IDENTIFICATION AND ASSESSEMENT OF FACTORS AFFECTING FOREST DEPLETION IN BRUNEI DARUSSALAM

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KEY WORDS: Forestry, GIS, Identification, Change Detection, Mapping, Data mining, SAR, DEM/DTM

ABSTRACT:

In this paper we attempt to isolate spatially those factors responsible for forest degradation in Brunei Darussalam. While human activities are one of the deforestation forces, the degradation of forest far from development corridors may implicate extra-human factors in its explanation. In the absence of apparent sources of pollution, mean temperature rise is a good candidate factor as heat stress is capable of reducing photosynthesis, which can manifest itself in a drop in canopy density. Considering that leaves are the most active scattering kernels of electromagnetic waves within tree canopies, especially in the C-band (λ=5.3cm), one can expect that the shuttle radar topography mission elevation data product (SRTM) developed for that band should exhibit a variable bias over forest depending on its density. This relationship, e.g., vegetation density versus elevation bias, is used to measure forest depletion. Based on data from a forest map, SRTM and a reference DTM we calculated a typical bias for seven forest types. A linear relationship was established between elevation bias and forest depletion level. The typical bias means zero depletion, and bias equal to zero means 100% depletion. A map of forest depletion was developed using that relationship. By excluding pixels most likely to be affected by human activities (2.5km buffer around settlements and 0.5km buffer around sealed roads), depletion levels for all remaining pixels were categorized by forest type. It was found that forest plots potentially free of direct human activities are also depleted to various degrees. It would indicate the presence of a forest depleting force, possibly an increase in the mean monthly average temperature, which has been observed in Brunei over the last 30 years.

1. INTRODUCTION

Forest depletion is akin to deforestation, which, broadly speaking, refers to the gradual or rapid process of temporary or permanent removal of trees, resulting in partial or complete eradication of tree cover in a locality (Jones, 2000). It can occur due to natural and human factors. The more important natural causes of deforestation which have been identified include fire from lightning strike, gales which cause trees to be broken or uprooted in the process of windthrow, diseases, native animals (such as elephants in the savannah woodland) and temporary severe weather or drought, which leads to tree death (die-back) (Spurr and Barnes 1980). Human activity is globally recognized as the foremost cause of deforestation, with the agricultural and urban-industrial activity complex being the most important factors. Poverty and other socioeconomic woes which force people in the Third World to exploit or pillage forest resources for purposes of energy and commercial gains are increasingly recognized as important deforestation factors (Odihi 2003, Geist and Lambin 2003, Vance and Iovanna 2006). Especially since the Earth Summit in 1992, deforestation has assumed relatively greater importance due to the growing awareness of the many fundamental roles forests play to keep Planet Earth as the home of humans. Such major causes of deforestation as human activities related to development are observable in Brunei Darussalam (hereafter Brunei). However, what is not so evident is the depletion of forests in areas outside human intervention, in the so-called pristine forest areas. The extent of forest area may not be diminished but its quality certainly is. It is the quest to understand this forest degradation –the nature, extent and factors affecting it- that informs our study and provides the focus of this paper.

The space shuttle topography mission (SRTM) elevation data product was developed for almost the entire globe using C-band interferometry synthetic aperture radar or InSAR technology (Slater et al., 2006). Acquisition of data for the project was performed during an 11-day mission of the space shuttle Endeavour in February 2000. SRTM is available free of charge in the three arc-second (or about 90m) pixels at 1m quantisation level from ftp://e0srp01u.ecs.nasa.gov. This site is recommended because of the optimal resampling procedure (Becek, 2007). The accuracy of the elevation data product (note that it is neither DTM nor DEM) is quoted at about (1σ) ±1.55m plus a term depending on the slope of terrain (Becek, 2008c). One of the features of the SRTM is elevation bias over vegetated areas estimated at about 50-60% of the vegetation height (Carabajal, et al., 2006; Becek, 2008a). It is caused by a complex interaction of electromagnetic waves and leaves as major scattering centres for the C-band InSAR. We will refer to the bias as 'impenetrability'. The level of impenetrability depends also on the horizontal density of vegetation or tree cover (Becek, 2008a). Assuming that a forest of a certain type has a typical or characteristic impenetrability, one can use variation of the impenetrability as a measure of both its horizontal and vertical density. Changes in the forest density can be caused by some more or less apparent forest depleting forces.

2. BACKGROUND

Negative changes in qualitative and/or quantitative characteristics of forests may be termed forest degradation. Forest degradation can be natural or anthropogenic in origin. Common examples of forest degradation include logging and deliberately lit forest fires (arson) to open up land for agriculture or urban expansion. Named anthropogenic factors account for the greatest loss of forest cover in the tropical belt of the globe, notably in Southeast Asia and South America. A lot of work has been done within the remote sensing community to develop techniques for detecting and monitoring those events, which are usually catastrophic and irrevocable in nature. However, there are forest degrading factors which act much more slowly and on much larger scale. Examples of those forest degrading forces include air pollution, change in the ground water level, drought and global warming. The effects on forests can be easily identified on the ground. They include die-backs, smaller annual growth and changes in fauna and flora composition of the forest ecosystem. Those changes are revocable if the destabilising forces are within the stability envelope of the forest ecosystem. For example, a periodic drought causes a certain level of stress on forest vegetation, but such droughts are a part of a natural regime which is tolerated by ecosystems, and vegetation is able to recover quickly from such a stress. Increasingly, however, there are anthropogenic factors previously absent in the environment which are capable of destabilising and permanently damaging a forest ecosystem. One of the factors which can initiate a cycle of vegetation meltdown or vegetation collapse is climatic variability, especially changes in the mean monthly average air temperature. Figure 1 shows the influence of day temperature on tree growth. The steepness of the inverted parabola-like curves indicates the tolerance of each tree species to variations in the temperature.

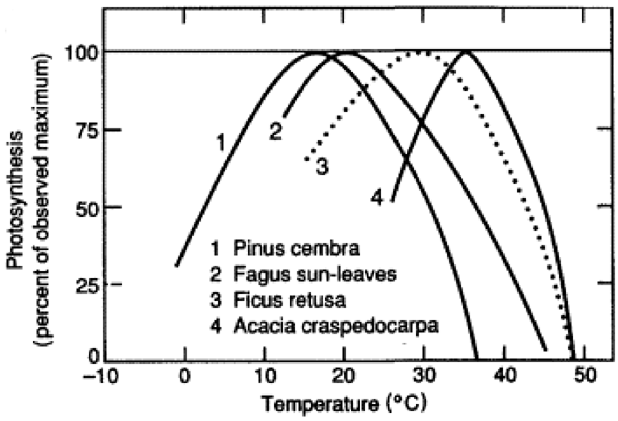

Figure 1. Photosynthesis versus mean temperature. (Botkin, 1993, p. 71)

Some species are naturally tolerant of a wide range of temperatures, for example, trees in the temperate climate zone can sustain a temperature range of, for example, -30ºC – 40ºC (range of 70º). However, in the tropics the natural temperature is between about 24ºC and 34ºC (range of 10º). One degree Celsius temperature increase in the tropics in relative terms is therefore equal to a change of about 10% (1/10º) of the natural thermal regime. In the temperate zone this is equivalent to just 1.4% (1/70º). Therefore, tropical vegetation is exposed to a much higher level of thermal stress than temperate zone forests because of global warming. We assume that one of the effects of thermal stress is the drop in the number of leaves on a tree, which may be measured in terms of leave area index (LAI). The rising average air temperature which is evident in Brunei as well as the rest of the world can be a candidate factor for forest depletion.

Figure 2 shows a definitive trend in the mean monthly average temperature observed during the last 29 years in Brunei. As a result a lower LAI and lower value of vegetation index can be expected. Those changes can be mapped and analysed. Our claim is that where there are no apparent forest-depleting factors such as air pollution, long-lasting drought conditions or drop of the ground water level acting on large areas global warming could be blamed for the forest alteration or depletion. By excluding obvious forest depleting factors highly correlated with human settlements and transportation routes, it was possible to identify forest areas which exhibit signs of change caused most likely by global warming.

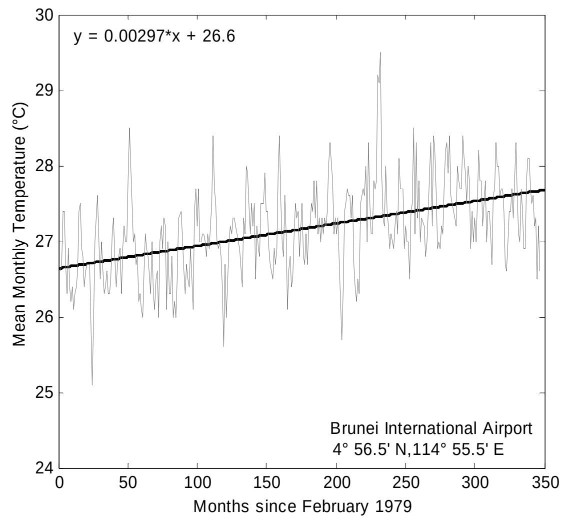

Figure 2. Mean monthly average temperature at Brunei International Airport since 1979 including linear trend line.

3. MATERIAL AND METHODS

3.1 Area of Interest

The test site comprises the territory of Brunei, a country located on the island of Borneo (4.5o N 114.5o E) with an area of about 5,765km2. It is bordered in the north by the South China Sea and elsewhere by the Malaysian state of Sarawak. The climate is described as wet tropical, with the monthly mean temperature around 27.3oC. Annual mean rainfall varies between 2300 mm and over 4000 mm.

Figure 3. Geographical context of the investigated site

The climate of Brunei is influenced by the south-west monsoon (April-August), and north-east monsoon (October-January).

Brunei has mainly low relief, especially in the coastal areas and much of the western part of the country comprising the three districts of Brunei-Muara, Tutong and Kuala Belait. In this part flat alluvial deposits are common. The eastern part of the country is the Temburong District. The south-eastern part of this district comprises the Temburong Mountain range with the highest peak of 1850 m in Bukit Pagon. A substantial area of the lower region of the Belait river system is covered by peat land swamp of which the Badas forest is a part (Jali, 2003). The present relief of the country was formed during the last significant sea level subsidence some 5,000-6,000 years ago. Brunei is drained by four major rivers. They are Sungai Belait (209 km), Sungai Tutong (137 km), Sungai Temburong (98 km) and Sungai Brunei (41 km). The total area of the natural inland waters is less than 0.25% or 15km^2. The eastern part of Brunei – the Temburong District – is detached from the rest of the territory by the Malaysian valley of Sungai Limbang. The estimated forest cover in Brunei in 2005 was 48% and 28 % respectively for primary forest (48%) and secondary forest (FAO, 2005). The forests in Brunei are dominated by the Mixed Dipterocarp Forest (46%) and Peat Swamp Forest 18% (See Table 4). The average forest stand area of a given forest type is 492 ha, varying in range from 5.9ha up to 40,000 ha. Location of the country in the tropical belt, which is characterised by persistent cloud cover (in average 7 octas between 9 and 11am local time), precludes acquisition of passive remote sensing data. According to some estimates the probability of acquiring a satellite image having a given percentage of cloud cover equals the percent of cloud cover. The situation in this regard is also complicated by the haze conditions usually associated with forest fires in Borneo and Sumatra which are frequent in the August/September period. Brunei is relatively free of air pollution apart from episodes of occasional haze during the August/September period. Strong winds causing widespread damage to vegetation are rare and of very limited spatial extent. Also, meteorological observations do not confirm any drought event prevailing over the area which would cause a water stress on the vegetation.

3.2 Data

The following datasets were used in this study:

- Forest map of Brunei Darussalam at 1:50,000 scale. This map was developed by Anderson et al. (1984), using photo interpretation of aerial photographs taken in 1975/76 and 1981/82, together with extensive ground truthing. As a reference year 1980 is assumed. This survey is the most comprehensive to date.
- Forest depletion map of the country. The method of development of the map is presented in the following sections.
- Shuttle radar topography mission (SRTM) band C elevation data product, which was downloaded from the recommended site ftp://e0srp01u.ecs.nasa.gov (Becek, 2007).
- Digital terrain model (DTM) developed from the 1:50,000 topographic map. It was ensured that the resolution and grid posting will match the corresponding parameters of SRTM.

According to Table 1, which contains the basic statistics about forest types in Brunei Darussalam (Anderson et al., 1984), 82% of the country was covered by forests. The remainder constitutes urban, cleared land, cultivation and inland water areas.

Forest Type	Area (ha)	(%) of forest areas
Mangrove	18,487	3.2
Freshwater swamp	13,656	2.3
Peat Swamp	105,994	18.2
Kerangas	9,506	1.6
Mixed Dipterocarp	266,159	45.7
Montane	7,160	1.2
Secondary	56,958	9.8
Total	477,920	82.0
Cleared & cultivation	104,277	18.0
Grand Total	582,197	100.0

Table 4. Extent of forest in Brunei Darussalam in 1980 (Anderson et al., 1984).

3.3 Method

3.3.1 Forest Impenetrability: One of the characteristics of the SRTM elevation data product, which was developed using C-band ((λ = 5.3 cm or f = 5.7 GHz) fixed-baseline radar applying interferometry synthetic aperture radar (InSAR) techniques, is an elevation bias over vegetated areas (Rodriguez et al., 2003). The magnitude of the bias depends on both vertical and horizontal density and distribution of scatterers (usually leaves) within the vegetation cover (Sun et al., 2008). We use the term impenetrability instead of, for example, vegetation-induced elevation bias, to underline the source of elevation error in SRTM. Impenetrability of a natural stand forest (leaves-on state) is about 50-60 % of the mean vegetation height (Carabajal et al., 2006).

3.3.2 Forest Depletion Level: Forest depletion level is defined as a ratio of the mean SRTM impenetrability for a given pixel to a characteristic SRTM impenetrability over an 'unspoiled' or pristine forest plot of a given forest type. This can be expressed in percentage terms using the following formula:

$$d_i = 100 - \frac{\Delta h_i^T}{\Delta h^T} * 100 \tag{1}$$

where: i = the i^{th} pixel,
T = forest type,
Δh_i^T = SRTM impenetrability of the i^{th} pixel,
Δh^T = typical impenetrability of the T forest type

Forest impenetrability can be calculated as the difference of elevation of the SRTM pixel minus reference 'bald-Earth' elevation (Becek, 2008a). The characteristic impenetrability of forest type can be estimated by analysing the behaviour of the second moment of impenetrability of forest plots belonging to a given forest type (Becek, 2008). The second moment or variation of the impenetrability is a measure of the degree of the homogeneity of a given forest plot. A loss of homogeneity simply means that a forest plot has been affected by some sort of depleting forces. For example, Figure 3 shows values of impenetrability and associated standard deviations exhibited by fresh swamp water forest plots. The values of impenetrability were ordered according to the growing values of standard deviation. Starting at Plot 12, the standard deviation of the impenetrability suddenly increases. We claim that all the plots below 13 can be considered as pristine or at least insignificantly influenced by the depleting forces. We used those plots to establish a typical (i.e. representative) SRTM impenetrability for that forest type.

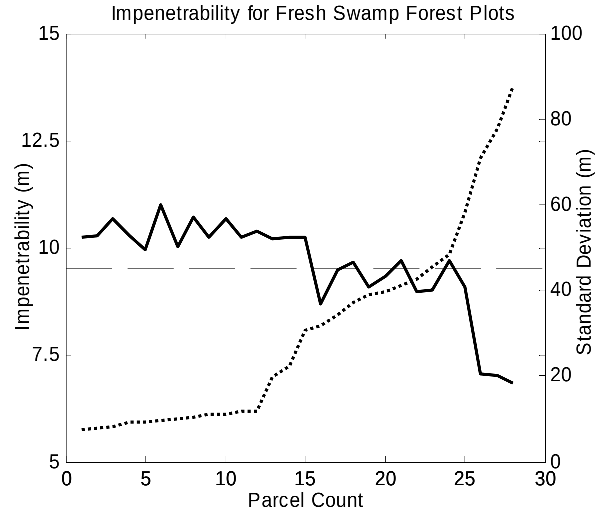

Figure 5. Impenetrability for fresh swamp forest plots. Solid line indicates impenetrability and dotted line is its standard deviation.

In Table 2 are the typical impenetrability levels for forest types in Brunei Darussalam. It has to be noted that those values are dependant on the radar band used and possibly other factors.

Forest Type	Typical Impenetrability (m)
Mangrove	9.0
Freshwater swamp	9.6
Peat Swamp	18.5
Kerangas	7.1
Mixed Dipterocarp	13.3
Secondary	4.2

Table 6. Typical impenetrability values for forest types of Brunei Darussalam.

3.3.3 Effective forest area (EFA): The notion of forest depletion and the suggested way it is measured (Eq. 1) allows assessment of the true extent of forest in a given area, for example a country. We measure the area of forest using the weighted average of forest area. The mean level of depletion of each forest plot is taken as the weighted calculation. Thus, the EFA - ϕ can be calculated from the following formula:

$$\phi = \sum_{i=1}^{N} a_i \frac{(100 - d_i)}{100} \quad (2)$$

where: N = number of forest plots in the are of interest
d_i = average depletion level of i^{th} forest plot varying between 0 and 100%, and
a_i = area of i^{th} forest plot.

EFA can be interpreted as a hypothetical area of pristine forest covering the area of interest.

3.3.4 Procedure: The following data processing steps were carried out:

1. For every pixel the corresponding impenetrability was calculated (SRTM minus reference DTM);
2. For every pixel the depletion level was calculated based on the typical impenetrability (Table 6), the impenetrability and forest type the pixel represented. This is what we call the forest depletion map (FDM);
3. The FDM was divided into the following categories, i.e. a) Human-active areas (2.5km buffer centred on every village and 0.5km buffer around sealed roads), b) Other areas which are outside of the above areas, and not belonging to type 9 areas (Urban, cleared land and cultivations);
4. Average depletion levels were calculated for both categories and grouped by forest type;
5. Using Eq. 2, EFA (see 3.3.3) was also calculated for every forest type.

4. RESULTS

A summary of the calculated forest depletion is presented in Table 7.

Forest Type	Depletion (%)	
	Human-active areas	Other areas
Mangrove	25	17
Freshwater swamp	14	10
Peat Swamp	17	19
Kerangas	24	16
Mixed Dipterocarp	13	15.5
Secondary	26	16

Table 7. Forest depletion in Brunei (1980 – 2000) versus forest type and areas under influence of different depleting forces. The 'human-active' areas refer to forest plots within 2.5 km buffer centred on every village or within 0.5 km buffer from sealed roads. 'Other areas' refer to areas less exposed to human activities.

The depletion levels for the 'other areas' are similar except for the freshwater swamp forest (10%). This can be explained by higher resistance of this type of forest to heat stress. Also, the higher depletion level of 19% for Peat Swamp and 15.5% for Mixed Dipterocarp forests is probably caused by the logging activities which are conducted in these types of forest in Brunei. Note also that logging is usually conducted in areas away from human settlements and sealed roads.

Forest Type	Area (ha)	(%) of forest areas
Mangrove	12,633	2.2
Freshwater swamp	12,001	2.1
Peat Swamp	78,269	13.4
Kerangas	7,453	1.3
Mixed Dipterocarp	221,414	38.0
Montane	7,160	1.2
Secondary	42,374	7.3
Total Forest	381,304	65.5
Cleared & cultivation	200,893	34.5
Grand Total	582,197	100.0

Table 8. Extent of forest in Brunei Darussalam in 2000

Table 8 shows the extent of forest in Brunei Darussalam expressed in terms of the effective forest area. The largest drop in forest area has occurred for Peat Swamp Forest (~5%) and Mixed Dipterocarp Forest (~7.7%) which are exposed to logging activities.

5. CONCLUSIONS

In this paper we investigated changes in forest cover of Brunei over a period of about 20 years (1980 – 2000). Some of the changes have occurred in the vicinity of human settlements and transportation routes and they are principally anthropogenic in origin. By subtracting those obvious and explainable changes from the total changes in the forest cover, we claim that the remainder is caused by regional or global factors, possibly an increase in the mean monthly average temperature. Increased temperature is the likely factor responsible because there has not been any significant change in any other forest depleting forces over the study area like widespread air pollution, wild forest fires or significant illigal logging acctivities, while temperature has changed.

The estimate for EFA is about 375,000 ha, which means that in the year 2000 forest covered about 65% of the area of the country. This means that the average annual forest depletion rate was at the level of about 0.8%/year. Considering the restrictive policy on logging (about 100,000 m^3 per annum can be logged out), this places Brunei in the forefront of sustainable forest management on Borneo. This figure is consistent with the assessment of forest cover of the entire Borneo Island of 57% (2002), and a deforestation rate of about 1.7%/year (2002-2005) (Langer et. al., 2007).

After discounting the human factors affecting deforestation no apparent forest depleting factors exist in the area of interest. However, there might also be other reasons than the temperature rise for the observed depletion. For example, inter-annual, inter-seasonal or even day/night variations of the tree foliage can potentially cause similar effects. The SRTM data over Brunei were collected within a short period of time (16, 17 February 2000 at about 9.39am and 7.39pm on 21 February 2000) and represent a particular narrow view of the area of interest. More and diverse types of observations are necessary in order to definitively confirm the increase of the temperature as the unequivocal cause of the forest depletion in Brunei.

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