Development of post-fire vegetation in the tropical ecosystem of Central Kalimantan, Indonesia

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Summary

This research illustrates the capacity of post-fire secondary vegetation for carbon storage and restoration of the tropical peatland ecosystem. It is evident that the extent and rate of vegetation regeneration greatly depends on fire frequency and burn severity, as well as the pre-fire vegetation condition and proximity to remaining forest. Our investigations show that secondary succession towards forest is possible following a single fire. However, the re-growth potential decreases for areas affected by multiple disturbances over a short period of time. For example, locations subject to two intensive fires are dominated by homogeneous, lower-growing plant communities dominated by ferns and sedges with very few trees. These locations have a much lower potential, if any, for regeneration of forest vegetation, even over a long time period. Restoration action is, therefore, urgently required in locations where the natural regeneration is halted. Moreover, it is clear that both regeneration and restoration are only possible if further fires are prevented and the remaining patches of natural forest are protected as a potential biodiversity source for recolonisation.

Key index words: post-fire vegetation regeneration, secondary succession, tropical peatland ecosystem, Borneo.

Introduction

Reducing deforestation and degradation of tropical forest has become a fundamental issue for sustainable land management and climate care. Extensive and intensive fires together with land conversion practices are the main causes of forest loss and degradation in the South-east Asia region (Rieley and Page, 2005), with heavily degraded forests and abandoned land susceptible to regular, repeated fires. Current research focuses on monitoring these phenomena in order to suggest effective actions for fire prevention and post-fire mitigation. In order to offset the negative consequences of forest degradation there is a growing need to investigate the extent of disturbance caused by repeated fires as well as to assess the natural potential for vegetation regrowth and rehabilitation. Ecological knowledge of post-fire vegetation response is necessary in order to undertake and implement appropriate restoration planning or to convert degraded land to a more efficient land use. It is also important to have knowledge of the condition, volume and biomass of regrowth as this will influence the potential fire risk (through effects on fuel load and fuel quality). Finally, tropical secondary vegetation can play a role as a potential regulator of climate change as a result of its capacity to act as a carbon sink, both now and into the future (Castro *et al.*, 2003; Lucas *et al.*, 2005). The benefits of vegetation restoration listed above emphasise the importance of this study, although it must be stressed that the regeneration processes in disturbed tropical forest are extremely complex and difficult to examine since they depend upon many factors, including land use history, frequency and severity of disturbance, pre- and post-fire condition of soil, hydrology, etc. (Hughes *et al.*, 1999; Lu, 2005).

This study focused on examination of post-fire vegetation regeneration under different fire disturbance regimes taking into account fire frequency and burn severity. These two factors have been shown to be a major driver of secondary vegetation succession in the heavily degraded tropical peatland of the Ex-Mega Rice Project area (Ex-MRP) in Central Kalimantan, Indonesia. The study was located in the western part of the Ex-MRP in a section called Block C, covering about 4,500 km^2. Our previous research had revealed that approximately 80% of the study area (mainly comprising of tropical peat swamp forest) had been heavily degraded over the preceding three decades, with the most serious degradation occurring during the last decade as a result of implementation of the Mega Rice Project (Hoscilo *et al.*, 2007). The over-drained peatland became fire-prone, with regular, repeat fires. Some locations have been subjected to two, three or even more fires.

This new phenomenon of regular, widespread peatland fires, which causes a range of environmental, social and economic impacts, has brought together scientists and decision makers in a desire to understand and investigate post-fire succession processes in order to take steps towards sustainable management of the degraded landscape. The research described in this paper focuses on the vegetation response to single and multiple fires over a five-year time frame.

Materials and methods

Investigation of post-fire vegetation succession was based on integration of data on biophysical variables collected in the field and spectral data derived from satellite images. This study was conducted in the northern part of Block C, where 20 plots were established to characterise different stages of secondary succession, driven by fire occurrence and burn severity. The main field data collection was carried out during the dry season of 2006. Fire occurrence and burned area maps derived from archive satellite images provided essential information on pre-fire land cover status and the spatial pattern of burned areas over the last three decades. The northern part of Block C was initially (before the fire of 1997) occupied by mixed peat swamp forest with some evidence of logging activities. The fire of 1997 destroyed a large portion of the original forest; new post-fire vegetation (secondary forest) managed to establish over the next five years, only to be re-burnt once again in the fire of 2002. Moreover, the 2002 fires spread over a larger area, entering fragments of remnant forest. The magnitude of fire damage, called burn severity, depends on many factors such as pre-fire land status, vegetation condition, fire regime and intensity as well as duration of the fire (van Wagtendonk *et al.*, 2004). The term burn severity refers to short-term ecological changes occurring as a result of a fire, on a daily or weekly scale, and biophysical effects of fire operating over several years during the post fire period (Roy *et al.*, 2006). Secondary vegetation succession was examined for locations that were burnt by a single fire (SF) and those burnt by multiple fires (MF) with different magnitudes. Three classes of burn severity (low, medium and high) were delineated based on integration of biophysical variables with widely-used multi-temporal spatial indices derived from remote sensing.

Field data collection

The characteristics of different stages of vegetation re-growth were obtained by studying four biophysical indicators: total above ground biomass, canopy cover, ground cover and species composition, in 20 plots, each 20 x 20 m. The diameter at breast height (DBH), height, canopy cover and species composition were recorded for all trees, saplings and seedlings within each plot. Trees were defined as having a DBH equal to or greater than 5cm, saplings with DBH ranging from 1cm to 5cm and seedlings with DBH less than 1cm. Woody above ground biomass (AGB) was obtained by applying the allometric equation proposed by Chave *et al.* (2005), which is based on DBH and height of canopy. In addition, individual and multiple stemmed canopies were recorded separately in each plot. Non-woody AGB was largely dominated by two fern species: *Stenochlaena* spp. and *Blechnum* spp. Non-woody biomass was measured using an oven-dried laboratory method.

Results

Plots experiencing multiple fires (MF) between 1997 and 2002 were separated into three classes: low (MFLSev), moderate (MFMSev) and high (MFHSev) burn severity and represented by four, six and six plots, respectively. Secondary succession following a single fire (SF) in 1997, was represented by four plots. Table 1 presents a summary of the major biophysical features characterising each of these categories.

Table 1. Average value of biophysical features for four succession classes in Block C of the Ex –MRP in Central Kalimantan, Indonesia; MFHSev, MFMSev, and MFLSev represent locations experiencing multiple fires with high, moderate and low burn severity; SF represents locations that have experienced a single fire; *Combretocarpus rotundatus* is the dominant recolonising tree species.

	MFHSev	MFMSev	MFLSev	SF
Number of tree species (no/site)	2.67	5.00	8.50	16.25
Tree density (individual/ha)	4.17	62.50	481.00	1881.00
Tree density (multiple stem/ha)	25.00	246.00	425.00	562.50
Tree density (individual + multiple stem)	29.20	308.00	906.00	2444.00
Saplings density (individual/ha)	617.00	1021.00	618.80	5900.00
Saplings density (multiple stem/ha)	20.80	200.00	231.30	0
Seedlings density (individual/ha)	313	779	87	8000
Ratio saplings/tree	29.40	14.20	0.99	2.46
% of *Combretocarpus spp.* for tree	86.70	98.73	84.47	60.70
% of *Combretocarpus spp.* for saplings	90.14	68.73	66.26	0
DBH of trees (cm)	6.07	6.58	7.43	7.69
DBH of saplings (cm)	2.58	2.58	3.18	2.20
% of tree DBH <10cm	100	98.33	86.75	84.75
% of tree DBH from10cm to 15cm	0	1.67	12.5	13.75
% of tree DBH >15cm	0	0	0.75	1.50
Basal area of tree (m^2/ha)	0.19	1.95	6.32	14.37
Fern cover (%/site)	96.50	68.40	38.00	0
Biomass of tree (t ha^{-1})	0.23	2.56	11.57	27.23
Biomass of saplings (t ha^{-1})	0.26	1.20	1.38	2.49
Total woody biomass (t ha^{-1})	0.52	3.89	14.30	29.77
Fern biomass (t ha^{-1})	8.52	7.01	3.20	0

Discussion and conclusion

Our study provides the most comprehensive examination of post-fire vegetation succession presently available for tropical peatlands. A key conclusion is that if only burnt once, tropical peat swamp forest has a high potential to recover naturally, assuming that fire does not have a short return period. Secondary re-growth following a moderately severe fire in 1997 was at a relatively advanced stage of succession with 2444 ± 238 (±SD) trees greater then 5cm DBH per hectare, although on average 85% of the total number of trees was represented by individuals with small stems of less than 10cm DBH, whilst only 15% was made up of trees with a DBH greater than 10cm. The total woody above ground biomass (AGB) was on average 30 t ha^{-1} (ranging from 20 to 51 t ha^{-1}). The highest value for woody AGB was recorded for a plot located in close proximity to the remaining intact forest, indicating the role that remnant forest fragments play in stimulating successional processes. There was also a significant variation in tree species composition within the SF class. The vegetation in the plot located closest to the edge of the remaining forest contained a mixture of primary forest species, with *Cratoxylon* spp., *Shorea* spp. and *Litsea* spp. representing 19%, 12% and 7% of the total number of all trees, respectively. In plots further away from the forest edge, primary forest species were replaced by pioneer species such as *Combretocarpus* spp. (comprising up to 75% of all trees recorded). Furthermore, species richness increased considerably from 16 to 29 species per plot on moving closer to the remaining forest. Hence, intact patches of natural forest play a crucial role as a source of biodiversity and also contribute to increased AGB accumulation.

The woody AGB of secondary vegetation in the multiple fire (MF) plots which were dominated by one pioneer species (*Combretocarpus* spp.) was much lower than that of the SF plots, although the woody AGB of MFLSev reached a value of 14 t ha^{-1}over four year post-fire period, which is equal to half the average AGB of SF. The AGB of MFLSev was dominated by a large number of saplings and trees, with 13% of trees greater than 10cm in DBH; these larger individuals probably resisted the last fire. Of interest is the fact that a half of all trees were multiple-stemmed; this could be related to a lack of competition in the exposed areas and could be used as one of the indicators of post-fire regeneration.

The woody AGB decreased rapidly to 4 tonnes per hectare in the MFMSev plots; this was three times less than the AGB of the MFLSev plots. The MFMSev plots also revealed some regeneration potential as they contained a higher number of seedlings and saplings (up to 14 saplings to at least one tree) dominated by *Combretocarpus* spp. and *Cratoxylon* spp. The tree canopy was dominated (80%) by multiple stemmed trees with a DBH of less then 10cm. The principal species was the pioneer *Combretocarpus* spp. (98% of total number of trees).

The lowest woody AGB was recorded in the MFHSev class (0.5 t ha^{-1}). The MFHSev plots represented locations exposed to two high severity burns where repeated fire had irreversibly changed the whole ecosystem. The woody biomass was replaced by non-woody AGB dominated by two species of fern: *Stenochlaena* spp. and *Blechnum* spp. The value of non-woody AGB ranged from 6 up to 12 t ha^{-1}, i.e. much higher than the value for woody AGB; fern biomass has a high flammability and can, therefore, greatly increase the fire risk. Moreover the MFHSev plots revealed an almost complete absence of trees, with only 29 ha^{-1}, and around 638 saplings ha^{-1} compared to the canopy inventory in MFMSev where tree density was ten times greater (308 trees ha^{-1}) and the density of saplings was twice as high. In these severely burnt areas, the exposed peat surface was subjected to on-going degradation through wind and water erosion: on the one hand, the MFHSev plots were more susceptible to fire during the dry season, but on the other hand, during the wet season, these sites were flooded regularly owing to subsidence of the peat surface, through a combination of loss of the original tree cover, and peat combustion and oxidation. In order to mitigate the risk of both fire and flooding additional restoration measures may be required.

This brief account of the different stages of post-fire vegetation re-growth following single and multiple fires on tropical peatlands illustrates the potential of secondary vegetation succession for carbon storage and regeneration. The SF and MFLSev plots revealed a considerable capacity for natural regeneration. Although the vegetation structure will take some considerable time to achieve that of primary forest, the accumulating AGB protects the peat soil from excessive degradation and mitigates the fire risk. This study emphasises, however, that it is very important to reduce recurrent fires in secondary vegetation, since this drives the system towards low diversity communities dominated by ferns which are at high risk of fire, and also threatens the remaining patches of natural forest which represent potential sources of biodiversity and act as an engine of AGB accumulation.

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