ABOVEGROUND BIOMASS AND TREE DIVERSITY OF RIPARIAN ZONES IN AN OIL PALM-DOMINATED MIXED LANDSCAPE IN BORNEO

M Singh[1, 2], Y Malhi[3] & SA Bhagwat[2]

[1]*Forest Ecology and Conservation Group, Department of Plant Sciences, University of Cambridge, Cambridge, CB2 3EA, United Kingdom; ms2127@cam.ac.uk*
[2]*Faculty of Social Sciences, Open University, Milton Keynes, United Kingdom*
[3]*Environmental Change Institute, University of Oxford, Oxford, OX1 3QY, United Kingdom*

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SINGH M, MALHI Y & BHAGWAT SA. 2015. Aboveground biomass and tree diversity of riparian zones in an oil palm-dominated mixed landscape in Borneo. Logging, deforestation and oil palm plantations have increased forest fragmentation in Borneo. Given the extent of forest loss and logging, evaluating the ability of remnant forests, especially fragments and riparian buffers, to provide aboveground biomass (AGB) storage and retain tree biodiversity is essential. This paper examines the variation in AGB stocks and tree species richness of riparian buffers located in forests of different disturbance intensities situated at the Stability of Altered Forest Ecosystem (SAFE) site in Sabah, Malaysian Borneo. Disturbance intensities ranged from pristine old growth forests to oil palm monocultures. The AGB of riparian buffers showed no significant variation between riparian buffers located in unlogged, once-logged and twice-logged forests but underwent sharp decline in heavily logged forests and oil palm (OP) plantations. However, riparian zones located within OP plantations exhibited significantly higher AGB than that of OP monoculture plantations. OP riparian buffers had the highest species richness although most were small, successional species. The retention of riparian buffers in OP plantations can yield AGB storage benefits while maintaining species-rich assemblages of trees.

Keywords: Riparian buffers, AGB storage, OP plantations, species richness, SAFE

INTRODUCTION

Forest clearance for creation of agricultural plantations, such as soy plantations in the Brazilian Amazon (Laurance et al. 2007) and oil palm (OP) plantations in South-East Asia (Persey & Anhar 2010), is a leading cause of forest loss and fragmentation in the tropics. Habitat fragmentation caused by agricultural plantations has a detrimental effect on not only biodiversity but also aboveground biomass (AGB) dynamics (Laurance et al. 2011).

The forest fragments created by deforestation have significantly altered and in many cases, drastically reduced biodiversity compared with intact forests (Laurance et al. 2011). Edge effects are a significant driver of change in fragmented landscapes. Evaluation of edge effects on unburned and burned forest area in Borneo indicated that distance from the edge influenced traits such as basal area and sapling diversity (Slik et al. 2011). Forest edges are more vulnerable to microclimatic variations, wind turbulence and elevated mortality of large trees, which affect AGB dynamics of fragmented patches. These effects have implications on the carbon storage potential of these areas (Nascimento & Laurence 2004, Saner 2009). Even after two decades of recovery, logged forests in the Malua Forest Reserve, Sabah, only achieved 60% of the carbon storage of primary forests (Hector et al. 2011). In addition, OP monoculture plantations support less biodiversity than the forests they replace. Across all taxa, a mere 15% of species recorded in the primary forest were found in OP plantations (Fitzherbert et al. 2008).

In addition to having detrimental effects on biodiversity, OP plantations contribute to carbon emissions in South-East Asia (Koh et al. 2011). The conversion of forests to OP monocultures has been estimated to release approximately

650 Mg CO_2 equivalent per hectare. This conversion creates 'biofuel carbon debt' by releasing 17 to 420 times more CO_2 than the annual greenhouse gas reductions that these biofuels provide by displacing fossil fuels (Fargione et al. 2008).

The maintenance of forest fragments and riparian vegetation zones within an OP-dominated matrix allows retention of biodiversity and ecosystem functionality across a wide variety of disturbances (Turner et al. 2011). Isolated forest fragments (< 100 ha) can often provide refuge for species and act as refuges from which the rainforest can recolonise a deforested landscape (Turner & Corlett 1996). The presence of riparian forests in a landscape can help in biodiversity conservation (Pardini et al. 2005, Lees & Peres 2008, Sekercioglu 2009). However, little has been done on AGB storage dynamics of riparian vegetation zones and how these dynamics function across a range of disturbance gradients.

An evaluation of different habitat types such as dry forests, forests on slopes and riparian forests was conducted in a 50-ha plot in Panama (Chave et al. 2005). They found riparian buffers dominated by trees with smaller basal area and that in these areas the AGB was lower than that of the other landuse types. Another study evaluated the impact of edge effects on riparian buffers located in fragmented tropical ecosystems (Williams-Linera et al. 1998). They argued that although riparian buffers are vulnerable to edge effects, they have significant potential in maintaining ecological diversity in disturbed landscapes. Restoring and reforesting riparian zones can increase carbon storage and improve water quality in agricultural landscapes (Rheinhardt et al. 2012). These studies were performed in the Neotropics and indicated that the biomass and structural dynamics of riparian forests differed from those of non-riparian zones. Most of the research on tropical riparian forests has been restricted to the Neotropics, and no research has examined the structural and biomass dynamics of riparian forests in Borneo. The forests of Borneo face the challenge of OP conversion and several cycles of logging. Therefore, evaluating how AGB stocks respond to varying levels of disturbance/logging regimes is vital.

The study has three main objectives: (1) to examine how AGB varies between riparian and non-riparian zones across a variety of landuse types that have been exposed to different levels of disturbance, (2) to examine how forest structure parameters vary across riparian buffers located in different landuse types and (3) to examine how tree species diversity varies across the riparian buffers.

MATERIALS AND METHODS

Study area

This research was conducted at the Stability of Altered Forest Ecosystems (SAFE) Project (SAFE 2011a, Ewers et al. 2011) in Sabah, Malaysia. The area comprises a mixed landscape that includes the following areas: (1) twice-logged forest (LF/LFE), (2) virgin jungle reserve (VJR), (3) OP plantations (covering 45,016 ha and containing palm trees of varying ages), (4) a 7200-ha heavily logged area known as the experimental area (EA), which was ear-marked for conversion to OP beginning December 2012 and (5) undisturbed, old growth, lowland primary (OG) forests in the Maliau Basin Conservation Area (MBCA).

There are three blocks of old growth forests in the MBCA: OG1, OG2 and OG3. These forests have never been logged commercially (Luke 2010). There are two blocks of twice-logged forests: LFE and LF. In the proposed OP concession (known as EA), 800 ha of forest will be spared cutting and maintained in an arrangement of circular fragments together with the maintenance of a few riparian vegetation zones as shown in Figure 1. The proposed circular fragments have varying levels of forest cover (Figure 2). The experimental area is located in the Benta Wawasan area. This area was last logged in the late 1990s. Logging was conducted intensively, with trees as small as 30 cm diameter at breast height (dbh) being extracted, effectively removing the entire pole (Ibbotson, personal communication). The LF/LFE areas are located in the Ulu Segama river catchment. This region has been selectively logged since the 1950s (Sabah Forestry Department 2008, Ancrenaz et al. 2010).

Figure 1 shows the layout of the MBCA and where the OG forests are located. Figure 2 shows

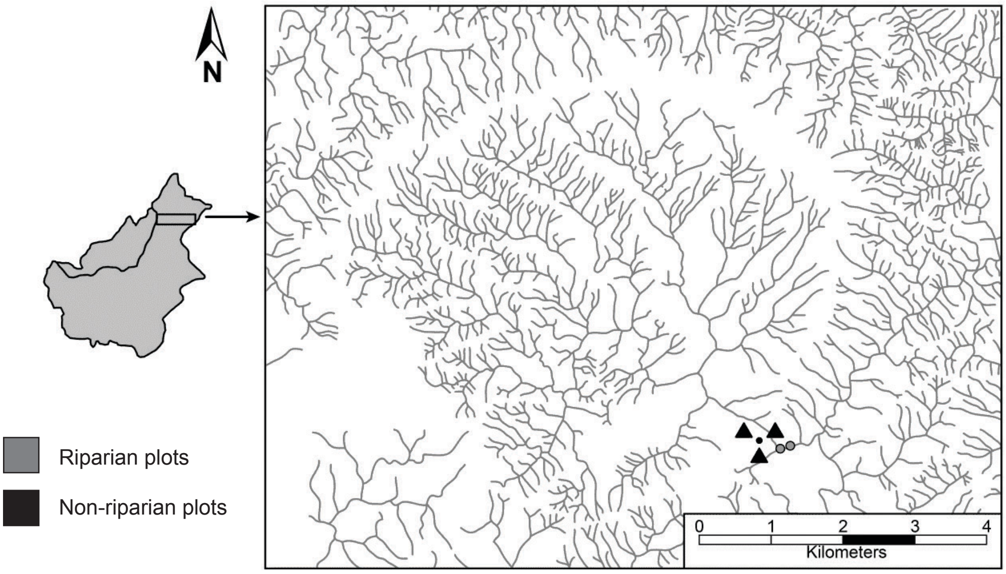

Figure 1 Layout of the Maliau Basin Conservation Area and old growth forests

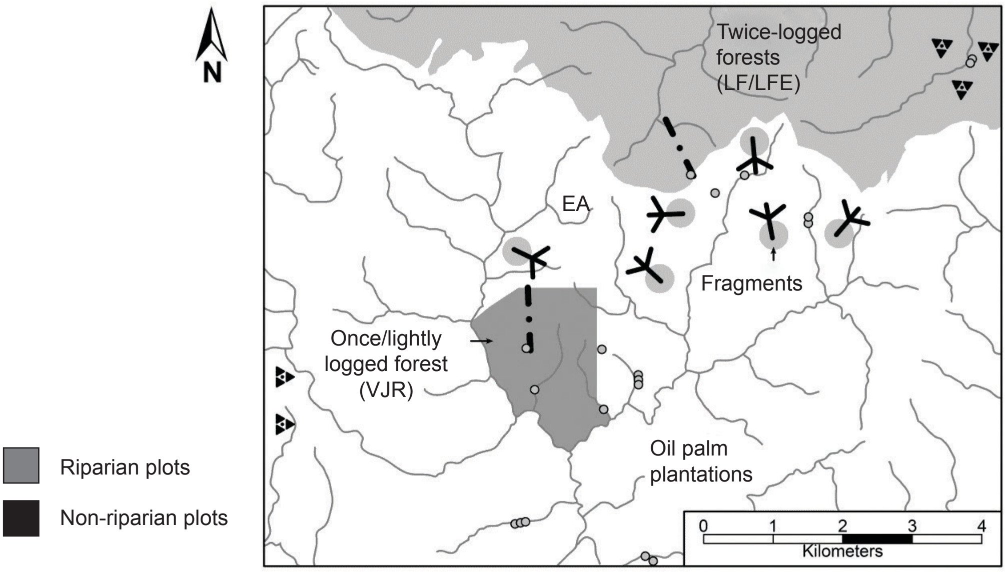

Figure 2 Layout of the SAFE area comprising plots of oil palm plantations, twice-logged forest (LF/LFE), heavily logged forest (EA) and once/slightly logged forest (VJR)

the layout of the mixed forests in the SAFE area. Of the entire SAFE landscape, field data collection was restricted to OG2 and OG3 for the old growth primary forests; to LF/LFE for the twice-logged forests and to EA for heavily logged forests. In addition to the riparian zones present in the EA, a number of riparian buffers were present in the other landuse types, including OP plantations.

Data collection

Riparian plots were set up in three riparian zones of the SAFE areas. The selection of riparian zones and location of riparian plots were conducted randomly to capture variation in spatial structure and biomass across the riparian zones. In each of the riparian zone, six plots were established, with each measuring

10 m × 50 m; the 50 m side was parallel to the river and the 10 m side was perpendicular to the river bank. These dimensions ensured that the plots fell within the designated riparian zones. For each landuse type, 18 riparian plots were created. The distances between the plots were not constant, although a minimum distance of 15 m was maintained between each plot. Instead, the distance was based on stratified random sampling, where the river acted as baseline. The plots were distributed with the aim of representing the entire riparian system. From these plots, forest mensuration data, namely, dbh and height were recorded using the RAINFOR protocols (RAINFOR 2012). All trees with dbh ≥ 2 cm were recorded.

The SAFE study site contains a total of 193 vegetation structure monitoring plots (25 m × 25 m). These plots were established across a landuse intensity gradient from slightly logged and twice-logged forest stands to heavily degraded forests and OP plantations. Additionally, some vegetation monitoring plots were located in the unlogged primary forests in the MBCA. Trees of dbh ≥ 10 cm were recorded for all 193 vegetation plots in 2010–2011. These vegetation plots were set up following a fractal design (Marsh & Ewers 2013). Although the sampling was performed at two different points in time, a similar rationale was followed for both samplings, i.e. randomly locating the plots while ensuring that the different forest types were represented.

In addition to collecting forest mensuration data, the field research focused on collecting species information across the different riparian zones. To analyse tree species diversity across all riparian buffers, species richness (N), Fisher's alpha index and Sørensen similarity index were used. These analyses were conducted to capture the magnitude of tree species difference in riparian buffers across a disturbance gradient. Riparian forests in OG were used as a reference point and the Sørensen index was calculated to evaluate the magnitude of tree species similarity between this and riparian forests of other landuse types.

Computing AGB

The AGB of trees in both riparian and non-riparian zones was calculated using the biomass equation recommended by Chave et al. (2005):

$$AGB = 0.0776 \times (\rho \times dbh^2 \times H)^{0.94} \qquad (1)$$

where H = tree height, ρ = wood specific gravity and dbh = diameter at breast height. The value of the latter for the study of this region was obtained from Brown (1997). Given the difference in the physiology of OP and trees in the forest, specific biomass equations were needed to calculate the AGB of the OP plantations. The AGB of OP was calculated using the biomass equation recommended by Morel et al. (2012):

$$(AGB)_{Trunk} = 100 \times \pi \times (r \times z)^2 \times h \times \rho \qquad (2)$$

where r = radius of the trunk (cm) without frond bases, z = ratio of the trunk diameter below the frond bases to the measured diameter above the frond bases (estimated to be 0.777 from the sampled trunks) and h = height of the trunk (m) to the base of the fronds. The trunk density ρ (kg m^{-3}) is defined as follows:

$$\rho = 0.0076x + 0.083 / 100 \qquad (3)$$

where x = age of the OP plantations.

Computing height of non-riparian trees

To compare the AGB of riparian buffers, dbh was collected for trees in the non-riparian zones. Although dbh data were available for trees in the non-riparian plots, height data for these trees were limited. As equation 1 requires height data for the calculation of biomass, the height of non-riparian plot trees was estimated using the Sabah-specific dbh–height regression equations derived by Morel et al. (2011).

Statistical modelling

This research investigated the difference between AGB of riparian buffers located in different landuse types, and between riparian buffers and neighbouring non-riparian buffers. A preliminary investigation revealed that the data were not normally distributed. Log transformations were conducted but still could not produce normal distributions. Hence, Kruskal–Wallis tests were employed to examine whether any variations were present in the AGB values. Tukey's post-hoc test was employed to identify the landuse type that was significantly different. The same procedures were repeated to examine variation in species richness between riparian buffers of different landuse types (Kruskal–Wallis) and to identify which of the riparian buffers under consideration were different from one another (Tukey's post-hoc test).

Canopy intactness

The intactness of the canopy structure was qualitatively evaluated. SAFE's percentage forest cover scale (SAFE 2011b) was used.

RESULTS

Variations in forest structure across riparian buffers

On average, trees in the riparian margin of OG forests had the highest basal area whereas the OP riparian buffers hosted the largest number of small trees (Table 1). In the riparian zones, trees (< 10 cm dbh) contributed on average 36.9% of the total stem number (ranging from 26.8% in the OG, 43.1% in the OP and 47.6% in the EA) but only 3.72% of the total basal area (ranging from 0.85% in the OG to 13.24% in the EA). The contribution of small trees was largest in the riparian zones of the OP and EA, although small trees only contributed 5.09 and 13.24% of the basal area respectively. In contrast to the OP and EA riparian buffers, the OG riparian buffers had a relatively higher concentration of large trees. The stem density of trees per hectare (dbh > 10 cm) varied from 488 for the OG riparian buffers to 601 for the OP riparian buffers. However, when trees of dbh < 10 cm were included, the stem density varied from 667 ha^{-1} for the OG to 1056 ha^{-1} for the OP riparian buffers. For non-riparian buffers, the stem density ha^{-1} (dbh > 10 cm) varied from 820 for the OG to 417 for the EA (Table 2). The basal area values varied from 56.28 m^2 ha^{-1} in the OG riparian buffers to 29.15 and 34.18 m^2 ha^{-1} in the EA and OP riparian buffers respectively (Table 1). In OG forests, the basal area of non-riparian buffers (65.39 m^2 ha^{-1}) was higher than that of the riparian margin (56.28 m^2 ha^{-1}) (Tables 1 and 2). In addition to variations in basal area and tree height between riparian buffers of different landuse types (see Table 1), the canopy intactness varied across the riparian buffers (Figure 3).

Aboveground biomass storage value of riparian buffers

The AGB values did not vary significantly between the riparian buffers of OG, VJR and LF/LFE forests (Figure 4). However, there was significant difference between the AGB of the riparian buffers of LF/LFE areas and those of the EA and OP plantations ($p < 0.05$). The AGB values dropped sharply for the riparian buffers of the EA (heavily logged forests) and OP plantations. Furthermore, the OG riparian forests had the highest AGB levels, which were reduced by 75% in the riparian OP plantations.

Comparison of aboveground biomass between riparian and non-riparian zones

The first step in comparing AGB values between non-riparian and riparian zones was to calculate the AGB of OP plantations. However, there was significant difference between the AGB of the riparian buffers of the LF/LFE and the EA ($p < 0.001$)(Figure 5). The AGB of the riparian buffers declined sharply from the LF/LFE to the EA. Furthermore, the LF/LFE riparian buffers had significantly higher AGB values than the surrounding non-riparian forest zones. The difference between the AGB of the riparian buffers of the EA and OP plantations was not significant. The LF/LFE riparian buffers had higher AGB than the OP plantation and EA riparian buffers. The AGB of the OP plantations and their riparian buffers was significantly different, with the riparian buffers exhibiting a much higher AGB.

Species richness and diversity of riparian buffers

There was no significant variation in species richness between the riparian buffers of the OG and VJR forests. However, there was significant variation between the OG and EA and between the OG and OP (Figure 6). OP plantation riparian buffers had the highest tree species richness. This could be explained by the

Table 1 Aboveground forest parameters across the riparian margins

Parameter	Riparian margin				
	OG	VJR	LF/LFE	EA	OP
Basal area (m^2 ha^{-1})	56.28 ± 9.27	55.00 ± 8.15	49.75 ± 9.19	29.15 ± 5.52	34.18 ± 3.21
Basal area of trees with dbh > 10 cm(m^2 ha^{-1})	55.80 ± 8.88	54.49 ± 7.98	48.00 ± 9.74	25.29 ± 5.18	32.44 ± 3.18
Tree height (m)	19.70 ± 0.83	18.90 ± 1.31	22.70 ± 1.44	9.20 ± 0.33	9.70 ± 0.25
Stem density (ha^{-1})	667	714	629	840	1056
Stem density of trees with dbh					
> 10 cm (ha^{-1})	488	481	456	440	601
< 10 cm (ha^{-1})	179	233	173	400	455
Fisher's alpha index	92.39	123.26	132.30	164.10	174.77
Sørensen index of similarity	1.00	0.72	0.65	0.56	0.49

n = 18 riparian plots for each landuse type; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm; values are means ± standard deviations; dbh = diameter at breast height

Table 2 Aboveground forest parameters across the non-riparian zones

Parameter	OG	LF/LFE	EA
Basal area of trees with dbh > 10 cm (m^2 ha^{-1})	65.39 ± 3.10	32.13 ± 13.43	17.14 ± 2.17
Stem density of trees with dbh > 10 cm (ha^{-1})	820	592	417

OG = old growth forest, LF/LFE = twice-logged forest, EA = experimental area; values are means ± standard deviations; dbh = diameter at breast height

pattern of dbh classes prevalent in the different riparian zones in Figure 7, whereby trees with dbh 2–10 cm dominated OP plantation riparian buffers. Tree species diversity (measured using Fisher's alpha index) also varied significantly across the riparian buffers of the different landuse types (Table 1).

Species composition of riparian buffers

Species composition varied significantly across the riparian buffers. A total of 1.4% of all the trees present in the OG riparian buffers belonged to the species *Shorea johorensis* (Table 3). Species similarity (computed using Sørensen similarity index) varied increasingly across the disturbance gradient from lightly logged forests to heavily logged forests and oil palm plantations. The species similarity also varied across the riparian buffers of the different landuse types. Although the riparian buffers of the OG, VJR and LF/LFE forests had a high similarity, species similarities were lower for the EA and OP riparian buffers (Table 1). The percentage composition of some of the more common tree species across the different riparian buffers is presented in Table 3. In addition to variations in tree family dominance, the tree species composition varied substantially across the different riparian buffers. For example, although *Pternandra coerulescens* accounted for 8% of the total trees in the OG riparian buffers, no record of this species was found in the OP plantation riparian buffers.

DISCUSSION

Variations in biomass and forest structure

The analysis of the forest structure and biomass values showed that the riparian and non-riparian buffers had characteristics that, in many cases, were similar to those of tropical forests. The stem density per hectare (evaluated for trees with dbh > 10 cm) in tropical forests varies from 245 (which is considered low) to intermediate values of 420–617 and a high value of more than 639 stems ha^{-1} (Suratman 2012). Based on this categorisation, the stem density of the plots in

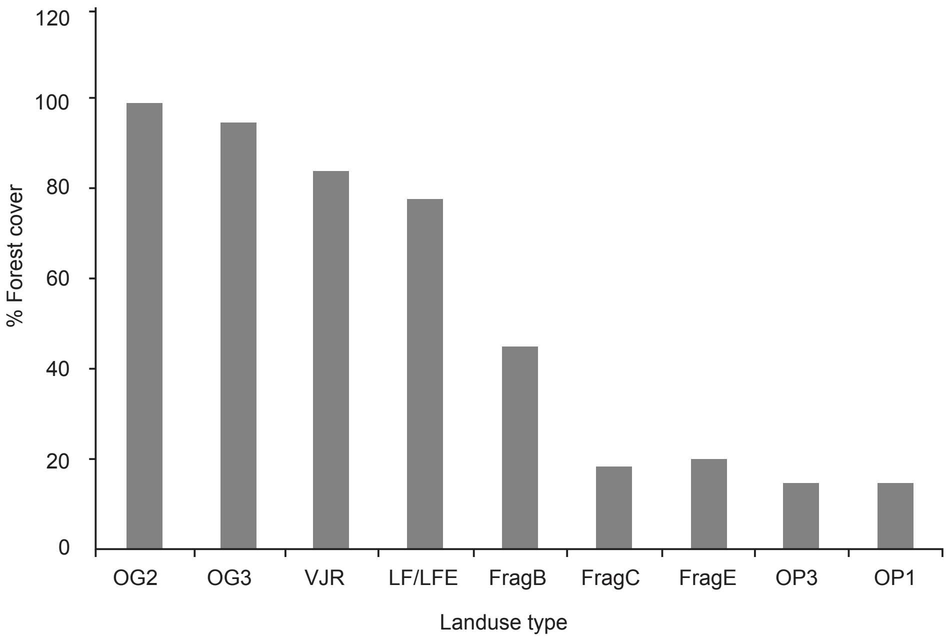

Figure 3 Canopy intactness of the different forest types; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, Frag = fragment, OP = oil palm

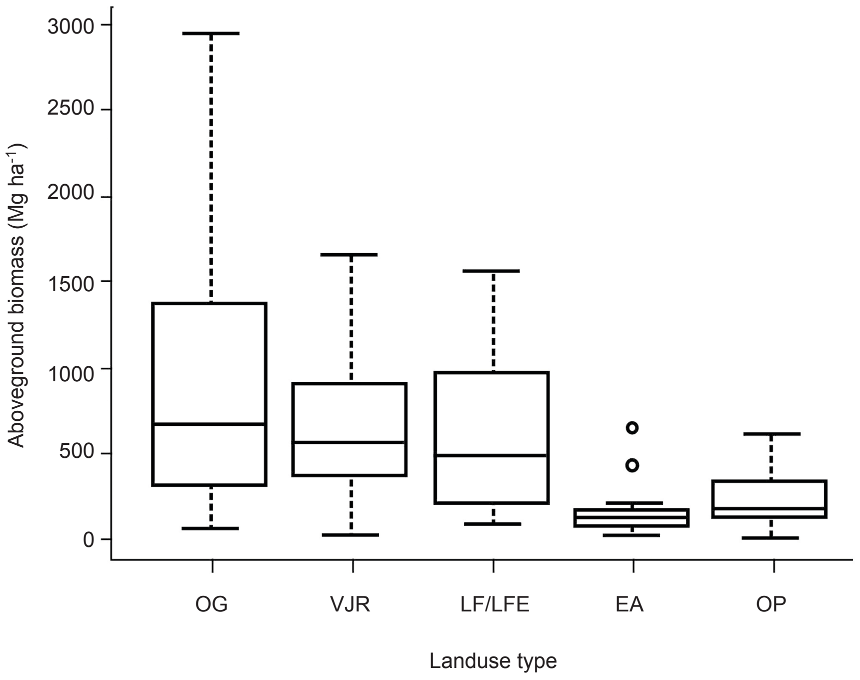

Figure 4 Aboveground biomass of riparian margins located in different landuse types; n = 18 riparian plots for each landuse type; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm

this study could be classified as intermediate to high. However, some interesting points of difference should be illustrated. A stem density per hectare of 637 was recorded in Lambir Hill Park, Sarawak, but an average stem density per hectare of 428 was recorded in the lowland forests of Brunei (Lee et al. 2005). The stem density per hectare (dbh > 10 cm) across both riparian and non-riparian zones of the different landuse types (except the non-riparian zones of

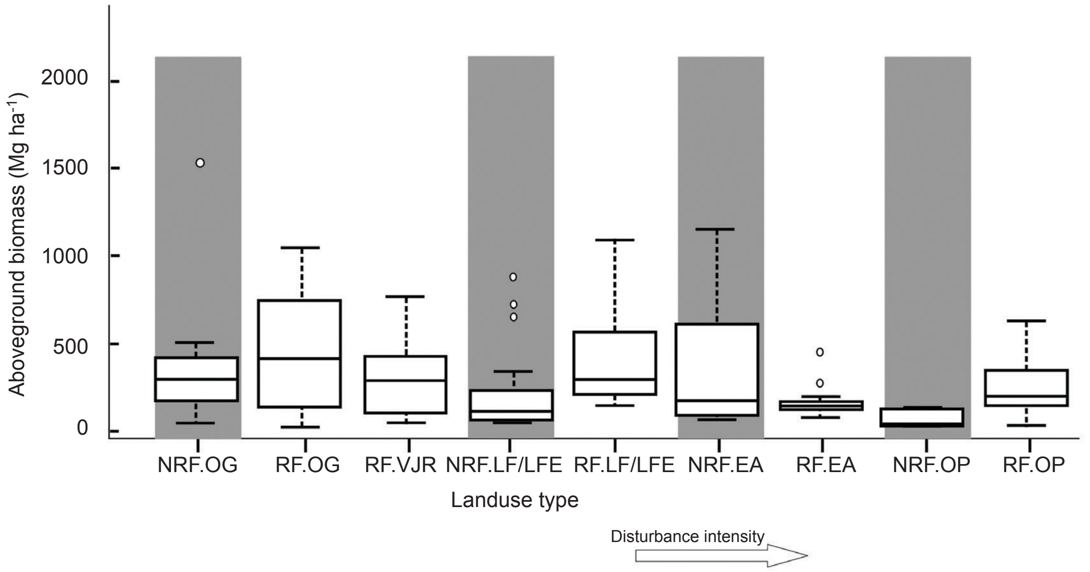

Figure 5 Comparison of aboveground biomass between riparian and non-riparian zones; n = 18 riparian plots and n = 12 non-riparian plots for each of the landuse type; grey indicates non-riparian forest zone; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm, RF = riparian forest, NRF = non-riparian forest

the OG) fell within this range. The stem density per hectare of the OG non-riparian zones was higher than that recorded in other undisturbed forests of North Borneo. The basal area of 73.6 m^2 ha^{-1} was recorded in an undisturbed lowland dipterocarp forest in Gum-Gum, Sabah (Burgess 1961), which was slightly higher than the basal area values in both the riparian and non-riparian forests of the OG forest. Intensely logged forests in Perak, Peninsular Malaysia have an average basal area of 29 m^2 ha^{-1}. The basal area of the riparian forests of the EA and OP were close to this value, indicating that the riparian buffers also underwent substantial logging. The EA non-riparian forests had an even lower value, indicating that the non-riparian zones were logged even more intensively. The riparian buffers of the OP and EA also displayed a characteristic reverse J distribution, with stem frequencies decreasing with increase in dbh. Consequently, the highest stem frequency was found in the 2–10 cm dbh category, indicating that the forests were regenerating and recovering (Suratman 2012). Forest structure, in turn, influences the AGB storage dynamics. The AGB values of unlogged and slightly logged forests were similar to the AGB values of similar undisturbed forests elsewhere in Borneo (Paoli & Curran 2007, Morel et al. 2011). Severely logged forests, including those that were logged within the past quarter of a century, underwent a sharp decline in AGB values. Such sharp declines in AGB values have been observed in other logged forests in the region (Morel et al. 2011, Saner et al. 2012).

An important feature of logging operations in Borneo is the removal of large dipterocarp tree species (Hector et al. 2011). Large trees play a vital role in influencing the AGB storage across a range of tropical ecosystems (Paoli et al. 2008, Letcher & Chazdon 2009, Silva-Costa et al. 2012). In addition to being valuable timber-producing species, dipterocarp trees play an important role in the maintenance of AGB stocks in the lowland tropical forests of Borneo (de Gouvenain & Silander 2003, Hector et al. 2011). Their removal substantially alters the biomass dynamics of the forests in this region (Saner 2009). A study on the impact of logging on carbon storage and tree biodiversity of the lowland dipterocarp forests of North Borneo found that the area underwent significant loss of AGB (up to 53%) (Berry et al. 2010). The removal of large trees by intensive logging also had significant impacts on species richness, diversity and composition of forests (Lee et al. 2005, Suratman 2012).

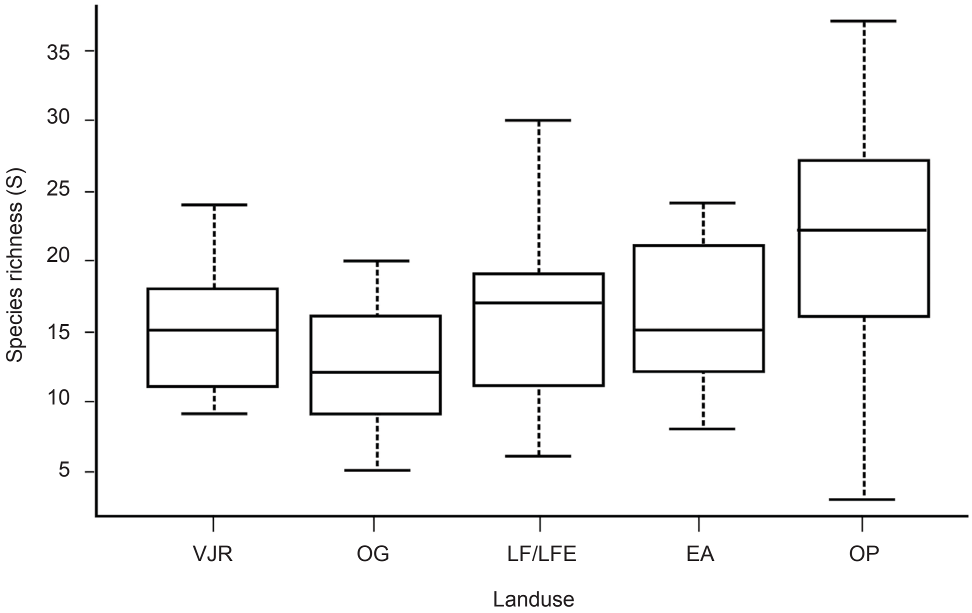

Figure 6 Species richness (S) of the riparian margins across different landuse types; n = 18 riparian plots for each of the landuse types; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm

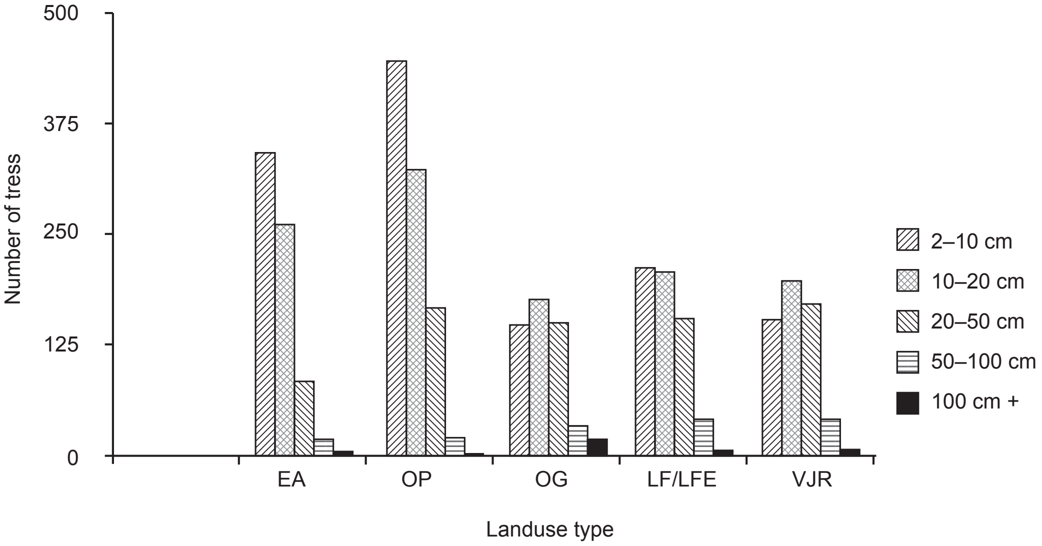

Figure 7 Dbh classes of trees across the riparian margins; n = 18 riparian plots for each of the landuse type; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm

Variations in species richness and composition

The tropical forests of South-East Asia have species richness varying from 62 to 247 (Losos & Leigh 2004). The species richness of the entire riparian plot network was towards the higher end of this range, which could partially be attributed to riparian systems being more productive as manifested in terms of their higher number of tree species (Azliza et al. 2012). Furthermore, anthropogenic changes (and their impact on forest structure) may have been pivotal in influencing species dynamics of the different riparian buffers. OP plantation riparian buffers had the highest species richness (Figure 6), which was attributed to high species richness of trees with dbh 2–10 cm. Trees of this dbh class

Table 3 Species composition (%) of trees across different riparian margins

Species	OG	VJR	LF/LFE	EA	OP plantation
Glochidion borneensis	18.80	11.16	4.00	2.43	3.76
Pternandra coerulescens	8.08	0.63	0.55	0.14	0.00
Walsura pinnata	2.28	4.46	4.19	3.64	5.39
Macaranga beccariana	1.58	3.18	2.91	14.30	4.98
Dryobalanops lanceolata	2.10	3.98	3.83	4.45	0.92
Nauclea subdita	0.35	8.77	1.82	2.69	2.23
Dendrocnide elliptica	0.00	0.96	3.64	3.64	3.86
Shorea johorensis	1.40	0.79	0.90	0.14	0.20

n = 18 riparian plots for each of the landuse type; OG = old growth forest, VJR = virgin jungle reserve, LF/LFE = twice-logged forest, EA = experimental area, OP = oil palm

are dominant in the OP plantation riparian buffers. The presence of such trees suggests significant anthropogenic disturbances and timber extraction in these areas (Slik et al. 2003). Research by Ibbotson (personal communication) indicated that these riparian buffers were subjected to intensive logging operations for the past 25 years. In contrast, the riparian buffers of the OG forests had the lowest level of species richness, which might be attributed to these riparian buffers having the highest proportion of trees possessing dbh > 100 cm and that most of the other trees exhibited dbh of 10–20 cm.

These results supported the third hypothesis of this research, which was that the variation in species richness could be explained by the forest structure of the different riparian zones. These results were in accordance with the findings of Grime (1977) who studied the impact of disturbance caused by the removal of biomass from a community on species richness. Studies by Berry et al. (2010) and Saner (2009) indicated that logged forests had higher faunal species richness than pristine forests. According to the Intermediate Disturbance Hypothesis, species diversity is low at low disturbance levels due to competitive exclusion and high at intermediate levels due to a mix of strong competitors and colonisers (Hughes 2010). This phenomenon has also been observed in the species richness of plant communities in the riparian buffers of a study area in Canada (Biswas & Mallik 2011). In the present study, both the OG and VJR forests and their riparian buffers underwent very little disturbance, which in turn, might account for their low species richness. In contrast, the LF/LFE, EA and OP plantation riparian buffers underwent a significant level of disturbance, although they still maintained a sizeable canopy cover, which explained their high species richness. The species composition also varied across the riparian buffers of the different landuse types, which could be that species composition of riparian buffers was influenced by varying levels of disturbance (Shafroth et al. 2002).

Another interesting feature of the riparian plot network is that for all the landuse types, true riverine tree species (typically known to grow along river banks) form a very small proportion of the total species. A similar phenomenon has been noted in the riparian forests of the Pasoh Forest Reserve in Peninsular Malaysia. In both cases, the majority of the tree species are not typically water loving but are well adapted to high levels of moisture (Azliza et al. 2012). Hence, riparian forests can be viewed as remnant forests that provide habitat to endangered species such as *S. johorensis* in this case. Other small forests similar to these have high species richness and rapid rates of regeneration, which contribute to the regional biodiversity (Pither & Kellman 2002).

This study compared the AGB of trees between different riparian areas and the AGB of trees between riparian areas and non-riparian areas. However, both the riparian and non-riparian plots were concentrated in the concession area rather than being spatially distributed (Figure 2). Increasing the sampling intensity and including the areas between the MBCA and SAFE area may help improve the robustness of the results and provide deeper insights into the spatial variation of tree species composition. Although detailed measurements of dbh and height were conducted, this research (similar to other plot-based studies) did not focus on quantifying the variation in the canopy structure such as measuring the crown radius or how such variation might influence the biomass dynamics across the different forest types. The ground-based measurement of canopy structure parameters was difficult due to density of the forest and presence of very tall trees (Chambers et al. 2007).

CONCLUSIONS

Riparian buffers appeared to be resilient to loss of biomass for up to two logging rotations. A decline in the biomass values began with heavy degradation/conversion to OP plantations in the surrounding landscape. Examinations of forest structure, AGB and species dynamics revealed that several years after a logging event (approximately one decade for the EA and longer for other landuse types), both riparian and non-riparian zones continued to bear a vivid imprint of their landuse histories. This finding is important for forestry management practices.

This research can provide information on sustainable OP plantation creation strategies. The AGB value was found to be much higher for riparian buffers than for the surrounding OP plantations. Hence, the retention of riparian buffers in OP plantations can yield significant carbon storage benefits, which may help counteract some of the detrimental effects of OP plantations. The examination of riparian buffers and non-riparian zones in heavily degraded areas indicated that these areas had undergone significant loss in AGB storage. Hence, future OP plantation conversions can be directed towards heavily degraded forests instead of once- or twice-logged forests, which retain significant carbon storage and biodiversity values.

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