Land Use Policy 57 (2016) 418–430

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Monitoring deforestation in Malaysia between 1985 and 2013: Insight from South-Western Sabah and its protected peat swamp area

Kamlisa Uni Kamlun[a,b,*], Renate Bürger Arndt[a], Mui-How Phua[b]

[a] Department of Nature Conservation and Landscape Planning, Faculty of Forest Science and Forest Ecology, Goettingen University, Germany
[b] Faculty of Science and Natural Resources, University Malaysia Sabah, Sabah, Malaysia

ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form 31 May 2016
Accepted 10 June 2016
Available online 19 June 2016

Keywords:
Land cover change
Deforestation
REDD+
Supervised classification
Wetland
Area estimation
Accuracy assessment

ABSTRACT

Monitoring land cover changes provides an effective and accurate evaluation of deforestation rates that shed light on reducing emissions from deforestation and forest degradation (REDD) implementation. Located in Klias Peninsula, southwestern Sabah, Malaysia there lies a pristine peat swamp forest area. This type of ecosystem plays a significant role in global climate regulation. Despite its importance, the peat swamp forest is threatened and highly degraded, due to the increasing demand for agricultural expansion. This is where we monitored deforestation and land cover change between 1985 and 2013. Temporal changes were determined by means of supervised classification, using the maximum likelihood classification rule to observe changes in the area. Post-classification change detection techniques were applied in order to understand the change in forest coverage in the Klias Peninsula and inside the protected area boundaries. The overall accuracy for the Klias Peninsula and the protected area were more than 88% (±4% margin of error) and 95% (±2% margin of error), respectively. Based on these findings, it appears that more than half of the forest area in Klias Peninsula disappeared from 142,713 ha (±6818 margin of error) to 73,403 ha (±6796 margin of error) between 1985 and 2013. The annual rate of change in the protected area was 10.94% (±0.85% margin of error) per year for deforestation and 0.86% (±5.19% margin of error) per year for forest area. The result revealed that most of the peat swamp forest was converted to other stable non-forest areas, including agriculture which can be a threat to the already disturbed protected area. Therefore, we also conducted an accurate monitoring of the forest cover change and deforestation data in the protected area and its surrounding environs in order to promote sound political decision-making regarding the future protection and sustainability of the remaining peat swamp area.

1. Introduction

The conservation of peat swamp forests is vital for fostering landscape ecology for human welfare. In parallel, sustainable forest management is essential for maintaining the social, economic, and ecological services of the peat swamp forest area. Peat swamp forests have tremendous conservation value due to their key role in global climate regulation (Jauhiainen et al., 2005; Page et al., 2011), water storage (Yule, 2010), community livelihood support (Mohd Azmi et al., 2009; Sagala et al., 2014), as well as rich biodiversity support, shoreline protection against soil erosion, tsunamis and hurricanes (UNEP, 2011). Globally, the total recorded area of peat swamp forests, is 441,025 km^2 (Page et al., 2011). Most of the world's tropical peatlands (62%) are located in the Indo-Malayan region, where Malaysia has the second largest share of this reservoir in the zone (25,889 km^2) (Page et al., 2011). These values indicate that, globally, Southeast Asia shares the largest carbon pool. The total estimated peat swamp carbon pool in the Southeast Asia region is 69Gt, and Indonesia has by far the largest share of the tropical peatland carbon pool (57Gt, 65%), followed by Malaysia (9Gt, 10%) (Page et al., 2011).

Despite the importance of peat swamp forests, they are still threatened and highly degraded. Often this forest type is regarded as wasteland that should be converted to more productive land use. Thus, there have been a series of dramatic changes in peat swamp forests globally, precipitated by increases in logging, fires, as well as conversion to agriculture and industry (Miettinen et al., 2012; Wijedasa et al., 2012; Yule, 2010). Human demands for agricultural expansion, especially by oil palm plantations, are among the main contributors to the recent deforestation of this wetland type (Carlson et al., 2012). The total peat forest surface area in Southeast

* Corresponding author at: Department of Nature Conservation and Landscape Planning, Faculty of Forest Science and Forest Ecology, Goettingen University, Germany.
E-mail addresses: unikamlun@gmail.com, kbintik@gwdg.de (K.U. Kamlun).

http://dx.doi.org/10.1016/j.landusepol.2016.06.011

Asia has decreased from 77% to 36% of total land mass (102,274 km^2 in 1990). If this trend continues, peat swamp forests may disappear entirely by 2030 (Miettinen et al., 2012). The activities associated with this deforestation, as well as other anthropogenic activities in the peat swamp forests, are a major cause of greenhouse gas emissions globally, accounting for 1.3%-3.1% of current global emissions (Hooijer et al., 2010). Deforestation causes the peat to dry out, making it susceptible to fire. Such peat fires account for 9.2% of the global fire-induced fine particle (matter) emissions and for 62% of all Southeast Asian fire emissions (Fujii et al., 2015). For these reasons, monitoring of forest changes is essential for tracking the health and productivity of the ecosystem, in order to facilitate proper management that is based on actual forest conditions. Most of the alterations in the forest have resulted in diverse ecological impacts, ranging from the local to the global scale, and including changes in nutrient dynamics, species diversity and forest vegetation composition, as well as increases in atmospheric carbon dioxide levels (Violini, 2013).

Monitoring the distribution and composition of large wetlands is often challenging, as these lands are heterogeneous across space and time (Hansen and Loveland, 2012; Houlahan et al., 2006). Mapping is an important tool for evaluating the forest resources that are needed to support sustainable forest management in a protected area. It plays a key role in detecting illegal logging and forest fires as early signs of degradation and thereby helps to reduce deforestation, and improve forest quality (Pungkul et al., 2014). Mapping is achieved through the intensive application of satellite remote sensing techniques. While traditional measurements such as field surveys are restricted to spatial or temporal coverage (Han et al., 2014), remote sensing offers a comprehensive, pragmatic and prudent assessment option, with the advantages of synoptic and repeated observations for monitoring (Adam et al., 2010). Landsat satellite remote sensing is a global asset that supports forest monitoring for tropical forest ecosystems management (Hansen et al., 2010; Wulder et al., 2012). The advantages associated with this data source include its data availability and frequent updates that enable scientists to understand forest changes. It provides cost-effective data that can be used for forest change assessment. Free and open access to this satellite data is essential for monitoring and supporting efforts to reduce deforestation and forest degradation (Wulder et al., 2012).

Thus, peat swamp forest decision-makers always require up-to-date, reliable spatial information on patterns and trends in the land cover, but relatively little research has investigated the composition of plant species in regenerating forests following a disturbance (Blackham et al., 2014). Knowledge of the peat swamp forest flora is far from complete and, as this forest type is rapidly vanishing, we are losing flora before we get to know what it is that we are losing (Yule, 2010). Numerous analysts have used multispectral information from Landsat data to distinguish vegetation classes, in an attempt to separate expansive vegetation types in tropical wetlands (Cardoso et al., 2014; Ibrahim and Jussof, 2009; Kamlun and Phua, 2010; Phua et al., 2007) or to map wetland vegetation at the species level (Harvey and Hill, 2010; Hoscilo et al., 2011; Nagabhatla et al., 2012; Zhang et al., 2011). Digital image classification (i.e., unsupervised or supervised classification) has been shown to be the most effective image analysis for mapping wetland vegetation (Churches et al., 2014; Ozesmi and Bauer, 2002; Tsuyuki et al., 2011).

Given this background, this paper reports about monitoring deforestation in southwestern Sabah, Malaysia, in the period between 1985 and 2013. In particular, it analyses deforestation in protected area peat swamp forests by means of change detection in multi-temporal satellite images from Landsat. This study will expand upon the preliminary results reported by Phua et al. (2008) and Kamlun and Phua, (2008). The research objectives were to: (1) quantify the rates of change in the forest area in southwestern Sabah (Klias Peninsula) between 1985 and 2013; (2) quantify the rates of change at three time periods within the peat swamp forest protected area boundaries (1985–1998, 1998–2004, and 2004–2013); and (3) determine the annual rates of change within the peat swamp forest protected area following a disturbance due to forest fire within the year of estimation (1985–2013).

2. Materials and methods

2.1. Study area

The study was conducted in the District of Beaufort in the southwestern part of Sabah, in eastern Malaysia (Fig. 1), where an extensive wetland area is found. Beaufort occupies approximately 466,804 ha and receives high annual rainfalls, between 2500 mm and 3000 mm. The wetland lowland plain is often referred to as the Klias Peninsula. It is a fully-protected peat swamp forest that is located between 115°.45′ – 115°.72′N and 5°.42′ – 5°.15′E. Peat swamp forests used to be selectively logged until two protection forest reserves were established in 1984. The Binsuluk Forest Reserve (12,106 ha) and the Klias Forest Reserve (3620 ha) were gazetted to conserve the remaining peat swamp forest in Sabah (Phua et al., 2008). They were introduced to protect the watershed and maintain the stability of essential climatic conditions and other environmental factors. Both forest reserves are surrounded by *Dryobalonops rappa, Dactylocladus stenostachys, Shorea platycarpa, and Gonystylus bancanus*. Kapur paya (*Dryobalonops rappa*), appears to be the most dominant species of the upper canopy (Phua et al., 2008). An endemic proboscis monkey species, known as *Nasalis larvatus* is primarily found in the Klias Peninsula (Sha et al., 2008).

Fire outbreaks have brutally degraded the wetlands, especially the peat swamp forests. The entire Klias peat swamp deposit is estimated to be at least 7400 ha, out of which only 3620 ha are protected within the Klias Forest Reserve. Much of the adjacent area has been lost, after it had been turned into small patches within the forest boundary due to fires during the El Niño events of 1983, 1991, 1998 and 2003. More specifically a series of human-induced forest fires severely degraded the entire zone, transforming all kinds of forests into barren land, which then regenerated naturally into grassland and shrubland. This change also affected the peat swamp forests, where extensive fires during the 1998 and 2003 El Niño seasons destroyed more than 60% of the original peat forest area (Kamlun and Phua, 2010). This drastic land cover change, in turn, generated tremendous demands by the adjacent local communities to convert the land to agricultural use, particularly palm oil plantations. This additional pressure even affected the protected peat swamp forest (Sabah Forestry Department, 2005), where logging as well as any livelihood activity, is strictly prohibited. Overall, it is becoming increasingly difficult to preserve this forest ecosystem and to safeguard its essential services supply.

2.2. Data acquisition

Time series satellite images were acquired from the United States Geological Survey (USGS) EarthExplorer (see http://earthexplorer.usgs.gov/, Path/Row: 118/56). All the data were processed to the USGS "Standard Terrain Correction (Level 1T)" level. The earliest satellite image was from the Landsat Multispectral Scanner (MSS), taken on June 29, 1985 (The image was free of cloud and haze from inside the forest reserve and had 10% clouding in the inland area). The Landsat 5 Thematic Mapper (TM) imagery data was obtained on November 24, 1998 and June 17, 2004 (Both the 1998 and 2004 satellite images were free of cloud and haze in the