THE UNDERLYING CAUSES AND IMPACTS OF FIRES IN SOUTHEAST ASIA

Vegetation Indices and Fires in Sumatra and Kalimantan, Indonesia

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1. Introduction

In 1997 extensive fires burned large areas of Indonesia, in particular Kalimantan, and Sumatra. These fires and the accompanying smoke caused serious air pollution, damage to public health, loss of life, destruction of property and substantial economic losses in many parts of Southeast Asia. Fires also started in East Kalimantan in 1998, which were even more serious than those in August-November 1997.

The 1997/98 fires in Indonesia resulted from a combination of extreme drought and human activity, including traditional slash-and-burn agriculture, large-scale land clearing for industrial plantations and forestry practices that predisposes the forests to fire.

The causes of the fires are poorly understood and this is highlighted by the way that blame has been variously attributed to different groups, such as small farmers, agricultural land conversion schemes, forestry concessions, industrial plantations projects, indigenous peoples and other land users. The following critical questions still remain unanswered: how much land has been burnt; what was the previous land use; when did it burn; who has perpetrated the fires and why; the relative role of large holders and small holders in the fires; and the ecological impact of the fires on different ecosystems. This lack of basic information has contributed to a general sense of confusion regarding the nature of the fires, their causes, impacts and the likely areas to be at risk in the future.

This project “The underlying causes and impacts of fires in Southeast Asia” investigates some of these issues at different levels and with different tools. The fires affected such large areas, that satellite imagery has been used for deriving information on the questions where, when and why fires occurred on a general scale. This study used broad scale NOAA (National Oceanic and Atmospheric Administration) - NDVI (Normalized Difference Vegetation Index) imagery. This report provides the methodology and analysis for the land cover/use distribution over Sumatra and Kalimantan over time using NOAA-AVHRR(Advanced Very High Resolution Radiometer) in broad land categories. Maps, tables and reports of NDVI distribution over time are also provided used to illustrate this.

1.1. NOAA-NDVI Data

The NOAA-NDVI data used in this study was obtained from the NOAA/NASA Pathfinder Land data, distributed via EOSDIS Distributed Active Archive Center (DAAC) at Goddard Space Flight Centre (http://eosdata/gsfc.nasa.gov/data/). The data is produced by the Global Inventory Monitoring and Modeling Studies (GIMMS) as part of the Pathfinder project.
The Pathfinder Land data sets are global land surface data derived from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA meteorological satellites. Because the Pathfinder goal is to develop global coverage, the actual 1 km resolution of

the AVHRR instrument is averaged on-board the satellite to 4 km resolution data to the so-called Global Area Coverage (GAC) data. This data (called level 1-b) is used to compile monthly data sets with 8 km resolution as used in this study. The data used in this study is the Normalized Difference Vegetation Index (NDVI). This index is related to the proportion of photosynthetically absorbed radiation and is calculated from atmospherically corrected reflectance from the visible and near infrared channels. The NDVI is frequently used to monitor vegetation dynamics, and is especially successful in monitoring vegetation health.

The objective of this study is to use the NOAA-AVHRR-NDVI 8 km data-set as a tool for prediction and/or monitoring fire. The NDVI data can detect diminishing vegetation health very well. Diminishing vegetation health can have several causes; drought and land cover changes being the main ones. Drought detection is one the strengths of the NOAA-NDVI 8 km data. Wilting vegetation is very readily detected. Another cause of diminishing vegetation health is land use change from a closed canopy to a more open canopy e.g. on disturbed forest to logged-over forest, or from secondary vegetation to agriculture. However this analysis should than taken place on a very large scale since the spatial resolution study is 64 km^2.

By identifying areas of diminishing vegetation health, vegetation fires, can be predicted while detecting diminishing vegetation health due to land use change (all except the change form forest to logged-over forest require fire) can be used to monitor fires. Therefore NDVI data is studied over large areas and for different land uses and different provinces and islands (Kalimantan and Sumatra) to detect trends and aberrations that could point out drought, changes in or land use.

1.2. Methodology and Data Collection

The dependent data in this analysis is the NOAA-NDVI 8-km resolution data. This data is averaged by year for island wide and provincial wide level analysis. For each level, land use monitoring and prediction for drought and/or fire, is evaluated. The provincial level is analyzed separately from the island wide data. The land use data is used for the independent variable for large holders and a category of 'Other", which is the total land use minus the large-holder land uses. The land use categories areas follows:

Forest logging concessions = HPH
Timber concessions = HTI
Tree crop plantation = plantations
Alang-alang grasslands = grassland
Transmigration areas = trans
Forest = unlogged forest
Small-holder land uses = Other

The HPH, HTI and Kebun data was provided by the Ministry of Forestry and Estate Crops of Indonesia (MOFEC), the alang is from the Soil Science Center (CSAR) and the transmigration data is from the Ministry for Transmigration. For all these land uses, the date for when this land use commenced is unknown. The assumption made is the independent data existed already from 1992.

The land use data per province was analyzed separately to investigate the NDVI pattern in each of the land uses and to monitor drought/fire detection in these land uses. By normalizing the data and obtaining average for each province, the climate factor was largely excluded and changes observed, and obtaining are then due to different reactions to climatic factors or because of land use changes in vegetation.

A comparison of provincial NDVI data for island wide analysis is calculated as:

$P_m - I_m$, where
Pm = Provincial average per month
Im = Island wide average per month

When there is a positive value, the NDVI of the province is higher than the average Kalimantan NDVI, (island) while a negative value means the NDVI is lower in the province than the average island NDVI.

The land use data is normalised by the provincial average, calculated as:

$L_m - P_m$
Lm = Land use average per month
Pm = Province wide average per month

A positive value means the land use has higher than the provincial mean NDVI values while a negative value means it has lower than average NDVI value.

2. Sumatra

2.1. NDVI Analysis

The NDVI does change considerably in different years (Figure 13). Although no diminishing trend in time can be recognized, the dry years 1992 and 1997 are very clear. Since many changes took place during this time period, the monitoring capabilities of NDVI on an island wide scale seems to be limited.

2.1.1. Temporal Analysis

In Figures 1-12, the NDVI data per month for Sumatra Island is shown. It is clear that no diminishing trend can be detected for the island wide data. However, for different years, different months, show lowest vegetation health. In general, the months from April to July show the highest NDVI values. 1994 and 1997 are on exception. In 1994, the NDVI values in the first half of the year reached maximum value, while in July, a sudden drop appears, and then no data are recorded because of sensor failure. 1997 starts also as a normal year, with little more than average NDVI. In August, a drop begins that reach its minimum in October, while quickly recovering in November and reaching one of the highest NDVI of this time series in December. This corresponds to the fire situation in 1997, where in October, a record number of hot-spots were recorded. The sudden high NDVI values recorded after October 1997, could be due to re-sprouting vegetation that is known to give a strong NDVI signal. This information is useful for monitoring activities.

Although the yearly evaluation shown in Figure 13 indicated that 1992 was a year with very low NDVI values, the monthly evaluation shows no extraordinary low values in any of the years. It shows though a lower than average value for almost all months. It appears that 1992 was an overall dry year, without a very sharp decline in vegetation health. 1997 shows the opposite, with September and October showing a very sharp decline in vegetation health.

Figure 14 shows the months of lowest NDVI values per year. In most years the driest month are in the final quarter of the year (1994 disregarded because of sensor failure) except 1995 and 1999 which show the lowest NDVI in January. The overall period with lowest vegetation health in Sumatra is at the end of the year.

2.1.2. Provincial Analysis

The province wide normalized data shows large variation in behavior of land in different provinces. In North Sumatra, Lampung and Bengkulu, different land uses show large deviation from the mean provincial NDVI, while Riau and South Sumatra show almost no deviation from the mean provincial NDVI values. Some land uses in one province can show lower values than the mean NDVI, while in another provinces, it can show higher than the mean NDVI values. It therefore seems that this deviation from the mean does not indicate land use change, but drought. It seems that when the entire area is dry, like in Riau and South Sumatra many fires will occur. If there are large variations in the mean, not all land uses and areas are dry and the fire situation is less.

North Sumatra
To investigate the trends further the provinces were analyzed separately. In North Sumatra there are very strong positive values for Transmigration. The only exception is the last quarter of 1997, in which all land uses show higher than average provincial values. All other land uses seem to be stable before 1996, with or a little less than average NDVI, or more than average (Kebun, HPH) e.g. Other, and Imperata grassland seem to be close to the provincial mean before 1996 and after that year, follows a pattern of regular ups and downs. This same pattern can be seen in all the other land uses. It appears that these land uses are in the later years more susceptible to changes in vegetation health status.

Riau
In Riau, there is very little deviation from the mean NDVI. Riau has recently undergone large land use changes and fires. This suggests that low deviation from the mean for the different land uses is an indication of high land use change. If land use change was going, then vegetation cover should change. The data shows that variation in NDVI is not due to land use change. It seems more likely that drought over the entire province was so severe that all land uses have equal NDVI values. That is a sign of land use change and fire.

Jambi
Jambi, another area with many fires and with large land use changes, shows the same low deviation from the mean. Here all alang grasslands from 1992-1996 show lower than average values. After 1996 they show a higher than average NDVI value. Since the date of conversion to alang-alang is unknown, it appears likely from the data that much of the conversion to alang-alang grasslands occured in 1996. All the other land uses show little variation except in natural forests that show lower than provincial means.

South Sumatra
South Sumatra shows little variation also, with the early years 1992-1994 showing strong variation in NDVI in almost all land uses. It is known that South Sumatra was one of the provinces, which suffered the most from the 1997 fires. The data suggests that low variation in NDVI value indicate a high numbers of fire and land use changes.

Lampung
Lampung shows partly the opposite trend with the early years showing lower variation than the later years. In general this province shows the largest variation in NDVI values together with Bengkulu. In the early years HPH had a higher than average NDVI, while in the later years, NVDI values are higher in the HTI. The change again occurred around 1996.

Bengkulu
Bengkulu shows very high variation from the mean in all land uses. After 1996, there are more land uses changes from above the mean NDVI to lower than the mean NDVI. It appears that after 1996, all land uses show regular oscillations.

The conclusion from all these different deviations from mean, suggest that after 1996, the situation seems to have changed. It is not clear whether the changes are due to climate or because of land use. It is clear that vegetation health in all land uses shows larger variation after 1996. This would suggest that the overall low variation in land use NDVI values is an indication of large land use changes.

In Figures 59 to 66, the mean NDVI per month for the years 1992-1999 are shown for Sumatra. These data show that drought can be easily distinguished by the low NDVI values. In 1997, the months of September and October show very low NDVI values over the entire island. In all years, the lowest NDVI values are in the mountain ranges and eastern swamps. Except during the very severe drought in 1997, high NDVI values for the mountain range are seen mainly in undisturbed forest. There are large areas of forest in that range that had lower than average NDVI values and these areas were less affected by drought than other areas. Here the NDVI is a good indicator of land cover.

2.1.3. Island Wide Analysis

Figure 15 shows the NDVI values for the large land use categories in Sumatra. Undisturbed forests (represented by the class, unlogged forest) have the lowest NDVI values, while the plantation forest (represented by HTI and Kebun) show the highest NDVI values. Furthermore, forest logging concessions have a higher NDVI value than unlogged forests. Conversion from natural forest to logged forest to plantation would increase the NDVI value. So an increase in NDVI could point out a land use change towards monoculture tree crops, such as forest and tree crop plantations interpreted.

Figure 16, could be interpreted as provinces with the highest occurrence of plantations. This would be Riau and Jambi. While Bengkulu and Lampung provinces show very low NDVI values, indicating more unlogged forest. To investigate this further, Figures 17-22 provide for each province the yearly NDVI data. The data shows two northern provinces (North Sumatra and Riau) with exceptionally high NDVI values in 1994. This seems to be a very wet year for these northern provinces. In the same year, Bengkulu in the south-western part of Sumatra shows the lowest NDVI values in this time series. Bengkulu shows the highest NDVI values in 1995. This suggests a large land use change, with the land characterized by re-sprouting/regenerating vegetation. The same logic can be applied to 1997 and 1998. 1997 was exceptionally dry, with low NDVI values followed by high NDVI values in 1998. Here the provinces Riau, Jambi, South Sumatra and West Sumatra show this characteristic. These were also the provinces worst affected by fires in 1997.

By combining low and high NDVI values in subsequent years, not only dryness as well as land use change can be monitored. To investigate this further, the yearly data as used

until know was split into monthly data as shown in Figures 24-30 for each province. Because the data is difficult to interpret subtracting the monthly provincial average from the overall Sumatra average NDVI normalized the data. These data are shown in Figure 31-37.
It is clear that some provinces show large variations, while others are relatively stable. Riau shows in many months a much lower than average NDVI, especially in the years 1994 and 1998. There is a higher than normal NDVI in 1997. Riau was not a very high-density hot-spot area in 1997. Jambi and West Sumatra show lower NDVI values. Although the low values are not as strong as in Riau, they are more the result of a generally lower than average NDVI over the entire time period. Because the data is normalized it appears that these 3 provinces show likely large land use changes have taken place that reduce the vegetation health or show specific droughts. The opposite happens in Lampung and Bengkulu. These 2 provinces show a far larger than average NDVI. Hence an increase in vegetation health is shown compared to the vegetation health in Sumatra. The explanation could be because of more moisture, or because of a land use change that increases the NDVI value. The reason is unclear. The deviation from the provincial mean for each land use type in the province is shown in Figures 45-58.

The Figures 38-44 are on the Sumatra wide NDVI values per land use type. Although these figures are difficult to interpret, there is one clear aberration in plantation (Kebun) NDVI values that do not drop in 1997 as strong as all the other land uses.

3. Conclusion

The analysis of island wide and province data show the following:

3.1. Island Wide

?? At the island wide scale different land uses can be distinguished by NDVI average values. The natural forests have the lowest NDVI values while the plantations show the highest NDVI values. Although per pixel it is very difficult to distinguish the different land uses because of the large variation in NDVI values, on the large average island wide basis, the NDVI can values be used to distinguish different land uses.

?? The island wide NOAA data can not distinguish large general land use changes on a island wide scale. Large land use changes did take place in the study period 1992-1999. However if land use change does influence NDVI values on this scale, then the change from forest to other land covers would show a trend in NDVI over the years. Since the general trend in Sumatra is from logged-over forest to plantations, it can be expected that the NDVI would increase (see above). However, no such trend can be detected.

- NOAA-NDVI 8km data is an unsuitable monitor of land use change and fires on an island wide scale.

?? NDVI values on an island wide scale can detect dry years. The El Nino year, 1997, shows up very clear with a decrease around of around 20% of average NDVI value. By using averaged data for each year the health of the vegetation can be very well distinguished. During dry years there is a clear decrease of NDVI values, and during wet years, an increase in NVDI is recorded.

- NOAA-NDVI 8-km data can be used to detect drought on an island wide basis.

?? December, January and February are the months with the lowest NDVI, and with the lowest vegetation health. Since the health is related to the dryness of the vegetation, these are the months when the vegetation is at its driest. However these are not the months when the most fires occur.

- NOAA-NDVI 8-km data island wide data indicates that dry months do not indicate fire risk for that month.

3.2. Province Wide

?? Yearly provincial averaged NDVI data shows specific patterns of low and high NDVI's in provinces which had the severest drought and highest fire occurrences.

- NOAA-NDVI 8 km data provincial wide can distinguish dry years and is therefore possible to monitor land use change.

?? Monthly provincial NOAA-NDVI 8 km data will show provinces that suffer more than average from drought and/or land use change as having few variation between the island wide and provincial wide mean.

- Provincial NOAA-NDVI 8 km data will detect provinces suffering more than average from fires and/or drought.

?? The vulnerability of land uses to fire seems to increase which coincides with high a NVDI value. Before 1996, the NDVI values were stable for many land use types. After 1996, there is much more variation in NDVI values. Since it shows up on almost all provinces, and land uses, it seems likely that this is a climatic phenomena.

- NOAA-NDVI 8 km data can detect a change in climatic circumstances over time.

?? NOAA-NDVI 8-km data presented as a map, can be used to monitor the ongoing drought period and areas affected. Using a time series, with dry and wet years, pixels can be used for detecting forest condition on a pixel basis.

- NOAA-NDVI 8 km data can be used for mapping drought and by using a time series can detect general land covers.

4. Kalimantan

4.1. NDVI Analysis

In Figures 67-78, the NDVI values per month and over the time period 1992-1999 are shown. The highest NDVI values in this time period are in the months of May, June and July. The lowest are the months of September, October and February. The months with the lowest NDVI values are very different in different years. In February 1997, NDVI values are lower, with this changing to March and April in 1998. In Figure 80, the month of lowest NDVI value, however is always in the first quarter of the year, except for 1997, when September had the lowest NDVI. The data suggests that the lowest vegetation health is not uniform throughout Kalimantan, although in general the lowest NDVI values are in the first 3 months of the year. There are a number of aberrations, possibly caused by climatic differences.

4.1.1. Island Wide Analysis

The island wide NDVI values per year (Figure 79) show neither a clear year with lower NDVI values. However, there is a clear year with very high NDVI values, namely 1994. Figures 67-78, show August 1997 until May 1998 show the lowest NDVI values separated by January and February with normal NDVI values. These values are the result of the severe drought associated with the El Nino phenomena. From these figures, it is clear that the drought in Kalimantan spread out over 2 years, with a short interval with normal climate conditions. Therefore in the yearly NDVI data the low NDVI years are not very well detected, since the low values are spread over two years.

In Figure 81, the island wide mean NDVI values are shown. The mean values differ strongly from the values found for Sumatra. Here, as in Sumatra, the plantations have very high NDVI but also the logged-over forest (HPH) and the natural forest (forest) show very high NDVI values. The natural forest and logged-over forest here are probably from a different (healthier) type than the natural forests and logged-over forests in Sumatra. Also the small-holder land use (Other) has high NDVI values in contrast with the Sumatran situation. This may be due to the small-holder land uses being different in the different provinces. Differences in island wide NDVI values can be found for the different land uses. However findings from one island can not be used to compare directly with another island.

4.1.2. Provincial Analysis

In Figure 82, the mean NDVI values per province are shown. Here there are large differences. East Kalimantan has the highest values, while South Kalimantan has the lowest values. This could have two explanations. Firstly, East Kalimantan is known for its large tracts of forests and logging concessions which give high NDVI values, while South Kalimantan has large swamp forests (and Transmigration areas) that might give lower NDVI values. The second explanation could be based on the assumption that there are more favorable climatic conditions for forest vegetation in East Kalimantan. NDVI however, can distinguish vegetation areas with different health status.

The provinces we analyzed separately as shown in Figures 83-86. There is a spread of lowest NDVI values. East Kalimantan does not show a distinct low NDVI year, apart from a distinct high NDVI year in 1994. Central Kalimantan shows 1997 was an exceptional year. South Kalimantan shows very low NDVI values in 1992 and 1997, the same as West Kalimantan, although in this last province, the values are not as low as the ones from South Kalimantan. None of the provinces show a clear upward, or downward trend in values. Large land uses could not be determined on the provincial wide NDVI values. However what is obvious, are climatic differences in and between provinces. The health values (minimum and maximum) are reached at different years in different provinces, so that when one province shows a serious decline in vegetation health, another province might not experience any problem. NDVI can detect different climatic sub regions on a provincial base. NDVI cannot distinguish land use changes at this scale.

In Figures 87-90, the NDVI values per month for the different provinces are shown. In figures 91-94, the deviation from average island NDVI values are shown. The provinces show very different patterns. East Kalimantan shows a large positive deviation from the mean while in South Kalimantan (except 4 months) shows a negative deviation from the mean. Central Kalimantan shows little deviation from the mean apart from strong negative values in 1997. South Kalimantan shows strong negative values in October 1993 and in 1997 in the month of January and October. The different provinces have very different NDVI patterns and values. The vegetation health is also very different. This can be due to strong provincial climatic differences or different vegetation dominating in the different provinces. NDVI does detect difference in vegetation health per province.

East Kalimantan experienced many fires in the first quarter of 1998. However, the provincial NDVI values show positive values during this time. However, NDVI values are negative for the first time in this entire time series from April to June 1998. From this, it is clear that the reduction is not because of climatic conditions (drought appeared early 1998), but a detection of the impact of fires on the vegetation, causing a change. NDVI can detect and monitor land use change at the provincial scale.

However this monitoring capability of vegetation change can not be detected in the other provinces. In Central Kalimantan many fires were recorded from August until November 1997 and September 1992, August 1993. The dates show low NDVI values, indicating climatic differences are indeed detected by the NDVI data but no decline in vegetation. From the data, it is clear that South Kalimantan has very different vegetation health status than the average island wide data indicates.

In figures 95-101, the monthly NDVI over the study period for each land use is shown. In Figures 102-109 provides the deviation value for each land use type for the mean provincial NDVI values.

South Kalimantan shows by far the strongest variation in NDVI values, while East Kalimantan shows a decrease in NDVI values in August/September 1997 and a very strong decrease in March and April 1998. This is particularly true in plantations. This coincides with the drought and fire situation that occurred in March/April 1998.

From the records, it is known that many forested areas and undisturbed natural forest burned in that time period. This can not be seen in this data. Natural forests and logged-over forest do not show any variation, the strong decline is only to be seen in plantations. This could be due to areas mapped for plantation development were burned and so the land use changes from forest to bare soil (which would give a decrease in NDVI values). NDVI and provincial land use data can not detect a decline in vegetation health per land use type.

Land use types in Central Kalimantan show less strong deviation from the mean provincial NDVI values. In East Kalimantan, the logged-over forest did not show any variation. In this some province, the logging concessions show the strongest values and over the entire time period, only negative values very recorded. The logged-over forest is less healthy in East Kalimantan. NDVI provincial land use data can detect differences in vegetation health of specific land uses on a provincial basis.

Undisturbed natural forest has its highest NDVI values in this time series in September 1997, while this month also shows the highest number of hot-spots. Apparently the hot-spots did not occur in large numbers in the undisturbed natural forests in this province. NDVI data can be used to detect affected areas undergoing land use change.

South Kalimantan shows very strong deviation from the provincial mean NDVI values. The deviation is mostly positive. There were many hot-spots detected in September 1993 and September 1997. The Other land use category shows the lowest NDVI values in these months. NDVI again detects decline in vegetation health. There is a big difference in behavior of the different land uses. While transmigration areas had higher values than the mean values, small-holder (Other) and Alang grasslands have below mean values. In the forested data, the timber plantation shows very high lows and highs, while logging concessions and undisturbed natural forests are always slightly positive. NDVI can separate the different land use type in this province by their time series pattern.

West Kalimantan does show very low variation in the non-forested land uses. However this province has known large land use changes. This might indicate a similar situation to that the case in Sumatra where low NDVI variation of provincial land use types indicate high land use change.

The plantations (Kebun) had very strong negative NDVI values in December 1993, August 1994 and October 1997. At none of these times are many hot-spots recorded. Forests show very high NDVI values in September 1997. NDVI values in this province do not show detection of drought, or fires very well.

The NDVI maps of Kalimantan are shown in Figures 110-117. The decline of vegetation health in different years are well detected. It is clear that some provinces suffer in different years in different seasons. Whilst West and Central Kalimantan had a strong decline in vegetation health in mid 1997, East Kalimantan had a strong decline in early 1998. It is also clear that from these maps, no land use change can be detected.

In Figure 118, the area with the lowest NDVI values of each month are mapped. Almost all the low NDVI pixels are coastal pixels, which is probably because one pixel (which is 8 by 8 km) includes part of the water value from the sea (these are very low NDVI values). One exception is the area in the southern part of West Kalimantan that shows an inland area. This detection of a strong decline in vegetation health is due to land use change caused by fire.

4.2. Conclusions

?? At the island wide scale, different land uses can be distinguished by NDVI average values. Although on one pixel, it is very difficult to distinguish the different land uses because of the large variation in NDVI values, on a large average island wide basis, the NDVI can distinguish different land uses. However, the average NDVI values of the large land use types do differ per island.

- NOAA-NDVI 8-km data can separate different land use types only per island and not over the entire country.

?? The island wide NOAA data can not distinguish large general land use changes on a island wide scale. Large land use changes did take place in the study period 1992-1999. However, the different island wide average land use type NDVI values are very similar and very high. It is so different than in the Sumatra case, where the change of land use could be detected by sharp increase or decrease of NDVI values.

- NOAA-NDVI 8-km data cannot be used to monitor land use change and fires on an island wide scale

?? There is a strong monthly variation in the NDVI values for the island wide data. It appears that the lowest vegetation health is not uniform throughout Kalimantan, although in general, the lowest NDVI values are in the first 3 months of the year.

- NOAA-NDVI 8-km data on an island wide basis can detect the month with lowest vegetation health caused by climatic changes.

?? Because the dry season in Kalimantan falls at the beginning and end of one year and the beginning of the next year, the yearly NDVI does not give a good representation of dry and wet years. However, the wet years are very well detected.

- NOAA-NDVI 8-km data on a yearly basis can detect wet years but not extreme dry years.

?? The provincial NDVI data varies from the overall island NDVI data in different areas. The minimum and maximum NDVI values are reached in different years and different months. The hot-spot and low NDVI values correlate well, thus showing that NDVI detects declining vegetation health. However in some provinces this correlation does not exist.

- NOAA-NDVI 8-km data can distinguish on a monthly basis, the provinces with different health status of the vegetation health status, but not for all situations

?? In East Kalimantan land use change can be detected by NDVI. However this is not usual. NDVI always detect declining vegetation health on a provincial scale.

- NOAA-NDVI 8-km data can detect and monitor the presence of land use change in a province as compared to island wide data.

?? Specific land use types known to have burned can not be recognized by the province wide NDVI data. Although the provincial wide data can show an overall decline, it does not show a decline in the specific land use type.

- NOAA-NDVI 8-km data on a land use basis per province, does not detect declining vegetation health for a specific land use type.

?? In a province, the temporal NDVI pattern is rather different for different land use types. Some land use types are always above the mean and rather low, others show great contrast between months and years in their deviation from the mean NDVI.

- NOAA-NDVI 8-km data can detect different land uses by using the temporal NDVI pattern.

?? Some provinces show lower variation in the NDVI values for the different land use types than in other provinces. The variation in NDVI can not be related to field knowledge of high land use change. The opposite seems to be more likely, i.e. low variation means high land use change.

- Low NOAA-NDVI 8-km data variation of provincial land use types indicate high change.

?? By using maps of NDVI values, the declining vegetation health can be very well detected. However no prediction is possible. When there are many hot-spots the NDVI is also very low. However this does not always apply.

- NOAA-NDVI 8-km data maps do detect declining vegetation health.

?? By using lowest monthly values, some areas do stand out and show very low NDVI values. These areas are rather small, and not due to a climatic condition. It is likely that a large land use change occurred at that location.

- NOAA-NDVI 8-km data maps using lowest monthly values, can possibly detect land use change.

5. Overall Conclusions

This study carried out research on the possibilities of land use change and to detect fires and drought by using NOAA-NDVI 8-km data as well as the results of the analysis. The advantage of this data is that it is world wide and available every 10 days.

These separate issues have been analyzed in time and in space. In time the spatial land use changes have been eliminated except when occurring on very large scales. From these data, conclusions can be reached on the detection of declining health of vegetation between years, between provinces and between months.

In space, influence of climate was eliminated by normalizing the land use data per province. Both analyses were carried out on a island wide scale and on a provincial scale. The nature of this 64 km2 resolution data does not allow comparison between dates per pixel. To obtain meaningful data, a large number of pixels should be averaged. Therefore, general land use maps showing the location of large land use types have been used.

It is clear that NOAA-NDVI 8-km can monitor very well declining vegetation health. Different dry years and months can be very well monitored. However, no trends which would enable drought prediction occurrence can be detected. The drought can be detected on an island wide scale. However land use changes on this scale cannot be monitored, so detection of fire on an island wide scale is not possible.

On a provincial basis, the NOAA-NDVI 8-km data does correlate with the high frequency of hot-spot occurrences. However this is not possible in every province. The data has to be interpreted with care and a low NDVI value does not automatically correspond to high fire occurrence.

NOAA-NDVI 8-km suggest high variation in NDVI values per land use type in each province does mean a stable system with few changes, so few fires. However, in Sumatra the data suggests that the variation of land use NDVI is increasing. So the area is stabilizing with less fires. This can not be detected in the data for Kalimantan. The longer time since development began in Sumatra island could be responsible for this. In Sumatra, a higher percentage of land has already changed from forest to other land uses and so the highest land use changes have already occurred. In Kalimantan the development stage (land use change) is less advanced with a lower percentage of land converted to plantation and other uses. The high changes in land use with many fires, so this might be detectable by low a variation in NDVI values.