Repeated and extensive fire as the main driver of land cover change in Block C of the former Mega Rice Project

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Summary
Analysis of a series of satellite images for the period 1973-2005 has revealed that extensive, repeated fires play a major role in land cover change in the tropical peatlands of Central Kalimantan. During the first two decades of the study period (1973-1992) fires were of limited extent and mostly associated with extended dry seasons related to the El Niño phenomenon. More significant fire degradation of peatlands has occurred during the last decade, with a 52% loss in area of peat swamp forest in Block C of the former Mega Rice Project. During this period fire frequency has increased owing to peatland drainage and the change in land cover from forest to secondary vegetation, which is more flammable. Our studies indicate that (i) post-fire land cover is strongly driven by widespread fires that have increased in recent years, and (ii) the incidence of fire is becoming decoupled from ENSO, with an increased risk of fire even during 'normal' (i.e. non-ENSO) dry seasons. These results emphasise the vulnerability of the tropical peatland carbon store under current land management practices.

Key index words: land cover change, fire, tropical peatland, Mega Rice Project

Introduction
Reduction of emissions from deforestation and degradation in tropical forests is a regional and global challenge to climate change mitigation strategies in which numerous uncertainties must be overcome to make this mission successful. Firstly, it must be known how much forest has been lost over past decades. Secondly, the major drivers of deforestation must be determined. Thirdly, the condition of the carbon stock must be established. Until now, with some regional exceptions, the greatest uncertainty and one of the biggest challenges is understanding and measuring carbon flux in tropical ecosystems. It has been shown that approximately 50% of the uncertainty is in biomass estimation and up to 80% in estimation of carbon flux, both of which have associated difficulties in the quantification of above- and below-ground biomass as well as the assessment of spatial and temporal biomass distribution (Coppin *et al.*, 2004; Houghton, 2003, 2005). In addition, these uncertainties also vary between tropical regions (Foody *et al.*, 2003; Lu, 2005).

Information concerning tropical peatlands in South-east Asia seems to be particularly lacking in terms of estimation of past rates of carbon loss, current carbon flux and stock (Fuller, 2006). Tropical peatlands are under serious threat of human activities, manifested through drainage, land use change, or burning by which stored carbon is released into the atmosphere, contributing to global warming. Fire has been reported to be one of the major drivers of degradation of tropical forest in Southeast Asia (Siegert *et al.*, 2004). Since the implementation of the Mega Rice Project (MRP) in 1996-1998, the drained peatlands of Central Kalimantan, Indonesia have been subject to recurring fires. Therefore quantifying both carbon losses through direct and indirect effects of fires as well as the amount of carbon sequestered by vegetation re-growth is required to compensate the negative consequences of forest degradation.

This research investigates sources and trends in land cover transformation that have occurred in tropical peatlands in the former MRP area over the last three decades (1973-2005), with particular attention paid to the fire regime and role of fire in land cover change.

Materials and methods
The study area was located in the western part of the former Mega Rice Project, in a section called Block C, with an area of approximately 4,500 km^2. Land cover maps were derived from a time series of satellite images obtained from several sensors, including Landsat MSS, TM, ETM+, Aster/Terra and Disaster Monitoring Constellation (DMC). In total, more than 20 images were used to map land cover for a period of 32 years from 1973 until 2005. Land cover parcels were mapped using manual segmentation into 15 classes. This approach was chosen as the optimal method considering different data sources, acquisition dates, and data quality and, additionally, because until now the widely used pixel based automatic classification technique could not separate classes owing to spectral overlap in a highly heterogeneous burnt landscape.

Burn scars were mapped using both the multi-temporal Normalised Burn Ratio (NBR) and the Normalised Difference Vegetation Index (NDVI). Both indices have been widely used to derive burnt areas (Epting *et al.*, 2005; Phua *et al.*, 2007; Wagtendonk *et al.*, 2004). Separation of burnt and non-burnt pixels was based on the expert threshold method, with additional manual error checking to correct misclassified areas resulting from small clouds and shadows.

A time series of burnt area products were then used to derive accumulative fire occurrence maps for three decades (1973-2005).

Results and discussion

This study reveals strong evidence of the role of fire as one of the major drivers of deforestation and degradation in the tropical peatland ecosystem, beginning in 1973. Originally, forest covered almost 72% of the total area of Block C, 60% of which was defined as peat swamp forest, i.e. mixed swamp forest on peat up to 6m thick and low pole forest on peat >6m thick (Page *et al.*, 1999). Fires that occurred during the first two decades (1973-1992) in this area were mainly associated with prolonged droughts driven by El Niño oscillations (ENSO) in 1972/73, 1982/83 and 1991/92 (Aiken, 2004; Fuller and Murphy, 2006; Wyrtki, 1975), which affected 6.9%, 7.9% and 7.5% of Block C, respectively. However, the most serious degradation occurred during the last decade (1997-2005) as a result of the implementation of the MRP. Widespread, intensive fires associated with the El Niño event in 1997 destroyed about 33.5% of the over-drained land, of which 84% was occupied by mixed peat swamp forest. Degraded forest did not have enough time to recover from fires in 1997 when a further progressive degradation of peatlands took place during the weak El Niño of 2002. Fire was again widespread, affecting 24% of Block C. Since 2002 on-going degradation owing to repeated and extensive fires has become a regular feature of this tropical ecosystem associated with dry seasons, even if El Niño climate conditions were not present.

During the dry seasons of 2004 and 2005, fire affected an additional 14.3 % and 12.4% of the study area, respectively, with the majority of fires now occurring in non-forest vegetation. In 2006, fire activity was again widespread across the region, associated with a moderate El Niño event. It appears that some locations have been subjected to two, three or even more fires within a relatively short period (Fig. 1).

The fire frequency analysis showed that approximately 29% of Block C was burnt once, 40% was burnt twice and 11% was burnt three times between 1997 and 2005. Our investigations reveal that repeated and extensive fire reduces the capacity for vegetation to regenerate naturally. Therefore, it is important to have a knowledge concerning the condition, stock volume and biomass of regenerating vegetation under various disturbance scenarios as this will influence potential fire risk as well as protect land from future fire. Land cover changes over the last three decades shows a shift in fuel components from forest toward exposed peat that leads to additional carbon being lost. The rate of loss of peat swamp forest in relation to the initial year 1973 greatly increased from 26% in the first two decades up to 72%, owing to the fire of 1997, reaching 80% in 2005. This means that 80% of the peat swamp forest has been lost over the last three decades in Block C. Natural forest is being replaced by slowly regenerating vegetation dominated by more homogeneous, low growing, largely non-woody vegetation of fire prone bushes, ferns and sedges.

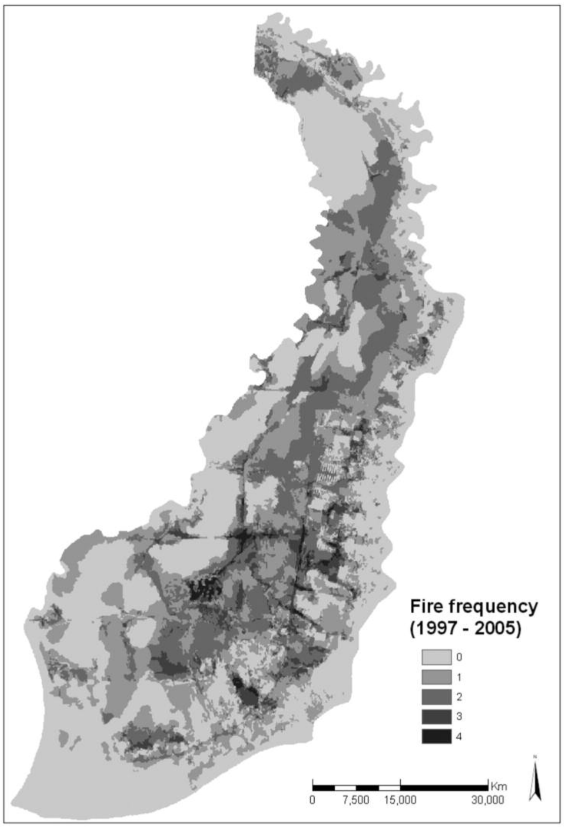

Figure 1. Accumulative fire frequency for period 1997-2005, within the Block C of the MRP

This fragile post-fire vegetation regrowth provides neither protection to the exposed peat surface that is subjected to on-going degradation through peat oxidation and subsidence nor resistance to fire and might well increase fire risk in the future. Despite increased fire activity, some locations show strong regeneration potential. The land cover map of 2005 shows an increase in area occupied by mosaics of trees and non-forest vegetation (11% of total area of Block C) and an additional 4% covered by secondary forest.

The results of this research emphasise the vulnerability of the tropical peatland carbon store under current unsustainable land management practices. Current research findings should be used as a baseline to implement appropriate land use planning, and undertake effective action for fire prevention, monitoring and post-fire mitigation.

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