,* all were of the genus *Cissus*, and all of those identified to species were the vine *C. verticillata.* Within *Poaceae, Paspalum spp.* was encountered most frequently. The *Cyperaceae* mostly included the genera *Scleria* and/or *Cyperus* 'navajuela.' The *Asteraceae* were mostly *Vernonia patens* 'tuete' with *Clibadium subariculatum* 'murcielaguillo.' The family *Cyclanthaceae* consisted of *Carludovica spp*. 'tococa,' also from the 4-year-old stand. The *Boraginaceae* included some small *Cordia spp*. 'laurel,' but were mostly *Tournefortia spp*. The *Palmae* were most all of the genus *Roystonea* 'palma real.'

Discussion –

Teak litter weight was not significantly correlated with either understory cover or species/m^2, thus not supporting the hypothesis that the amount of teak leaves accumulating on the forest floor negatively impacts species diversity or understory cover. The main problem with this hypothesis seems that teak litter does not accumulate with any relation to teak growth beyond the first few years. The higher correlations in the 3-year old stand probably were due to shading effects of live teak leaves from trees that had not reached crown closure, where teak litter is dropped immediately below the trees, as well as more recent cleaning around the teak. The teak litter weight lacked significant correlation between any variable except for slope. The teak leaves seemed to decompose more slowly on the slopes. Exposed soil and resultant erosion were often obvious in the flatter stands. A potential cause of this exposed soil is increased and more constant humidity in the flat stands, leading to faster decomposition of the teak leaves. That the highest teak litter weights were found in both the youngest and the steepest stands was probably due to increased air movement and drier conditions in these stands resulting from a more heterogeneous canopy. Teak litter could still be negatively affecting the understory, but this was not correlated to teak litter weights.

Open canopy percentage measurements positively correlated to understory cover and species/m^2, but with a relatively low correlation. Diffuse light on slopes and from nearby gaps were not easily measurable with the concave spherical densiometer, and so this tool seems at best a very rough gauge for understory cover and diversity. Comparing cover and species counts using a light meter that measures diffuse light may show tighter correlations.

The aggregate BA estimate was the highest correlated single predictor for species/m^2 and was a strong factor for predicting cover. By implication, more timely thinning regimes along a teak/forest ecotone might enhance diversity and cover. One teak stand visited but not sampled during this study had well-spaced, large and healthy teak growing amidst a lush understory several meters tall. It was clear that thinning had created conditions for this understory to fill in very well.

The distance from the edge of the teak was a strong negatively correlated indicator variable for cover and species/m^2. Distance was only very weakly correlated to BA and open canopy percentages. Further studies that examine understories across plantation strips of different widths next to forests may yield strategies to maintain cover and diversity at desired levels.

The taxonomic data suggest that families such as *Amaranthaceae*, *Acanthaceae*, *Sapindaceae*, and *Papilionaceae* in particular have an advantage growing underneath teak.

Papilionaceae and the other families with higher coverage percentages noted in Table 3 may be starting points for research on useful understory plants to encourage beneath teak.

Lastly, several taxa are suggested as worth more consideration to encourage for erosion control or to help establish a more diverse site owing to their presence. They were all well represented for their family. Some field observations are included.

● *Machaerium spp*.- specifically *M. acuminatum*, *M. pittieri,* and *M. biovulatum* (*Papilionaceae*). These plants were seen to grow in low shrubs with good ground coverage, and were most evident on steeper slopes.

● *Clitoria javitiensis* (*Papilionaceae*) – another leguminous shrub with good thick cover.

● *Serjania spp*. and *Paulinnia spp*. (*Sapindaceae*) and *Cissus spp*. (*Vitaceae*) - were commonly encountered vines that were not seen to climb nor girdle the teak, yet could grow around and over teak leaves, with rhizomes reaching over 10 m.

● *Piper marginatum* or similar *Piper spp*. (*Piperaceae*) – these plants provide large flat leaves for cover and were often seen a few meters into the teak in thick patches, particularly near runoff depressions.

Conclusion –

Teak is a popular plantation tree, yet the understory can often be sparse to non-existent, resulting in erosion problems along with low biodiversity. Plantations located adjacent to forest remnants may be ecologically important buffer zones, especially at the teak/forest interface, as this is an area of increased biodiversity. Further understanding of this teak/forest ecotone may lead to plantation management that can encourage or maintain a full and diverse understory while still realizing the advantages of a plantation. This study attempted to further understand variables associated with understory cover, species diversity, and taxa by considering three teak/forest ecotone understory aspects: (1) The relationship between teak litter weight and understory variables. There was very little to no association between teak litter weight and cover or species/m^2. However, teak litter weight did vary strongly with slope. (2) Regression estimators for understory cover and species diversity. Basal area was the single variable most correlated with species/m^2, whereas the log of the distance from the teak edge was the closest correlated single variable for understory cover. In multiple regression equations, the square root of BA, the cubed roots of open canopy percentages, and either the log or square root of the distance to the edge were determined to be the best estimators of species per plot and understory cover. (3) The effects of distance from the teak/forest edge on the understory, and taxonomic trends. Averages of cover and species/m^2, and family percent cover over different distances into the teak were given showing declines in both cover and species/m^2 further into the teak. *Papilionaceae* had the strongest family presence in percent understory cover. Certain plant groups were recommended for further study as to their potential utility as understory cover and diversity enhancers beneath teak.

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