Detection of deforestation and analysis land conversion from high resolution satellite imageries in Bintulu District, Serawak, Malaysia

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Abstract. Primary forests are continuously threatened day to day by urbanisation and the conversion to agricultural plantation such as palm oil production and other land uses being one of the major reasons. In South-East Asia, the widespread of oil palm has boomed over the last two decades, resulting in the downfall of tropical forest land. This change has been particularly prevalent in Borneo with protected lands increasingly developed for palm oil and already deforested lands are being converted into industrial plantations. The primary concerns relating to this pattern of land use change are the short and long-term impacts of logging on our natural environments and ecosystems and how patterns of deforestation are contributing to global environment issues such as climate change. By detecting and mapping logging activities, forestry departments are better able to predict land cover changes in a particular region as a result of development and deforestation. In this study, land cover assessment based on remote sensing techniques was used to analyse changes in the Bintulu district, Borneo especially oil palm growth and its influence on the decline of forest areas between 2016 and 2018. High resolution satellite imageries (3 m spatial resolution) from PlanetScope were used due to the benefits in helping to differentiate several land cover classes over a higher spatial resolution. Results showed that a decline of primary forests in Bintulu is about 26.5% over the past 2 years. With that decline, comes a rise of oil palm growth by 17.6% just within 2 years. An increased in logged areas (36.1%) for conversion to other land-covers with a steady decline of other land cover classes by at least 20% each year was detected. The accuracy of results proved a reasonable accuracy with 90.0% confidence with satellite imagery. Thus, with the result a necessary step can be considered to monitor and prevent deforestation and various encroachment in the forest. With high-resolution satellite data, monitoring at local scales has become possible to resource managers as a way to create timely and reliable assessments.

1. Introduction

Major deforestation in Malaysian Borneo first started in the early 1960’s after rubber tree prices fell and oil palm production was viewed as potentially a major source of income for the economy [1,2]. As the European demand for palm oil gave rose, developing countries began to recognise the potentially economic gains from palm oil cultivation and development [3]. Oil palm cultivation was first introduced in South-East Asia in the late 1910’s from West Africa (species *Elaeis guineensis*) but only expanded in a large scale in the latter part of the twentieth century [4,5]. In particular, oil palm cultivation has grown into a significant industry
in South-East Asia over recent decades driven by increasing use in frying oils and processed food as well as more recent uses in detergents, cosmetics and diesel production across the developed and developing world [6]. Palm oil is often a more favoured oil source because it produces more oil per square km than many other forms of plant oil (including soybean, sunflower and rapeseed) [7]. The oil palm species is known as a perennial monocot plant and lives up to 25 years. One of the main advantages of oil palm is that it is able to bear fruit throughout its lifespan with a short-term reproduction cycle, hence why it is seen as an important economic crop across tropical areas along the equator [8,9].

Over recent years, issues relating to environmental protection have moved towards the forefront of the global scientific agenda. This is evident by the range of academic literature and research which has been conducted to investigate these issues and their implications across a variety of spatial and temporal scales [10]. Several issues will be examined with regards to the growing problem of oil palm plantations, the impacts of this growth and how Geographic Information Systems (GIS) and Remote Sensing technologies are increasingly being utilised to help manage this growth in forested areas of the world [11,12,13].

1.1 Oil palm plantations and deforestation

South-East Asia has faced rapid rates of environmental change over recent decades – particularly as a consequence of deforestation, forest degradation, and plantation development [11,14,15]. An estimated 4.2 million hectares of Malaysian Borneo’s old-growth forest was cleared between 1973 and 2015, while 3.7 million hectares of that total was used for industrial plantations [16]. The abundance of forested land and natural resources has seen rapid agricultural development which is increasingly unregulated and uncontrolled. As a result of this, deforestation and degradation in forest environments is becoming increasingly problematic, due to the limited amount of land available for agricultural production [17].

In the last five years, on the island of Borneo, Malaysia has overtaken Indonesia at the rate of industrial plantation growth (57% vs 16%). In Indonesia, the rate is low due to them growing oil palm seedlings on previously deforested lands [16]. This rate of conversion of secondary forest to oil palm plantation has been increasing out of proportion in the last 10 years as total square km of industrial plantations are overtaking the total area of intact forests in the region [7,16]. As a result, the rapid rates of deforestation which have been seen in many forested regions are increasingly being attributed to the growth of plantation industries over the past four decades [16,11]. It is also a major concern for carbon emissions and biodiversity conservation in Southeast Asia. In Borneo for example, forested areas have acted as a large natural carbon reserve and this region has the largest carbon density of all tropical forests [18,19,4].

If the constant deforestation is not put to an end, the carbon content in our atmosphere would continue to rise breaking the near 420 ppm threshold further increasing the elevated events following climate change [20,6]. Remote sensing and satellite technologies can also help to determine where oil palm plantations can be effectively utilized as a sustainable economic alternative to other plant-based oils if appropriate incentives for expansion outside of forested areas area established [21]. To understand these issues, researchers have suggested that more focus needs to be given to the development of methods of monitoring and analysis of annual land cover changes associated with oil palm expansion [21]. The use of high-resolution imagery has also been used in conjunction with other techniques to further refine land use change in certain areas. Strestasathiern and Rakwatin [8] utilised high resolution satellite images to examine oil palm plantations in Thailand in conjunction with a refined vegetation index based on rank transformation and non-maximal suppression – with the resulting research demonstrating increased oil palm growth in forested areas. Issues relating to the environmental impacts of palm oil cultivation have been noted in a range of literature which has been published over the past decade. One issue has been how this is starting to affect ecologically sensitive regions in many developing economies and how this will ultimately impact environmental protection in these regions [22]. One example of this can be seen in the Malaysian state of
Sarawak, an area which - is rich in plant and animal diversity and has established itself as one of the most globally significant biodiversity hotspots [17]. Despite its significance in relation to its rich biodiversity and importance in scientific global studies on ecology and habitats, habitat destruction and over exploitation of forest resources throughout the region is threatening its long-term ecological stability [23]. Further negative impacts which have been associated with oil palm plantations include habitat fragmentation and the increased emissions of greenhouse gases [5]. In addition, across South-East Asia, peatland areas in particular have been subject to extensive logging activities which have ultimately affected patterns of land-use and ecological sustainability - with these logging activities making vast areas of peat swamp forests highly susceptible to fire [11]. This is particularly problematic in areas such as Borneo where patterns of deforestation and the slow natural regeneration of burnt peat forests results in large areas of degraded peatlands [11].

2. Materials and methods

2.1 Descriptions of study area

The study area is at Bintulu Sarawak (Figure 1) which is located between longitudes (113° 13’ 15.1968” E and 113° 21’ 43.8948” E) and latitudes (3° 13’ 5.1096” N and 3° 33’ 46.0224” N). Total study area size is approximately 670.287 sq. km and is concentrated on a major area designated for plantations. This study area was chosen due to its high rates of deforestation and oil palm growth in the last 5 years. Growth of oil palm trees are uncontrolled, as multiple shareholders have claimed their plot of land in this region - the government, private organizations and non-private small farmers.

![Figure 1](image)

Figure. 1 Study area showing the study area in Bintulu, Sarawak, East Malaysia. Highlighted as a light yellow rectangular (Data processing, 2018)

One of the key issues which is currently being analyzed in Sarawak is the impact of oil palm overexpansion and the sustainability of this growth on patterns of land-use across the state. Indeed, the continued growth of this industry is now threatening to encroach on protected forestry areas across the region. Not too far from the border of Bintulu to the North, of Miri, lies the ‘Heart of Borneo’ (HOB) boundary – an area destined for safekeeping of intact forests for further generations. The government of Malaysia has vowed to keep only 40% of its natural rainforests, of which the majority (35% of natural forests in East Malaysia) lies in the Malaysian Borneo side of the HOB project, which runs through Northern Kalimantan, Indonesia [24]. From literatures, logging roads have been found (Figure 2) to encroach into this protected boundary as early as 2010 even though it is classified as a protected sanctuary by the World Wildlife Fund (WWF)-an agreement signed by the three countries (Brunei, Indonesia and Malaysia) in 2006 to maintain a corridor of tropical rainforest untouched [16,25,26,27,28,29,30,31]
2.2 Data Sources

A 3 m spatial resolution composite image created with PlanetScope Ortho Tile data (https://www.planet.com/products/planet-imagery/) was used in the creation of the three years of land cover mapping. The dates chosen for this study were as followed: 30th May 2016, 23rd Jan 2016 and 14th April 2018. The gap between each date is not fully equal due to imperfect satellite image availability (caused by clouds during monsoon season). PlanetScope imagery was particularly chosen over Landsat 8 ETM due to its high resolution (3 m vs 30 m) to determine land cover with ease. The quality of the image composite was generally very good, however for the 2016 classification, a small portion of the southern Bintulu area had to be merged with a composite image from 2015.

This small portion change is negligible and will not affect the data analysis due to the land being untouched during this time; satellite imagery shows minimal to no changes in the land cover in between the dates. Although, the dates of satellite imagery chosen had minimal cloud cover (< 5-10%), in some areas still covered significant details of the land and supported land use change assessments. In addition, various corrections include radiometric, atmospheric, haze and noise reduction were applied using ENVI 5.3 [32] and ERDAS ER Mapper [33], software; however, these yielded only small success rates as the majority of the haze was cleared but the larger clumps of clouds still remained. To fully remove cloud clumps, a method called pixel mapping was employed [34,35]. Shapefiles were manually created by drawing a polygon around the individual clouds with the use of ArcMap 10.5 [36]. Images from a month before the study dates where the areas were cloud free were downloaded and the ‘extract by mask’ function was utilised in ArcMap. It was important to ensure that those areas that was masked had to be cloud free as well to ensure full visibility of the terrain. The images from a month before were now extracted into those shapefiles before overlaying them together with the latter data. This process was repeated for all years as well. Finally, a new spatial data image was created without cloud cover, though minor levels of haze still remained. The work flow of the proposed method is summarized in Figure 3.

Figure 2. Logging roads in the district of Belaga, Kapit division. Recent satellite imagery shows that forests has been cleared for oil palm plantations [16,27,28]
2.3 Methods

2.3.1 Land cover classification. The supervised classification was performed using the same approach as in [16,11,12]. Land cover classes were identified through visual inspection using varying scales between 1:50,000 and 1:100,000. Occasionally, there was a need to inspect at 1:10,000 due to small but important details (a mixture of oil palm plantations and orchards in the same plot, presumably by small scale farmers). The classification scheme includes five classes (Table 1) with a total mixture of 100 training data points and polygons placed for each class (500 in total).

| No | Land cover classes | Brief description (As categorised by the Sarawak Forestry Department), Refer to Figure. 5. |
|----|---------------------|-----------------------------------------------------------------------------------------------|
| 1  | Water Bodies (A)    | Water features, including sea, rivers, lakes and artificial ponds.                          |
| 2  | Primary Forests (B) | Forests of native tree species, where there are no clear visible indications of human activities and the ecological processes are not significantly disturbed. |
| 3  | Oil Palm Plantation (C) | Planted or recently cleared industrial scale oil palm plantations.                   |
| 4  | Secondary Forest (D) | Agriculture land for orchards as well as vegetative crops.                                |
| 5  | Logged Lands (E)    | Various types of old-growth forests that have become so severely degraded by logging and fire that they no longer resemble the spectral signatures of forests. |
| 6  | Man-made (F)        | Settlement areas, ports, roads, industries.                                                 |

2.3.2 Accuracy assessment of land cover classification. For this accuracy assessment, high resolution (3 m pixel size) satellite images from the PlanetScope service was used. The acquired data was of recent dates and had almost 95% of clear cloud coverage. The accuracy assessment covered the entire study area plot. A total of 500 sample plots were used for the land cover accuracy assessment of which the majority went into
the three main classes and minority into non-forest and water. This process was randomly plotted by hand and then repeated for the other separate years. The approach taken here was the stratified random sampling approach. Due to the usage of high-resolution imagery, the visual interpretation was performed at a 1:5,000 scale. In other areas where only one land cover class dominated, the sample plots were taken as a polygon rather than points.

3. Results and discussion

3.1 Land cover distribution of years 2016, 2017 and 2018

The 2016 land cover distribution in the plantation governed site of Bintulu (Figure. 4; Table 2) reveals that oil palm plantations cover 25.5% (171 Sq. km) of the study area, while the majority of area is covered by primary forests (30.9%). The industrial extensive plant is located on the northern tip of the study area depicted by a white shade. It should be noted that the oil palm processing plant was building structures to enclose oil palm seedlings in a convertible greenhouse enclosure at that time [37].

![Figure. 4 Land cover classification of the study area in 2016](image)

| Land Cover          | 2016          | 2017          | 2018          |
|---------------------|---------------|---------------|---------------|
|                     | Area (Sq. km) | Area (%)      | Area (Sq. km) | Area (%)      | Area (Sq. km) | Area (%)      |
| Water Bodies        | 10.45         | 1.6           | 11.01         | 1.6           | 10.53         | 1.6           |
| Primary Forest      | 207.20        | 30.9          | 156.30        | 23.3          | 152.20        | 22.7          |
| Oil Palm Plantation | 171.09        | 25.5          | 173.50        | 25.9          | 201.26        | 30.0          |
| Secondary Forest    | 164.20        | 24.5          | 226.44        | 33.8          | 200.80        | 30.0          |
| Logged Forest       | 59.60         | 8.9           | 54.24         | 8.1           | 81.10         | 12.1          |
| Man-made            | 57.75         | 8.6           | 48.80         | 7.3           | 24.40         | 3.6           |
| Total               | 670.29        | 100           | 670.29        | 100           | 670.29        | 100           |
From the results above (Table 2), we are able to see a trend in which the reduction in area of man-made and primary forest would result in a rise of oil palm plantations (8.6% to 3.6%, 30.9% to 22.7% and 25.5% to 30.0%) (Summarized in Figure 5 and Figure 6).

| Land Cover         | 16 - 17 % diff | 17 - 18 % diff | 16 - 18 % diff | % growth 16 - 18 |
|--------------------|----------------|----------------|----------------|-----------------|
| Water Bodies       | 0.56           | 0              | -0.48          | 0.08            | 0.76            |
| Primary Forest     | -50.90         | -7.6           | -4.10          | -0.6            | -55.00          | -8.2            | -26.5           |
| Oil Palm Plantation| 2.41           | 0.4            | 27.76          | 4.1             | 30.17           | 4.5             | 17.63           |
| Secondary Forest   | 62.24          | 9.3            | -25.64         | -3.8            | 36.60           | 5.5             | 22.3            |
| Logged Forest      | 5.36           | -0.8           | 26.86          | 4               | 21.50           | 3.2             | 36.1            |
| Man-made           | -8.95          | -1.3           | -24.60         | -3.7            | -33.35          | -5              | -57.7           |

The palm oil mill located in the north corner of the study area (Kuala Suai Palm Oil Mill) is seen to have a reduction area of their processing plant. It is interesting to see that man-made areas had a decrease in area growth between 2017 and 2018 (7.3% to 3.6%). Buildings are thought to be converted into oil palm plantations; however, this research shows that this isn’t the case, due to classification signatures showing oil palm vegetation growth in the area following their construction of greenhouse in 2016 (Figure 10 for oil palm classification in the area in 2018).
Figure. 6. Estimated land cover type areas in years 2016, 2017 and 2018 in Bintulu

Figure. 7 Land cover classification of the study area in 2017

The classification result of 2017 is rather peculiar due to the obvious separation of classes in the middle of the map. It is that an entire stretch of land has been cleared of its orchards and replaced with oil palm plants (Figure. 7). This trend continues over time and further data sets reveal that oil palm plantation will soon cover the entire study area. Logged forests are marked in a red color, and this spatial assessment has revealed that vast areas of land are being cut down for their timber and then burned for an effective land clearing operation. Oil palm plantation growth is at the second highest, behind the conversion of other lands into secondary forests this year. With this trend, it is highly possible to see a fully covered study area with oil
palm, possibly at 80% of area coverage in the next 2 years. Furthermore, it is important to note the rapid growth rates of palm oil plantations in this region – with the research showing a rapid growth of 101% from the previous year.

![Figure 8](image)

*Figure. 8* Land cover classification of the study area in 2018.

It appears that several areas classified as logged forests in the previous year of 2017 (Figure 7) still remain as it is in 2018. The satellite imagery demonstrates areas of degradation where recovery and growth may take considerable time. In these regions, it is evident that there is little vegetation cover using the satellite imagery (Figure 9, Year 2017).

![Figure 9](image)

*Figure. 9* Bands 3, 2, 1 used to visualize the burning of secondary forest and the re-plantation of oil palm trees. Boundary lines are marked before the tearing down of secondary forests to enable an easier allocation of oil palm seedlings per plot after the process.
Since the lower areas of Bintulu are situated in coastal regions with a rich composition of sandy/loamy structures, oil palm cultivation is able to flourish in this region due to the ideal climatic conditions - high temperatures (average 33°C) alongside extremely high precipitation (average 4000 mm) [38]. Although these regions are ideal for oil palm growth, the availability of suitable land for cultivation is becoming scarcer and, as a result, oil palm cultivators are pushing for growth further inland in the mountainous areas of Borneo.

3.2 Accuracy Assessment
The accuracy assessment of the land cover maps reveals an overall accuracy of 90.0%, 94.8% and 85.2% (Table 4, 5, 6). Only ‘Water Bodies’, ‘Man-made’ and ‘Secondary Forest’ achieved high accuracies across the 3 years, averaging at 98.3%, 94.7% and 92.0% respectively. This had meant that those classes were easy to distinguish amongst the rest. Both orchards and oil palm have a similar spectral signature and close shade of green, however the latter was planted with much larger gaps in between trees. In 2018, it was difficult to distinguish both tree classes due to the proximity of growth between the two; some oil palm plantations were grown similarly to secondary forest plots in a rectangular manner rather than the usual hexagon shape.

| Land Cover 2016 | Water Bodies | Primary Forest | Oil Palm | Logged Forest | Man-made | Secondary Forest | Total | User Acc (%) |
|----------------|--------------|----------------|----------|---------------|----------|------------------|-------|--------------|
| Water Bodies   | 97           | 0              | 0        | 0             | 0        | 0                | 97    | 100          |
| Primary Forest | 0            | 84             | 9        | 4             | 0        | 9                | 106   | 79.3         |
| Oil Palm       | 0            | 0              | 85       | 11            | 0        | 1                | 97    | 87.6         |
| Logged Forest  | 3            | 0              | 4        | 85            | 1        | 0                | 93    | 90.4         |
| Man-made       | 0            | 0              | 0        | 99            | 0        | 0                | 99    | 100          |
| Secondary Forest| 0            | 16             | 2        | 0             | 0        | 90               | 108   | 83.3         |
| Total          | 100          | 100            | 100      | 100           | 100      | 100              | 600   | 90.1         |
| Producers Acc (%)| 97           | 84             | 85       | 85            | 99       | 90               | 90    |              |

| Land Cover 2017 | Water Bodies | Primary Forest | Oil Palm | Logged Forest | Man-made | Secondary Forest | Total | User Acc (%) |
|-----------------|--------------|----------------|----------|---------------|----------|------------------|-------|--------------|
| Water Bodies    | 100          | 0              | 0        | 0             | 0        | 0                | 100   | 100          |
| Primary Forest  | 0            | 94             | 12       | 0             | 0        | 0                | 106   | 88.7         |
| Oil Palm        | 0            | 1              | 80       | 0             | 0        | 0                | 81    | 98.8         |
| Logged Forest   | 0            | 0              | 99       | 4             | 0        | 0                | 103   | 96.1         |
| Man-made        | 0            | 3              | 0        | 1             | 96       | 0                | 100   | 96           |
| Secondary Forest| 0            | 2              | 8        | 0             | 0        | 100              | 110   | 90.9         |
| Total           | 100          | 100            | 100      | 100           | 100      | 100              | 600   | 95.1         |
| Producers Acc (%)| 100          | 94             | 80       | 99            | 96       | 100              | 94.8  |              |
Table 6. Confusion matrix of 2018 land cover classification.

| Land Cover 2018 | Water Bodies | Primary Forest | Oil Palm | Logged Forest | Man-made Forest | Secondary Forest | Total | User Acc (%) |
|----------------|--------------|----------------|----------|---------------|-----------------|-----------------|-------|---------------|
| Water Bodies   | 98           | 0              | 0        | 0             | 0               | 0               | 98    | 100           |
| Primary Forest | 0            | 84             | 3        | 2             | 5               | 1               | 95    | 88.4          |
| Oil Palm       | 0            | 6              | 75       | 3             | 0               | 8               | 92    | 81.5          |
| Logged Forest  | 0            | 1              | 1        | 79            | 6               | 4               | 91    | 86.8          |
| Man-made       | 2            | 9              | 1        | 16            | 89              | 1               | 118   | 75.4          |
| Secondary Forest| 0            | 0              | 20       | 0             | 0               | 86              | 106   | 81.1          |
| Total          | 100          | 100            | 100      | 100           | 100              | 100             | 600   | 85.6          |
| Producers Acc (%) | 98           | 84             | 75       | 79            | 89               | 86              | 85.2  |               |

Non-vegetation classes such as man-made and water bodies provided mixed results in terms of accuracy. An expressway as well as a river runs through the study area, which are easily confused if not identified properly, hence, in some occasions the road was classified as water bodies and vice versa. There were several classification errors mainly in ‘Logged Forest’ that had been picked up in the ‘Man-made’ area, when a building had been demolished and its land cleared up, the barren land had been denoted as logged forest instead. The accuracy assessment achieved a 90.0% confidence across the 3 years whilst using the supervised classification method. A higher percentage of confidence is able to be obtained should the classification be processed again using the Object based Image Analysis classification (OBIA) [39,40]. It is proven that the OBIA method is able to distinguish classes of land cover better in higher resolution images, just like the PlanetScope imagery (3 m) used within this project [41,42].

4. Conclusions
This study has accomplished its main aim, being able to map land cover change in Bintulu, Sarawak and achieving a high level of accuracy. Several limitations and drawbacks to monitoring this region as well as similar parts of the world have been highlighted from primary and secondary datasets, due to the unfavorable and unpredictable weather patterns all year round. The results from this study highlight substantial differences in relation to land cover change over different spatial and temporal scales. With regards to the maps generated, it is hoped that policymakers and government bodies for will ultimately utilize these technologies to identify patterns of oil palm expansion and how this has impacted forested areas. Where this is not actioned, illegally planted oil palm plantations will continue to grow in unregulated and uncontrolled ways in many remote parts of the world, even though the land has been designated as protected ground for national parks or aboriginal land rights.

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