

Original Research

Assessing Land Cover Changes and CO₂ Emissions in Tropical Forests, 1998-2016: A Case Study of the Sungai Wain Protection Forest

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Abstract

Tropical forests have long been known for being home to a huge biodiversity of plants, animals and microbes. Nevertheless, one of the most dangerous threats to the existence of tropical forests is fire. Fire in tropical forests does not only devastate the forest structure and biodiversity, but it also releases huge amounts of CO₂ to the atmosphere. This study aims to observe land cover changes in the Sungai Wain Protection Forest (SWPF) via Landsat multitemporal data from 1998 to 2016 and to calculate their resulting emissions. The findings showed that the total area affected by forest fire during this period was 6,400 ha, which amounts to 5,000 and 1,400 ha of lost forest in 1998 and 2015, respectively. The potential of CO₂ emissions due to aboveground biomass (AGB) loss was 4.66 Tg during that period. This study also showed that SWPF was able to recover naturally after the 1998 fire. Fires in 2015 mostly occurred in regenerating forests, implying that it is more flammable than primary forests. As an implication, the fire phenomenon is still threatening the SWPF because it has potential value to cut down succession from regenerating to primary forests.

Keywords: tropical forest, land cover change, CO₂ emissions, landsat

Introduction

Tropical rain forests play an important role in maintaining biodiversity [1]. Large, contiguous forest areas have long been traversed by animals for food,

mates, and other resources [2]. There are specific and essential interactions among species and the biotic and abiotic environments, forming cooperation and competition that can eventually lead to niche partitioning [3]. Therefore, conserving tropical rain forests would matter for biodiversity and environmental interaction inside [4]. In terms of climate change, protecting tropical forests is a strategy for combating the increase of greenhouse gas emissions through carbon

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sequestration [5-6]. This also means that a maintained forest would secure environmental services beneficial for human wellbeing such as fresh water [7] and air [8].

Research has unfortunately shown that the long-term existence of tropical rain forests, particularly in Indonesia, is under threat [9-10]. Tsujino et al. [9] revealed that Indonesia lost 59 Mha forest area between 1950 and 1997. It was also claimed that 9 Mha forest were lost during 1997-2015. Other research shows that Indonesia has lost as much as 14.7 Mha of its tropical rain forest cover from 2000 to 2010, which was spread over the five biggest islands, i.e., Sumatra, Kalimantan, Sulawesi, Moluccas, and Papua [11]. Margono et al. [12] noted that 7.54 Mha of primary forests were lost in Sumatra in 1990-2010, followed by 2.31 Mha of forest degradation by 2010.

Forest fires have contributed a significant impact to forest degradation in Indonesia over the past three decades [13-15]. The primary causes of these fires can be attributed to the increased population, land clearing for agricultural purposes and long-term droughts [16, 17]. Forest fires do not only directly affect biodiversity loss, but also lead to increases in the amount of anthropogenic gasses in the atmosphere through carbon dioxide (CO₂) emissions [18-19]. Page et al. [20] revealed that in 1997, forest fires in Indonesia released 0.81-2.57 gt carbon to the atmosphere, which amounted to 13-40% of global fossil emissions in that year. Furthermore, research conducted by Lohberger et al. [15] has shown that 0.89 gt CO₂ were released from forest fires in 2015. Forest fires occurred not only

in logged and palm oil concessions [14, 21], but also in protection areas that contain huge biodiversity [16, 22].

The Sungai Wain Protection Forest (SWPF) is one of the remaining primary lowland tropical rainforests in East Kalimantan [23]. This forest provides valuable habitat for endemic animals of its island, like the orangutan (*Pongo spp.*) and sun bear (*Helarctos malaynus*) [24-25]. Due to its connectedness for the mangrove forests in Balikpapan Bay, the SWPF is also an important habitat for the proboscis monkey (*Nasalis larvatus*) [26]. Forest cover in the SWPF, however, seems to have decreased over time, caused by natural and anthropogenic factors. During the long drought period in 1997/1998, for example, forest fires driven by the El Niño Southern Oscillation (ENSO) impacted the SWPF. Therefore, the changes of forest cover within the SWPF may pose a serious threat to the ecosystem within its boundaries. On the other hand, degradation of SWPF can reduce carbon storage potential and, consequently, large amounts of CO₂ will be emitted into the atmosphere.

Despite these serious forest losses and degradation, there is a lack of definitive information on the extent and pattern of land cover changes in the SWPF. Most research in the SWPF has concentrated on the ecology [24-25, 27]. This current study, therefore, aims to address this issue. In addition, this study would also estimate the potential emissions of CO₂ from areal loss of aboveground biomass (AGB). Our study is particularly significant as the SWPF experienced forest fires in 1998 and 2015 due to the long drought season.

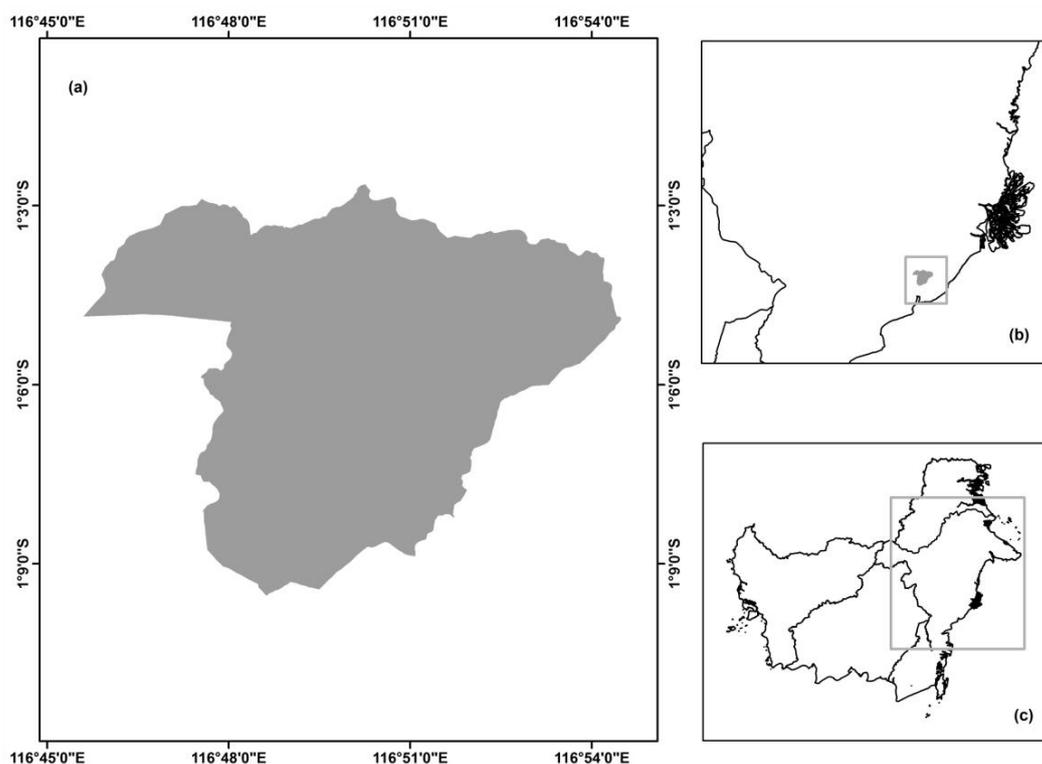


Fig. 1. a) Map of the SWPF, b) location of study area in East Kalimantan, and c) map of East Kalimantan in Kalimantan island.

Materials and Methods

Classification Analysis

Study Area

The SWPF lies in the city of Balikpapan, East Kalimantan, Indonesia, between 116° 47'–116° 55' east and 01° 02'–01° 10' south (Fig. 1). The local government of Balikpapan has the authority to manage the forest, which is approximately 10,000 ha consisting of both gentle and steep topography. Its elevation is between 30 and 150 m a.s.l [28]. Even though there is no consistency in annual rainfall, the dry and wet seasons are distinguishable. The dry season usually occurs between August and November, while the wet season comes from December to March. Annual average temperature in the SWPF is around 26.5°C [29].

Data Processing

We used Landsat 5 and 8 in this study. The images selected were acquired from 1998, 2014, and 2016 in the United States Geological Survey (USGS) archive (Table 1). We utilized 4 (four) images from 1998 to 2016, since they had less than 5% cloud cover due to the difficulty in procuring cloud-free imagery in wet tropical regions.

Generally, the Landsat data processing included radiometric calibration, atmospheric correction, mosaic and subset. Radiometric calibration was used to convert the digital number (DN) of the Landsat images to top of atmosphere (TOA) radiance. Then the atmospheric effect of the image was corrected using the dark object subtraction (DOS) method [30]. Layer stacking was utilized to convert three bands (NIR, red, green) to single layer for enhancing the image. The image was cropped using shapefile of the study area. The subset image was then orthorectified into WGS 84 datum and projected on Zone 49N using Universal Transverse Mercator (UTM) projection.

Supervised classification was used to classify forests and non forests on Landsat images of different times, such as 1998, 2014 and 2016 using the maximum likelihood algorithm, which is widely used by researchers to deliver landuse/land cover (LULC) [31–33]. Maximum likelihood algorithm employs a bayes-family classifier to assign pixel likelihoods on the basis of mean class values as well as class covariance [34]. In order to use this algorithm, a sufficient number of pixels is required for each training area, allowing for the calculation of the covariance matrix. The training areas were collected from the Landsat images via visual interpretation based on combination references between field survey results at the end of 2016 and based on a map from google earth. Two classes of forest and non-forest were created for each image.

An accuracy assessment from supervised classification from the image in each year was done. A hundred reference points were generated randomly from each image. Information from the base map was used to recognize land cover for each reference point. Then, reference points were compared to images from supervised classification results through a confusion matrix to perform an accuracy assessment.

Estimate of CO₂ Emission

In this study, emissions of CO₂ were measured in two different ways. The first method was applied in the 1998 forest fires by using the AGB value from Yamakura et al. [35], who conducted research in Dipterocarpaceae lowland in Sebulu, East Kalimantan which is similar to the type of forest in Sungai Wain by using an allometric equation for the larger trees and harvesting for small trees. The research found that AGB value for lowland Dipterocarpaceae was 509 ton/ha in 1.0 ha of plot [35].

The second method for analyzing CO₂ emissions after fire in 2015 was the stratify and multiply approach.

Table 1. Satellite data used in this study.

Acquisition Date	Satellite	Sensor	Spatial resolution	Radiometric resolution	Spectral band used in this study
1998/02/11	Landsat 5	TM 5	30	8	B2 (0.52–0.60 μm) B3 (0.63–0.69 μm) B4 (0.76–0.90 μm)
1998/12/12	Landsat 5	TM 5	30	8	B2 (0.52–0.60 μm) B3 (0.63–0.69 μm) B4 (0.76–0.90 μm)
2014/02/23	Landsat 8	OLI	30	16	B3 (0.53–0.59 μm) B4 (0.85–0.88 μm) B5 (0.85–0.88 μm)
2016/02/13	Landsat 8	OLI	30	16	B3 (0.53–0.59 μm) B4 (0.85–0.88 μm) B5 (0.85–0.88 μm)

Remarks : TM = Thematic Paper ; OLI = Operational Land Imager

This method was chosen as a result of non availability of AGB information in the study area after the 1998 forest fires. The stratify and multiply approach was carried out by an intersecting map of 2016 classification result with land cover map [36]. We employed Indonesian land cover map 2014 from the Ministry of the Environment and Forestry (MOEF) of Indonesia. The Indonesian land cover by MOEF was created by Landsat image and had 30 m spatial resolution. The AGB mean from each type of land cover was captured from the Forest and Climate Change Program (FORCLIME) project in Kalimantan [37].

The AGB of each method was converted to carbon by assuming that 50% of dry biomass is carbon. CO₂ emissions were obtained by multiplying carbon stocks by 3.67, which is the molecular weight ratio of CO₂ to C [15, 38]. It was considered that the forest maintains a certain percentage of biomass after fire so that conservation fire efficiency was applied to the CO₂ emissions. In this case, we employed the Lohberger et al. [15] approach, who utilized 92% conservation fire efficiency for forest area and 100% for other land cover classes.

Results and Discussion

Land Cover Changes

Given the difficulty in obtaining a comprehensive temporal trend of forest cover changes due to a big gap in the image acquisition year, this study presents the two largest forest cover changes in the SWPF. Estimated forest and non forest areas of SWPF in February 1998, December 1998, February 2014 and February 2016 were obtained by supervised classification. The current study found that the total forest and non-forest areas in February 1998 were 10,159 ha and 1,150 ha, respectively (Table 2). Non forest area comes from the agricultural area by communities in the western and eastern sides of SWPF. These communities have been given permission legally by MOEF to utilize approximately 1,000 ha area of SWPF through the forest community program [39].

The magnitude of forest decreased drastically in December 1998 and accounted for 4,914 ha. Forest fires are known to be a major contributor to this forest loss in the SWPF in 1998. The most interesting finding about the 1998 forest fires were the unburned forest in the central SWPF, implying that forests grown in that area can be considered as primary forest. The long period of the dry season resulted from the influence of

the ENSO contributing to the more severe fire during that time [40]. An analysis using a combination of ERS-SAR and ground data by Hoffman et al. [41] found that 5.2 Mha land in East Kalimantan was damaged due to the 1997/1998 forest fires. In total, the number of forests in the SWPF affected by forest fires was more than 5,000 ha at that time.

Sixteen years later, the trend changed with an increase of forest cover from 46.28% to 10,418 ha. The amount of non-forest decreased at 1,161 ha in the same period. The increasing trend of forest cover in 2014 was connected to successional recovery of the burned forest. After 7 years of burning, stand density in SWPF showed a significant increase in burned area and the largest diameter of the class in burned achieved the same levels compared to unburned forests [42]. The majority of stand density is dominated by pioneers expected to recover forest structure for a 10–20-year period, except for forest composition and AGB [43]. Toma et al. [44] conducting research in Bukit Soeharto, East Kalimantan found that after 16 years of burning, the pioneer is going to become the late successional tree and have the potential to recover AGB of the burned area similar to natural forests if there is no damage in the longterm.

In 2015, a forest fire again struck out the remaining burned area to the west of SWPF. This side was a regenerating forest and part of the area was already burned in 1998 (Fig. 2). It is interesting to note that massive fire in 2015 mostly occurred in regenerating forests than primary forests of the SWPF, which is linked to the composition of both type of forest inside the SWPF. The 1998 forest fires remained regenerating forest, which is composed of mainly shrubs and saplings. Shrubs have the ability to rapidly recover the forest following disturbance [45], but they are also a prominent fuel in the forest floor [46]. Further implication is that the area is more susceptible to fire than primary forest, which has full canopy cover. As is known, canopy cover potentially helps maintain microclimate in the forest so that it will diminish flammability of above and below ground biomass fuels [47]. This phenomenon has been studied by Page et al. [20], who observed that forest fires mostly affect logged forests with less canopy cover than primary forests. Balch et al. [48] found that the intensity of forest fires was higher in open-forests than closed-canopy forests. Forest fires by 2015 were also the result of El Niño, during which extensive fire spread in November 2015 [49].

The two classes of forest cover in February 1998, December 1998, February 2014 and February 2016 images are described in Fig. 2. The green and red colors

Table 2. Land cover changes in Sungai Wain during 1998-2016.

Classes	February 1998	December 1998	February 2014	February 2016
Forest (ha)	10,159	4,914	10,148	8,604
Non Forest (ha)	1,150	6,395	1,161	2,705

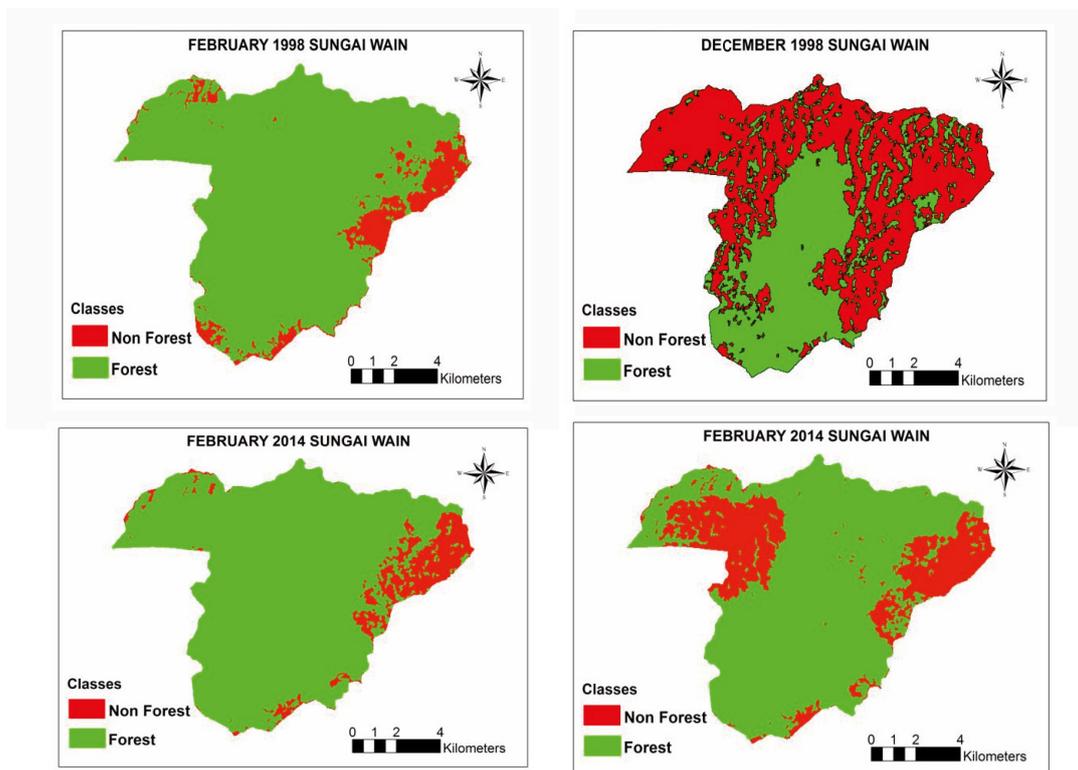


Fig. 2. Four classes in February 1998, December 1998, February 2014 and February 2016 images.

represent forest and non-forest, respectively. The images also depict that there was forest cover change in the west of SWPF occurring in 2014-2016, but lower frequency

than in 1998. Overall, the accuracy including producer's accuracy, user's accuracy and kappa accuracy, were calculated through a confusion matrix. Finally, user's and producer's accuracy were both found to be between 92% and 98%, kappa accuracy was 86-96%, and the overall accuracy was 93-98% (Table 3).

Table 3. Accuracy assesment of image classification results.

Years	Accuracy	Forest (%)	Non forest (%)
February 1998	User's accuracy	94	96
	Producer's accuracy	96	94
	Overall accuracy	95	
	Kappa accuracy	90	
December 1998	User's accuracy	94	92
	Producer's accuracy	92	94
	Overall accuracy	93	
	Kappa accuracy	86	
February 2014	User's accuracy	98	98
	Producer's accuracy	98	98
	Overall accuracy	98	
	Kappa accuracy	96	
February 2016	User's accuracy	96	98
	Producer's accuracy	98	96
	Overall accuracy	97	
	Kappa accuracy	94	

CO₂ Emissions from the Study Area

A study by Yamakura et al. [35] showed that the amount of AGB carbon in the SWPF was 254.5 t C ha⁻¹. We utilized this data for estimating AGB carbon loss in the study area before the 1998 forest fires. Based on this method, 1 ha forest cover loss is equivalent to 934 tons potential CO₂ emissions in due of time. After the value was multiplied by molecular weight ratio and conservation fire efficiency, the potential of CO₂ emissions in 1998 was 4.50 Tg (Tera gram).

Estimation of CO₂ in 2015 was conducted by stratify and multiply analysis. Spatial analysis between landcover map 2014 from MOEF and classification results in 2016 in this research derived 1,236 ha (regenerating forest), 153 ha (secondary forest) and 4.9 ha (primary forest) burned areas. Then the values were multiplied by AGB carbon from Navratil et al. [37], who found that AGB carbon for regenerating forest, secondary forest and primary forest were 31 t C ha⁻¹, 46 t C ha⁻¹ and 160 t C ha⁻¹, respectively. In total, estimated CO₂ emissions at this time were 0.16 Tg after multiplying by 3.67 as molecular weight ratio and conservation fire efficiency. The total potential

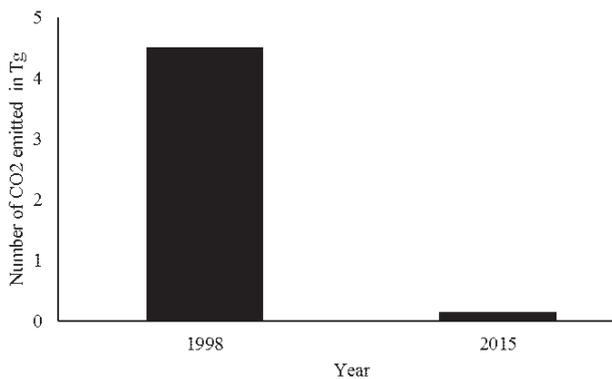


Fig. 3. Comparison of CO₂ emissions between 1998 and 2015.

CO₂ emissions due to fires was estimated at 4.66 Tg during 1998-2016.

This study shows that magnitude of CO₂ emissions in 1998 was higher than emission results of forest fire in 2015 (Fig. 3). It can be linked to different types of forest burned in both years. The 1998 forest fires occurred in primary forests containing high amounts of AGB. On the other hand, the majority of forest fires in 2015 occurred in regenerating forest that was burned in 1998. Regenerating forest is classified as shrubs according to Indonesian land cover 2014, then based on the result of Navratil et al. [37], AGB carbon of shrubs is 31 t C ha⁻¹. As a result, the CO₂ emitted to the atmosphere was very small.

The estimates of CO₂ emissions given in the current study are lower than the CO₂ estimates calculated from deciduous forests in India (12.6 Tg) [50]. Saranya et al. [50] performed their study in Similipal Reserve area, where the area and intensity of fires are greater than our study. Nevertheless, the mean of CO₂ emissions of their study was 1.26 Tg and still lower than our study, which accounted for 2.33 Tg from 1998 and 2015 forest fires. In comparison, we can emphasize that tropical forests contains greater amounts of above and below ground biomass than other forest types. Thus, it will release a huge amount of CO₂ if disturbed, since a tropical forest stores approximately 40% of carbon in a terrestrial ecosystem [51]. Fragmentation of tropical forest is able to reduce carbon storage and consequently will elevate carbon emissions, thereby worsening the impacts of climate change. Vicharnakorn et al. [52] stated that 15-20% of global carbon emissions were delivered from forest degradation, where the majority originated from tropical forests.

Our results suggest that forest fires are prominent factors causing forest loss and degradation in the SWPF. The authority of the SWPF can take an effort to establish a collaborative institution consisting of stakeholders and government agencies [53]. Particularly in the SWPF, the community who live inside and outside the SWPF should be involved to prevent forest fire through community empowerment [54]. Furthermore, a fire web application based on GIS technology can be considered one of the fire management strategies [55].

Conclusions

The present study was designed to estimate the amount of forest degradation and CO₂ emissions estimation during 1998-2016 in the SWPF. The investigation using multi-temporal landsat imagery showed that fire has a remarkable effect on forest degradation in the SWPF. It was also shown that forest fires in SWPF produced 4.66 Tg CO₂ emissions during the period. Although SWPF was recovering from fire in 1998, tree composition in regenerating forests is easily burned. It revealed that the fire in 2015 affected regenerating forests more than primary forests. This result gives strict evidence to management of SWPF to apply effective fire management to the entire SWPF area.

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Conflict of Interest

The authors declare no conflict of interest.

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