関東森林研究 No.62 (2011)

Monitoring deforestation in Sarawak, Malaysia using multitemporal Landsat data

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Abstract: Deforestation is the most important problem facing tropical countries. This paper discusses the use of medium resolution Landsat data for monitoring deforestation in Sarawak, the largest state of Malaysia. Missing line correction and filtering of the SLC-OFF Landsat data was necessary prior to supervised classification. The overall accuracies of the classifications of 1990 and 2009 exceeded 80%. Of the total loss of 1.2 million ha of forests in the past two decades, more than 90% was peat swamp forests and intact forest. The overall deforestation rate of Sarawak was 0.64%. Deforestation at coastal divisions (e.g. Mukah) was due to forest to oil palm conversion in recent years. In inland divisions (e.g. Kapit), intact and secondary forests decreased due to logging followed by clearing for oil palm plantation.
Keywords: Sarawak, land cover change, Landsat, deforestation, missing line correction.

I. Introduction

Deforestation is one of the major contributors to the emission of green house gases (GHGs). It is responsible for 17% of the total anthropogenic GHGs emission (*6*). Deforestation in the tropics has been recognized as the massive source of emission of GHGs (*2*, *8*). Satellite remote sensing has been used in quantifying the deforestation rate (*11, 13, 14*). Langner *et al.* (*7*) assessed the land cover change and quantified the deforestation rate in Borneo Island between 2002 and 2005 using Moderate Resolution Imaging Spectroradiometer (MODIS). However, this rate may not be representative for the scenario at a state or province level because the spatial resolution of MODIS is coarse.

Sarawak is the largest state that occupies 37.5% of the total land area of Malaysia. One of the driving forces to land use change is the dependency on the state economy of forestry which contributed to 52% of state revenue (*5*). It is currently facing rapid deforestation due to agricultural expansion. Oil palm plantation in Sarawak has increased from 28,500 ha in year 1985 to 744,372 ha in 2008 (*10*). However, recent studies on long-term land cover change and deforestation in Sarawak are lacking. The 30-year archive of Landsat data offers an opportunity of land cover change monitoring in Sarawak using the multi-temporal remote sensing approach. We aim at examining land cover change pattern and deforestation in Sarawak from 1990 to 2009.

II. Method

Sarawak is the largest state of Malaysia which located in the northern part of Borneo. There are 4 major forest types in Sarawak, which comprise intact forest, secondary forest, peat swamp forest and mangrove forest.

In this study, we assessed the deforestation in Sarawak between 1990 and 2009 using multi-temporal Landsat data. A total of nine Landsat scenes were needed to cover the whole Sarawak. For 1990, nine images of Landsat5-TM were downloaded from USGS website. For 2009, three Landsat7-ETM+ images were downloaded for each of the nine scenes in order to correct the missing line errors due to SLC-Off in the ETM+ data. All Landsat images contained 5% to 40% cloud covers. The image of best quality and least cloud cover was placed on top while the remaining two images were used to fill the missing lines. 3x3 minority filtering followed by 5x5 median filtering was applied to eliminate the remaining linear residues after the gap-filling.

The postclassification comparison approach was used to identify the land cover changes. We classified all the preprocessed Landsat images using a supervised classification approach with the maximum likelihood algorithm. Nine land cover classes comprising intact forest, secondary forest, peat swamp forest (PSF), mangrove, rubber, oil palm, grassland, bareland and water were classified. 5x5 majority filtering was applied to reduce the salt and pepper effect in the classified images. Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM) data was used to correct pixels highland areas that were misclassified as PSF. Using the DEM, pixels classified as PSF with elevation higher than 60m were corrected as intact forest. This is reasonable because PSF in Sarawak is distributed in coastal area to about 50m (*15*). For the land cover classification of 1990, we generated the reference data from land use maps with scales of 1:50,000 and 1:25,000 from Department of Survey and Mapping, Malaysia. The groudtruth points was distributed relatively well in Nanga Tamin, Tian, Sibu, Sarieki, Serantok and Kuching areas covered by the maps. The number of points for accuracy assessment of land cover classification of 1990 was 660. However, groundtruth points for land cover classification of 2009 can only rely on field work and quick-looks of high-resolution satellite images in Google Earth. In total, 450 points were collected for assessing the accuracy of land cover classification of 1990. 150 points of ground data that were collected during field work were limited to accessible roads. The remaining points were digitized from the limited quiklooks images in Google Earth.

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III. Results and discussion

The overall accuracy of land cover classification of 1990 was 86%. Despite of the missing line error in the Landsat 7 ETM+ data, the overall accuracy of the land cover classification of 2009 was 80%. This can be considered as satisfactory (*16*). Kappa accuracy, an unbiased measure of accuracy, of land cover classification of 1990 was 0.84 while the accuracy for the 2009 classification was lower, at 0.75.

From Figure 1, with a total area of more than 6 million ha, intact forest was the largest land cover type in 1990. In 2009, intact forest was still the most extensive land cover type but its area has shrunken about 500,000 ha. This is second highest decrease among other forest types. Most of the deforestation in intact forest occurred at inland areas (Figure 2). The intact forest has been cleared mainly for establishing large-scale oil palm plantations.

The forests in Sarawak have been pressured by agricultural development especially large-scale expansion of oil palm plantation. The oil palm plantations have been increasing at about 70% annually from 1990 to 2008 (*10*). Our classifications indicate that annual area increment of oil palm is 77% per year (Figure 3). Oil palm plantation is the fastest growing crop in Sarawak. It has increased almost 15 folds in about two decades. The state government has targeted since 2007 to have 1 million ha of oil palm plantation in year 2010 (*9*). Currently, there is about 1 million ha of oil palm plantation (Figure 1). It is also notable that most of the PSF was replaced by large-scale oil palm plantation. Deforestation of PSF occurred mostly at coastal divisions of Sibu, Mukah, Bintulu, and Miri (Figure 2).

Based on the land cover statistics in Figure 1, PSF in Sarawak was estimated at about 1.05 million ha in 1990. This is greatly reduced compared to 1.6 million in 1980 (*17*). As in 2009, only around 500,000 ha of PSF are left in Sarawak. Anthropogenic activities such as logging, draining, burning and cultivating at PSF areas can cause irreversible environmental impacts (*12*). Moreover, agriculture has serious impact on the hydrology of lowland PSF. As to maintain the appropriate water level for agriculture purposes, peatland is usually drained, thus the hydrological function of PSF is affected (*15*). Oil palm planters favor to have their plantation on peat partly due to the oil palm growing on peat has high fruit production (*12*). Moreover, planting oil palm on flat plain such as lowland peat swamp is easier for management and harvesting.

In 2009, more forest land has changed to bareland compared to 1990 (Figure 1). This indicates that more land clearing activities is being carried out. The bareland is most likely to be converted to large-scale agriculture plantation and usually oil palm in the case of Sarawak (*3, 4, 5*).

Only about 65,000 ha of mangrove are covering Sarawak in 1990. Over the change period, more than 40,000 ha has disappeared (Figure 1). Mangrove has been largely cleared for aquaculture and the timbers are being used as poles for construction. As mangrove is found along the coastal settlements, it is also cleared for urban development such as housing and industrial purposes.

Rubber is the only agricultural crop that decreases significantly within the change period. The first export of rubber from Sarawak commenced in 1910 and increased rapidly to become Sarawak's main agricultural export until the 1960's (*1*). In 1941, there were 239,557 acres rubber plantation and increased to nearly 300,000 acres in 1962 (*1*). Most of the rubber plantations have been planted until 1990 (about 50,000 ha) were abandoned due to discouraging price (Figure 1). By 2009, only less than 35% of the rubber plantation remained (Figure 1). Most of the rubbers have been converted to other agricultural crops especially oil palm.

Annual change rates of all land cover types are shown in Figure 3. All forest types have experienced negative change of deforestation. There has been a trend of increasing agricultural land use except rubber. Among the four forest types, mangrove is the fastest depleting forest type where the deforestation rate is 3.26% per year, followed by PSF at 2.63% per year while the intact forest are depleting at 0.43% per year. Overall, the average deforestation rate in Sarawak is 0.64% per year.

The deforestation rate in Sarawak seemed much lower compared to the rate of Borneo (*7*). We assessed the annual deforestation rate in almost 20 years. Furthermore, the agricultural statistics (*10*) shows that Sarawak's oil palm has been greatly expanding after the millennium and thus forest-to-agricultural land conversion took place most rapidly in recent years.

On the other hand, the carbon rich PSF in Borneo is depleting at 2.24% annually (*7*). Compared this to the deforestation rate of Sarawak's PSF, Sarawak's PSF is depleting faster than the average rate of Borneo. In fact, PSF area shows highest decrease in area compared to other forest type (Figure 1). At the current depleting rate, Sarawak's PSF may be vanished in another two decades.

IV. Conclusion

At a state level, deforestation monitoring necessitates sufficient spatial and temporal resolutions. We used multitemporal Landsat data for producing land cover classifications of 1990 and 2009. The SLC-OFF data can be corrected and provides accurate data for examining land cover change pattern and deforestation in Sarawak. Deforestation in Sarawak has been significant in the last two decades especially intact and peat swamp forests due to forest-to-oil palm conversion. At an annual deforestation rate of 0.64%, Sarawak's forests especially PSF are disappearing rapidly from its landscape.

The authors wish to acknowledge supports from Asia-Pacific Network for Global Change Research (ARCP2009-14NMY-Phua).

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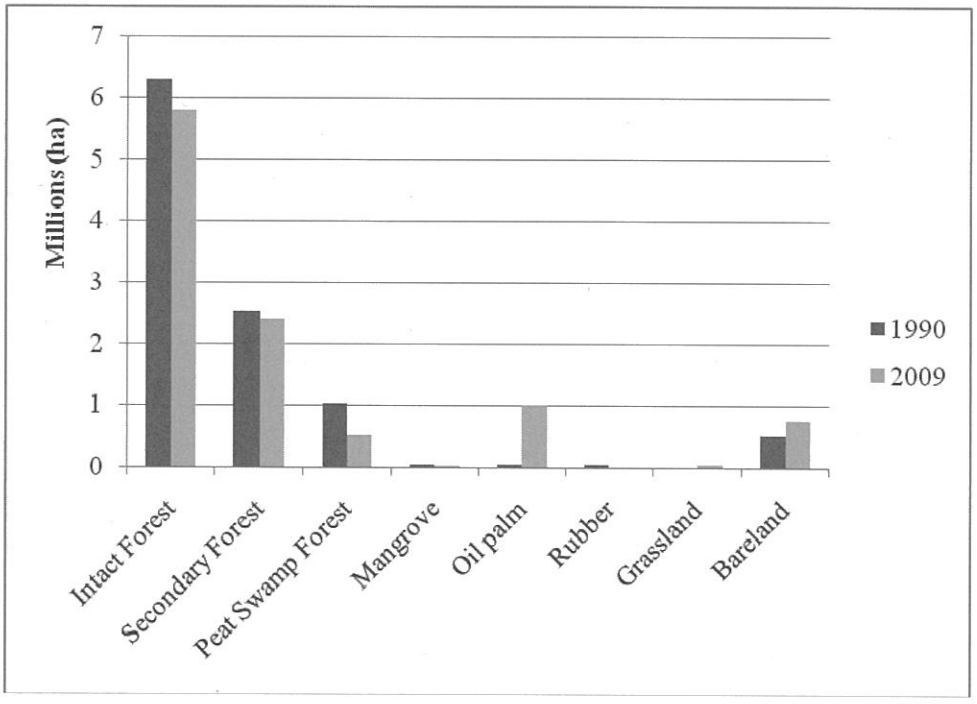

Figure 1. Land cover statistics of Sarawak Forest in 1990 and 2009

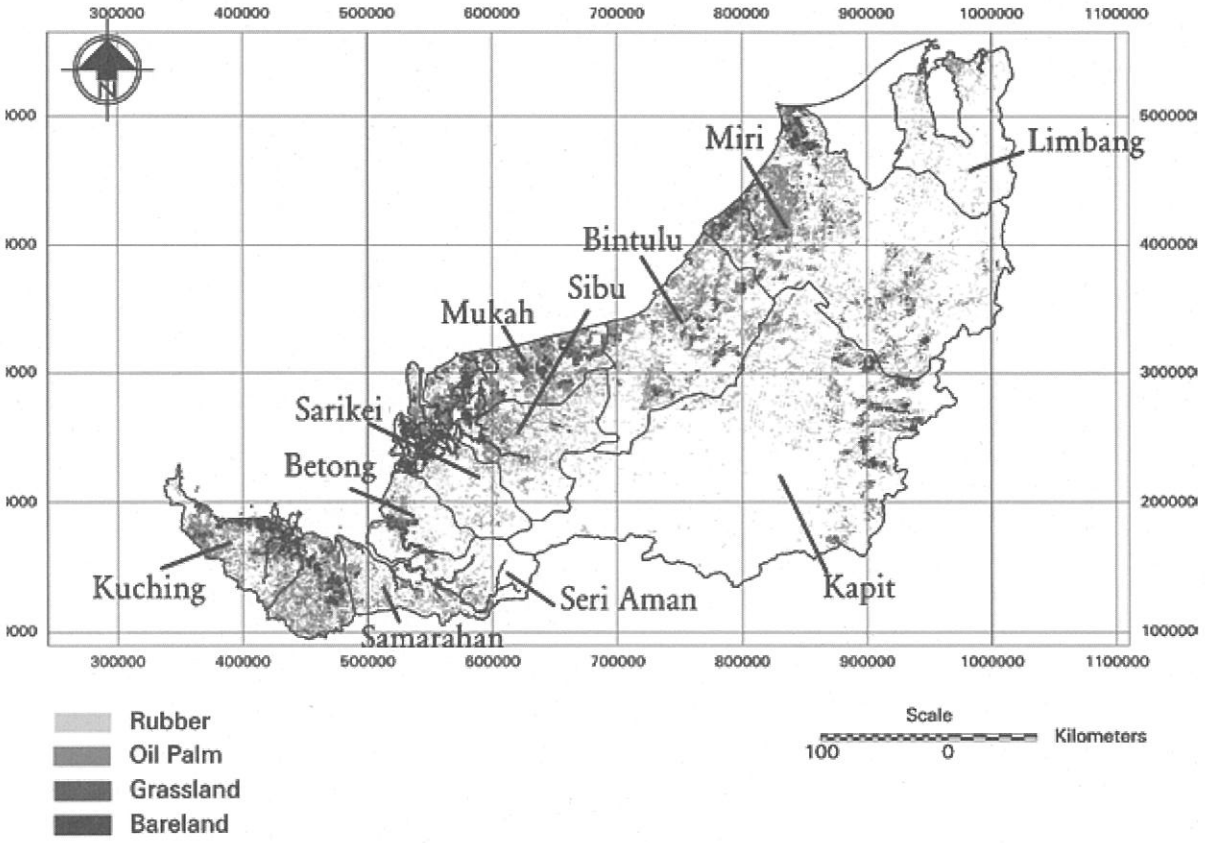

Figure 2. Distribution of deforestation between 1990 and 2009 in Sarawak
(Note: white colors are areas of no deforestation between 1990 and 2009)

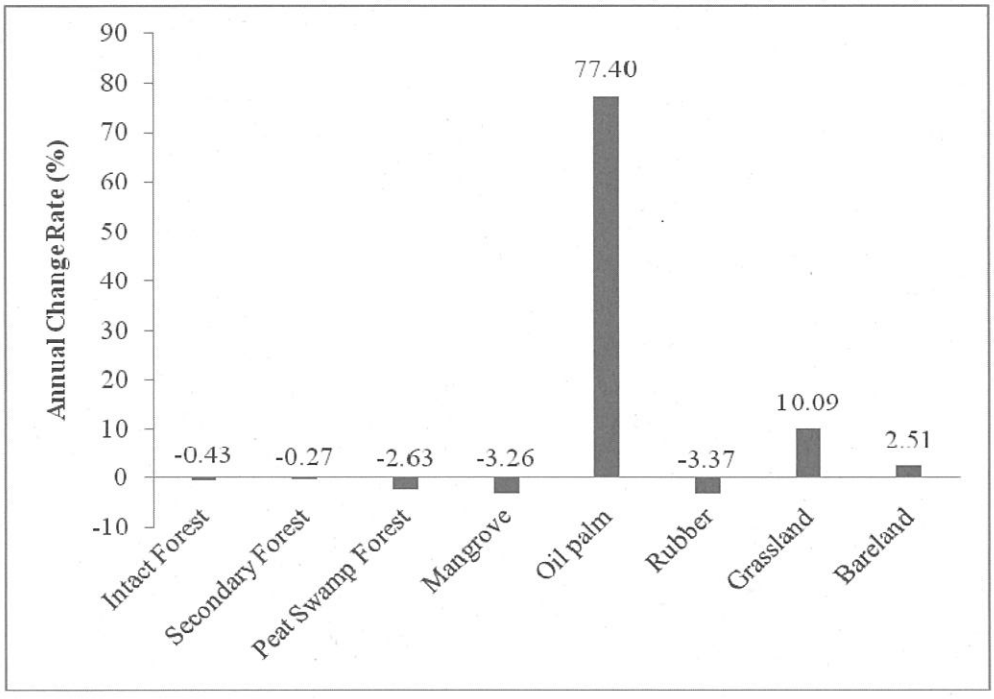

Figure 3. Annual change rate of land cover type