Local surface temperature change due to expansion of oil palm plantation in Indonesia

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Abstract A high world demand for crude palm oil has caused a reduction in the area of Indonesia's tropical rainforests over the past several decades. Our hypothesis is that the expansion of the area devoted to oil palm plantations at the expense of primary and secondary tropical rainforests will increase the local surface temperature. While similar studies of other crops have been reported, this is the first time this particular hypothesis has been investigated and reported using the remote sensing methods described in this paper. In this study, we used remotely sensed data to quantify land use changes from tropical rainforests to oil palm plantations, calculated the surface temperature from thermal infrared data supplied by band 6 of the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+), examined the correlations of surface temperature to foliage cover, and conducted field work to verify the results obtained using the remotely sensed data. For this study, we used a new spectral index, Principal Polar Spectral Greenness (PPSG), that is potentially more sensitive than other index to small changes in foliage cover at high cover levels. The outcome of satellite image processing is only 0.2 °C different from direct temperature measurement in the field. Our study indicated that less density of the closed-canopy composition of oil palm trees resulted in higher surface temperature.

1 Introduction

Expansion of the area devoted to oil palm plantation has contributed to total forest loss in Indonesia (Koh et al. 2011). The current total plantation areas are approximately 8 million ha and are projected to reach 13 million ha by 2020 (National Statistical Bureau 2011). Forest loss to palm oil plantation accounts for approximately 3.9 % to 10.5 % of total deforestation in Indonesia (Susanti and Burgers p 2012). At least 56 % of the expansion of the oil palm plantation area in Indonesia is attributable to the conversion of primary, secondary, or

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plantation forests (Koh and Wilcove 2008). Between the introduction of oil palm plantation in Indonesia and 2011, the area devoted to oil palm plantation has grown to 8.77 million hectares (National Statistical Bureau 2011).

Tropical rainforests was the primary land source in the early stages of oil palm plantations development in Riau Province (Ramdani and Hino 2013). A tropical area is a suitable location for an oil palm plantation because tropical climate conditions are suitable for production of high-quality fresh oil palm fruit bunches (Fitzherbert et al. 2008; Corley and Tinker 2003). Land use/land cover changes associated with local climate change effects have a much more significant influence than large-scale warming associated with increased global carbon dioxide emissions (Georgescu et al. 2011).

Some researchers have analysed the correlation between agricultural expansion and local climate changes. Loarie et al. (2011) evaluated the correlation between sugarcane expansion and local climate change in Brazil. They found that the conversion of natural vegetation to a crop/pasture mosaic warms the air temperature over a *cerrado* by an average of 1.55 (1.45–1.65) °C, but subsequent conversion of that mosaic to sugar cane cools the region by an average of 0.93 (0.78–1.07) °C, resulting in a mean net increase of 0.6 °C. Ho et al. (2012) detected differences between land surface temperature and vegetation cover in northern China using satellite images. They found that double-cropping significantly increased temperatures in June compared with single-cropping. Park et al. (2012) examined vegetation feedback in the United States (US). They found that increases in the vegetation greenness level increase moisture transfer from the soil to the atmosphere by the evapotranspiration process and create lower land surface temperatures in subhumid regions, such as the southern, midwestern and northwestern US. Luskin and Potts (2011) examined how habitat characteristics changed when forests were converted to oil palm plantations. They monitored the changes in microclimate conditions and vegetation structures of oil palm plantations and found that oil palm plantations are hotter and drier than forests. Oil palm plantations is well known to have higher local temperatures, as well as lower humidity (Luskin and Potts 2011; Foster et al. 2011)

Until recently, there have been very few scientific studies on the effect of oil palm expansion on surface temperature changes over large areas. Land-based methods for direct surface temperature measurements might suffice for small area temperature studies. However, for large area studies it is important to develop a suitably sensitive remote sensing method for determining surface temperatures.

The objective of this study is to apply remote sensing technology using the newly proposed PPSG (Principle Polar Spectral Greenness) index, which is sensitive to small changes in foliage cover at high levels of cover to investigate the correlation between land use/land cover changes and land surface temperature and the PPSG index. Observed case in this study is the expansion of oil palm plantation on local surface temperature. We assessed local surface temperature changes by spatial investigation, using satellite images obtained over two areas, Ukui I Village and Ukui II Village in Riau Province in Indonesia (Fig. 1). Surface temperatures in this study refer to the surface temperature of the land use/land cover canopy in the study area.

2 Study area

Riau Province in Indonesia produces more fresh fruit bunches than any other province in Indonesia (Ramdani 2011). Its economy is largely a resource-based one that includes planta-tion of oil palm, rubber and other forest resources. Ramdani and Hino (2013) carried out a study to monitor land use changes and tropical rainforest conversion in Indonesia. Their study

Fig. 1 Study Area; 1. Ukui I Village; 2. Ukui II Village. Riau Province, Indonesia. Source: Background map is from Google Map; Provincial administration boundary is from Indonesian Geospatial Information Agency; Villages' coordinates derived from field work

revealed that the deforestation rate increased substantially in the 1990s and 2000s and that oil palm plantation development experienced a boom in the period between 2002 and 2010. This rapid expansion of oil palm plantation development in Indonesia was mainly driven by Indonesia's biofuel policy, the increasing price of palm oil in the global market, and other related land use policies (Ramdani and Hino 2012).

The local climate in the study area is a tropical climate influenced by monsoons, with rainfall amounts ranging from 2,200 to 3,000 mm per year. The range of temperatures is 22 °C–32 °C. The wet season is from September to January, and the dry season is from May to August. February to April is a transitional season in the study area.

We present information about two villages to describe the analysis of the data (Fig. 1) from 1988 to 2002. These two particular villages were chosen for this study because they were the destination of the transmigration program in 1988 and because the oil palm plantations were the main income sources for the transmigrants. During transmigration program the Central Government converted tropical rainforests on a large scale, the Central Government made 591,000 ha of forest available for conversion, 110,380 ha for plantation and 124,980 ha for transmigrant resettlements respectively. The expansion of oil palm plantations occurred in primary and secondary tropical forests, which have mineral soils in the early stages (Ramdani and Hino 2013). The land cover had completely differed during the 14-year assessment period. The geomorphology was relatively flat and the chosen Landsat spectral images had clear sky conditions, which made it possible to assess changes in land surface temperature and foliage cover.

3 Data and methods

The oil palm plantation analysis conducted in this study was derived from two satellite images: Landsat 5 TM (1988) and Landsat 7 ETM + (2002 and 2012), obtained from http://glovis.usgs.

gov/. We chose the year 1988 because this was the first year that oil palm plantations were introduced to transmigrants and because the primary tropical forest could still be found in this year. The destination location of transmigration in the study area was Pelalawan Regency, Riau Province, Indonesia. The purpose of the transmigration programme was to overcoming over population in Java island, as well as to increased the social-economy condition of transmigrant in the destination location (Whitten 1987). The years 2002 and 2012 were chosen to evaluate the development of oil palm plantations in the study area after 14 years and 24 years, respectively. Furthermore, the cloud cover of the images for 2002 and 2012 were less than 5 %.

The Enhanced Thematic Mapper Plus (ETM+) has a spatial resolution of 30 m for blue, green, red, visible, near IR, and mid-IR and 60 m for thermal IR. The resolution of the Thematic Mapper (TM) is the same for the blue to mid-IR bands, but for thermal IR, its resolution is 120 m. Table 1 shown datasets used in the study

The main software package used to analyse the data was IDRISI. This software has powerful image processing operation capabilities. With the image calculator module, we were able to apply map algebra and a logic modeller in this study. The flowchart of the data processing is summarised in Fig. 2, and the explanation of each step is available in the Electronic Supplementary Material.

Pre-processing (e.g. radiometric and atmospheric corrections) which are necessary for analysis of energy fluxes and land use/land cover parameters was conducted. The Landsat TM and ETM+ sensors store information as digital numbers (DNs). The DNs are then converted to radiance data, and then the radiance data are converted to ToA reflectance. Radiance data are also used to derive surface temperature value. Meanwhile the ToA reflectance is used for calculation of PPS greenness index scores using the principal reference index coefficients per the method proposed by Moffiet et al. (2010).

The first three principal reference index scores are shown below (Moffiet et.al 2010):

$$PR1 = 0.1063 * \rho1 + 0.0068 * \rho2 - 0.2589 * \rho3 + 0.2356 * \rho4 + 0.6435 * \rho5 + 0.6723 * \rho7 \quad (1)$$

$$PR2 = 0.1580 * \rho1 + 0.0587 * \rho2 - 0.3792 * \rho3 + 0.2747 * \rho4 + 0.4769 * \rho5 - 0.7245 * \rho7 \quad (2)$$

$$PR3 = 0.2609 * \rho1 + 0.0404 * \rho2 - 0.5765 * \rho3 + 0.4676 * \rho4 - 0.5985 * \rho5 + 0.1453 * \rho7 \quad (3)$$

where:

$\rho1$–5 & $\rho7$ = top-of-atmosphere (ToA) reflectance for the Landsat TM and ETM+ bands 1–5 & 7 (from 2)

Table 1 The satellite images used in this study

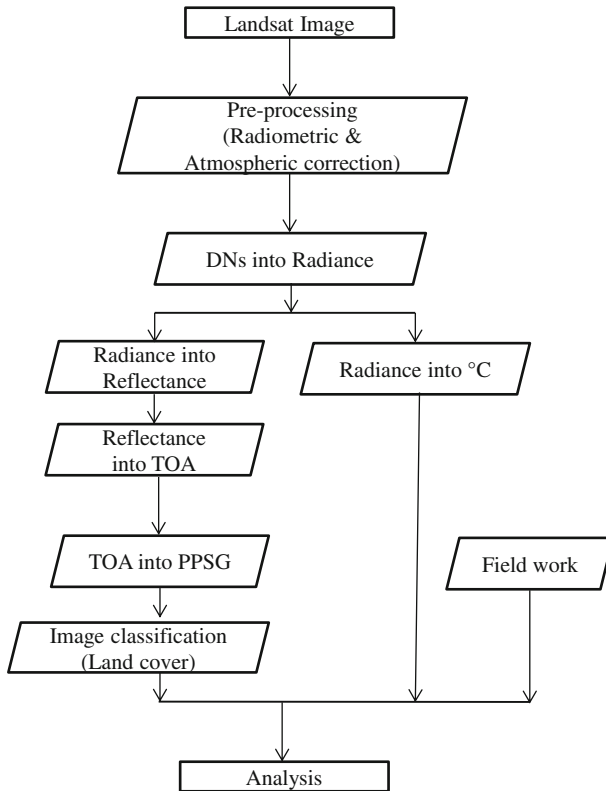| Satellite image	Index	Acquisition	Band used	Wavelengths
Landsat 5 TM	P126/R60	July 31st, 1988	Blue, Green, Red, NIR, SWIR, Thermal IR	0.45–2.35 10.40–12.50
Landsat 7 ETM+	P126/R60	August 15th, 2002	Blue, Green, Red, NIR, SWIR, Thermal IR	0.45–2.35 10.40–12.50
Landsat 7 ETM+	P126/R60	August 10th, 2012	Blue, Green, Red, NIR, SWIR, Thermal IR	0.45–2.35 10.40–12.50

Fig. 2 Flowchart of the data processing. Abbreviations: DNs - Digital Numbers; TOA - Top of Atmospheric; PPSG - Principle Polar Spectral Greenness

Only the first three principal reference index are needed to produce the first three PPS index (see Moffiet et al. 2010):

$$PPSG = Tan^{-1}\left(\frac{(PR2-SF2)}{(PR1-SF1)}\right) \qquad (4)$$

where:

PPSG is the greenness index value

PR1 and PR2 are the first two principal reference index

Tan^{-1} (inverse Tan) is identical in meaning to Arctan

SF1 = SF2=-0.25

IDRISI software has been equipped with the image calculator module to calculate the PPSG index scores for each pixel.

The PPSG (Moffiet et al. 2010) was chosen as the greenness index to be used in this study because, in unpublished work, it has been demonstrated that it performs better than other index because of its sensitivity to small changes in foliage cover at high levels of cover. Additionally, it is known that the commonly used NDVI index rapidly loses sensitivity (saturates) at moderate to high levels of cover.

The range of PPSG index is between 0.7 and 1.0 for dense foliage cover, and to interpret the PPSG index in this study we used the classification as follow:

–   High density (PPSG-index greater than 0.70),
–   Mid density (PPSG-index greater than 0.3 but less than 0.69), and
–   Low density (PPSG-index greater than 0.1 but less than 0.29).

To analyse the data on a pixel-by-pixel basis (surface temperature changes across space) corresponded with vegetation index, we employ regression analysis from the entire images of the study area. Surface temperature images act as dependent variable, while vegetation index images act as independent variable. The analysis is being performed on the changes across the scene at the given fixed time-period (1988, 2002, and 2012).

The extensive field work survey was conducted from May to August 2012 to verify the result obtained using the remotely sensed data in the laboratory and compared with the data obtained in the field.

4 Results

Our objective in this study was to gain a greater understanding of the direct impact that expansion of oil palm plantation has on the local surface temperature. During the 14-year period covered by this analysis, the first and second village lost 31,626.54 ha and 38,000 ha of natural tropical forest, respectively, due to conversion into oil palm plantation.

A comparison between satellite-derived surface temperature values and average field measurements is shown in Table 2. We extracted the temperature values from the same sample point locations, interpolated the values, and analysed the results of the interpolation by overlaying the satellite images with the surface temperatures. Table 2 shows that the average Landsat-derived temperature value for 1988 was 24.7 °C, for 2002 it was 27.3 °C, and for 2012 it was 31.8 °C, which means that

Table 2 Comparison between land surface temperature derived from remotely sensed imagery and field observation

No.	LULC (2012)	Average field tmp (°C) 2012	Average landsat tmp (°C) 2012	Average landsat tmp (°C) 2002	Average landsat tmp (°C) 1988	Average PPSG values
1	Primary forest	–*	–*	–*	22	0.78
2	Wetland/secondary forest	27.3	27	24	22.3	0.77
3	Mature oil palm trees (10–20 years old)	29.8	28	28	**	0.73
4	Unpaved road	30.8	30	27	26	0.61
5	Young oil palm trees (3–9 years old)	31.7	31	29.6	26	0.65
6	Residential	33.2	33	28	26.3	0.60
7	Oil station/oil well	39.2	42	27.3	24.3	0.56
	Average temperature	32	31.8	27.3	24.7	

Field observations were conducted on May to August 2012, from 09.00 am to 12.00 pm (local time) The satellite data acquisition times were 03.11 am GMT for Landsat 7 and 02.53 GMT for Landsat 5, or 10.11 am and 09.53 am local time, respectively (the time difference between the local time and GMT is +7 h)

*There is no primary forests left in the year 2002 and 2012 in the study area

**There is no mature oil palm trees in the year 1988 in the study area

the average Landsat-derived temperature value differed by 2.6 °C from 1988 to 2002 and by 4.5 °C from 2002 to 2012.

The extensive development along the national road network produced higher temperatures than conversion of tropical natural forests into areas of oil palm plantation.

The surface temperature differences are due to differences in land cover during different parts of the analysis period. For example, mature oil palm trees that were 10–20 years old in 2012 are located in areas that were transformed from primary tropical forest in 1988. Unpaved roads, residential areas, and oil palm trees that were young (3–9 years old) in 2012 are located in areas that were transformed from secondary tropical forest in 1988. The surface temperatures of the wetland and secondary forest increased slightly when the surrounding environment was transformed into oil palm plantations, road networks, and residences for transmigrants. While oil wells have been present in the area since the late 1980s, their surrounding environment in 1988 was tropical forest. When the land cover changed to oil palm plantation, the surface temperatures around the oil wells increased because more of the surrounding bare land was exposed to direct sunlight.

For illustration, we present four example red boxes (two boxes in Fig. 3a and b and another two boxes in Fig. 4a and b) to illustrate the analysis. The areas represented by the red boxes were chosen because the landscapes were completely transformed. The foliage cover and surface temperature were also differed (the vertical red line to the right of B in Fig. 5). For example, in the red box in Fig. 4a, the land cover in 1988 was tropical forest, with an average PPSG value of 0.78 (high density). In 2002, the red box shown in Fig. 4b is an area that was dramatically transformed into oil palm plantation, with an average PPSG value of 0.69 (mid density).

To illustrate the results, we created a transect line (A–B) over the different land uses and land covers shown in the images (Fig. 3a and b). The values of the transect line inside the red box in Fig. 3a in 1988 are shown in Fig. 5 as a vertical red line to the right of B), while the values of the transect line inside the red box in Fig. 3b in 2002 are shown in Fig. 5 by a vertical red line to the right of B.

In Fig. 4, lower PPSG values are shown in light yellow. In the high-conversion areas on the southwest and northeast sides of the image, this corresponds to a new oil palm estate, road
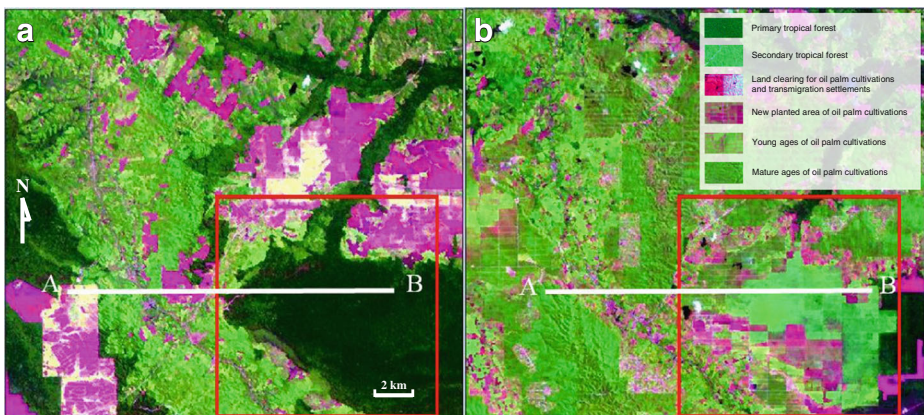

Fig. 3 Study area and transect line across different land use land cover (false colour composite using bands 7, 4 and 2). **a** The Landsat 5 TM image year 1988 (with percentage stretch, 2 % lower limits and 98 % upper limits) after matching its histogram to that of the ETM + reference image (Fig. 1b). **b** False colour composite using bands 7, 4 and 2 of the Landsat 7 ETM + year 2002
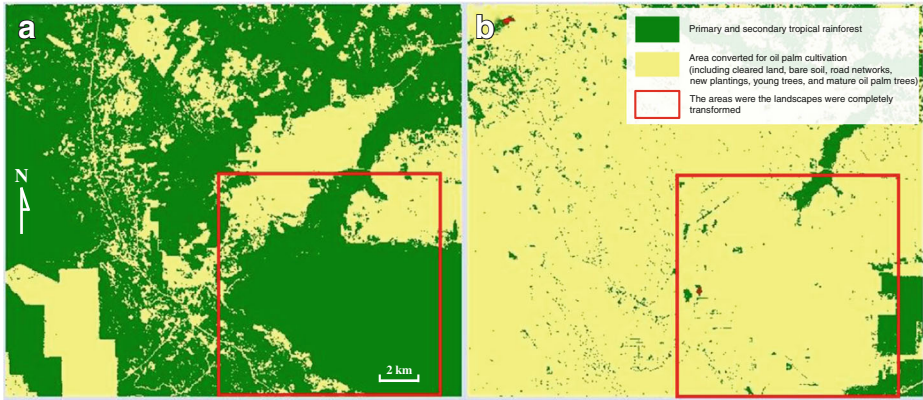
Fig. 4 Land use land cover changes, the *green color* is represented for tropical forest (primary and secondary) and the *yellow color* represented for area converted for oil palm plantation (including cleared land, bare soil, road networks, new plantings, young trees and mature oil palm trees). **a** Year 1988. **b** Year 2002. The areas represented by the *red boxes* were chosen because the landscapes were completely transformed. The foliage cover and surface temperature were also differed. For example, in the *red box* in (**a**), the land cover in 1988 was tropical forest. In 2002, the *red box* shown in (**b**) is an area that was dramatically transformed into oil palm plantation

networks and bare land for a new village for the transmigration program. The average value of PPSG for this area is 0.61 in 2002. Higher PPSG values, shown as dark green, are observed in the southeast, northwest, northeast, and southeast parts (forest) in the 1988 image. The average value of PPSG for this area is 0.78. The remarkable expansion of the oil palm plantation area in the 2002 image appears as light yellow, corresponding to lower PPSG values over the whole area. The average value of PPSG for this area is 0.69.

As. Fig. 5 shows, when the foliage cover increases, the surface temperature decreases. These pixels are also indicated by the wet pixels (the vertical red line to the right of B). When the land cover was tropical rainforest in 1988 (Fig. 3a), with an average PPSG value of 0.78, and the average surface temperature was 22.5 °C. These pixels were tropical rainforest and wetland in 1988 and were transformed into areas containing mature oil palm trees by the year 2002 (the vertical red line to the right side of B).

When the foliage cover decreases, the surface temperature increases. These pixel are indicated by the dry pixels (the vertical red line to the right of B). This phenomenon was observed for cleared land and bare soil in 1988, and bare soil and newly planted and young oil palm trees by 2002. The average PPSG values for the transect line inside the red box in Fig. 3b in was 0.69 in 2002, and the average surface temperature was 26.5 °C.

The pixels with PPSG values below 0.29 are water bodies, PPSG values 0.30 – 0.60 are bare soil and land cleared for oil palm plantation (in 1988 and 2002). PPSG values between 0.61 and 0.69 correspond to newly planted oil palm trees (in 1988), newly planted and young oil palm trees, and extensive development along the national road network (in 2002). The pixels with PPSG values between 0.7 and 0.8 and more than 0.8 correspond to tropical rainforest and wetland (in 1988) and mature oil palm trees (in 2002), respectively.

However, there are slight differences in the foliage cover of tropical rainforest in 1988 and mature oil palm trees in 2002 and 2012. The average PPSG value difference is only 0.09. The average surface temperature of mature oil palm tree areas appears to be higher than the average surface temperature of tropical rainforest areas by 2 °C. The leaf density cover of oil palm
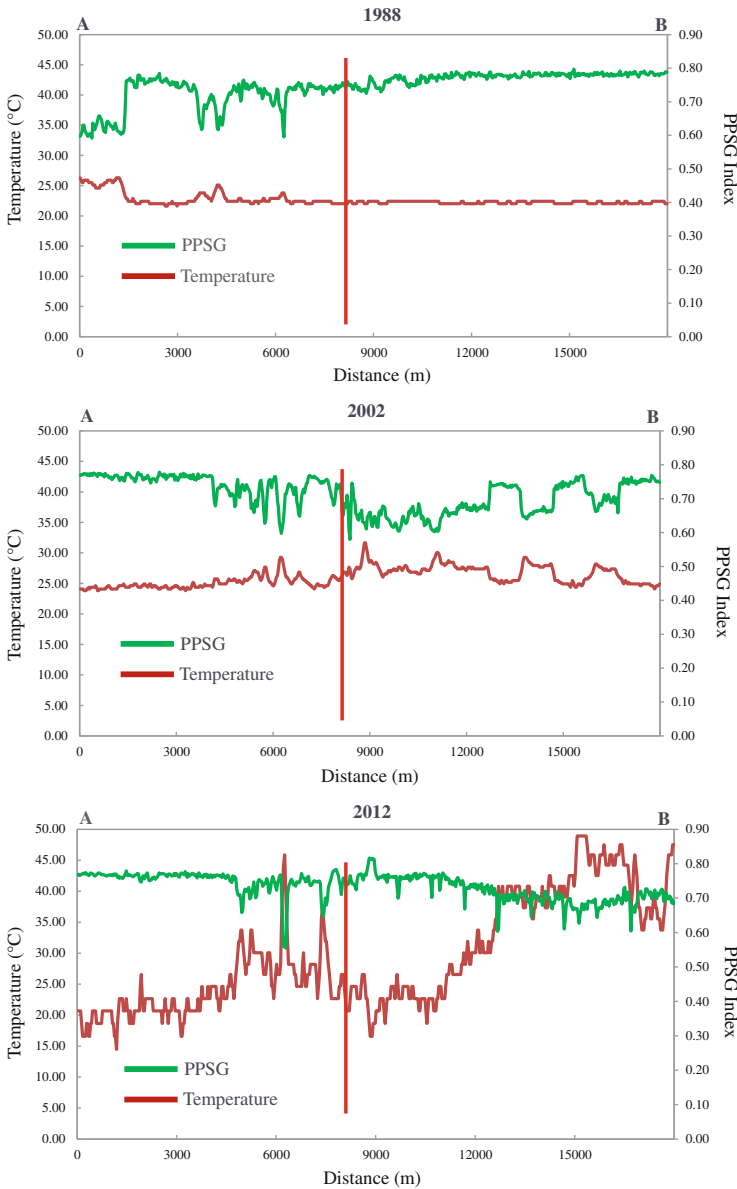
Fig. 5 Behaviour of PPSG and surface temperature. When the foliage cover increases, the surface temperature decreases. These pixels are also indicated by the wet pixels tropical rainforest (the *vertical red line* to the right of B in year 1988). When the foliage cover decreases, the surface temperature increases. These pixels are indicated by the dry pixels of oil palm plantations (the *vertical red line* to the right of B in year 2002 and 2012). The values of PPSG and surface temperature were extracted from transect line A-B as shown in Fig. 3

plantations are also not stable over different stages. When the oil palm trees become older, the leaf cover becomes more dense and soil exposed to direct sunlight is decreased, whereas in tropical rainforests leaf, density cover is stable over time.

The result of pixel-by-pixel basis (surface temperature changes across space) corresponded with vegetation index, from regression analysis of the entire images of the study area are shown in Table 3.

The results show that there is negative-strong correlation between the changes of foliage cover and surface temperature. Table 3 shows that the R were between 0.80 and 0.87, indicating that the changes of foliage cover and surface temperatures were correlated. Changes of foliage cover in this study means intra-scene changes across space at the given fixed time-period of analysis (1988, 2002, and 2012)

5 Discussion

Between 1988 and 2002, mineral soils in the primary and secondary tropical rainforests were the primary land areas used for conversion into palm oil plantations in the study area. This finding is consistent with that of Gibbs et al. (2010), who found that between 1980 and 2000, more than 55 % of new agricultural land became available at the expense of intact forests across the tropics.

The new vegetation index, PPSG, was used as an indicator of foliage cover. Use of this index allowed us to assess the land-clearing stage for new oil palm estates. Changes in PPSG values were then compared with changes in surface temperature. Mature tropical forests have slightly higher foliage cover than mature oil palm plantations, and the PPSG analysis applied in this study has been shown to perform better than other vegetation index methods (Ramdani 2012).

The direct field measurements in 2012 indicated that surface temperatures in our study sites differed by an average of 4.7 °C. Satellite imagery for 2012 is available for comparison with the field measurement results and assessment of changes that have occurred since 2002. Temperature differed by an average 4.5 °C, the outcome of satellite image processing is only 0.2 °C different from direct temperature measurement in the field.

Oil palm plantations are not stable in foliage cover at different stages. When oil palm trees become older, the foliage cover becomes more dense, and the amount of soil exposed to direct sunlight is decreased, whereas in tropical rainforests, foliage cover is stable over time. Luskin and Potts (2001) found that oil palm plantations were substantially hotter (+2.84 °C) and drier (a +0.80 hPa vapour pressure deficit) than forests during diurnal hours. Because the oil palm canopy is lower, more open and simpler than a closed-canopy rainforest, the temperature and humidity conditions are different than for a tropical forest (Foster et al. 2011). There are two elements to this difference: the conditions are more extreme (higher temperatures, lower

Table 3 Regression result: correlation between the changes of foliage cover (independent variable) and surface temperature (dependent variable) from the entire images of the study area

Regression parameters	1988	2002	2012
Coeff. of det (R square)	0.76	0.72	0.65
R	−0.87	−0.85	−0.80
S.E. of estimate	0.78	0.70	0.70
Sample size (n)	617433	617433	617433

The analysis is not being performed on changes across time, but is being done to analyze the changes across the scene at the given fixed time-period (1988, 2002, and 2012). The results show that there is negative-strong correlation between the changes of foliage cover and surface temperature. Table 3 shows that the R were between 0.80 and 0.87, indicating that the changes of foliage cover and surface temperatures were correlated

humidities) and they also vary much more on a daily basis (Koh et al. 2009, Turner and Foster 2006).

Unfortunately, there are no long-term meteorological data available for the study area to compare with our results. However, this is the first study that has successfully documented land surface temperatures in Riau Province in Indonesia over oil palm plantation areas that replaced tropical rainforests on a large scale.

The methodology used in this study is possible to apply in other crops plantations such as maize, soy, and wheat to monitor the changes of surface temperature.

6 Conclusions

This study demonstrated an association between local land surface temperatures and replacement of forest cover with oil palm plantation. Landsat satellite spectral images were used to assess changes in these variables, where vegetation cover was measured by the greenness index (PPSG). The negative relationship between the greenness index (PPSG) with surface temperature successfully documented. The associations found provide support for the hypothesis that the changes of land surface temperature is caused by the reduction in foliage cover when tropical rainforests are replaced by oil palm plantations. Satellite imagery for 2012 is available for comparison with the field measurement results and assessment of changes that have occurred. Surface temperature differed between 1988, 2002, and 2012. The outcome of satellite image processing is only 0.2 °C different from direct temperature measurement in the field. Oil palm foliage cover is lower, more open and simpler than tropical rainforest foliage cover, so clearing land for oil palm plantations and planting oil palm trees results in higher surface temperatures. However, the surface temperature conditions for mature oil palm trees are slightly higher than those in the primary tropical rainforest areas.

An additional outcome of the study was that the PPSG index was found to be useful for distinguishing the characteristics of foliage cover between oil palm plantation at every stage and the differences between tropical rainforest cover. The methodology applied in this study is not labour intensive and can be applied to other types of agricultural commodities on a large scale with relatively high accuracy.

References

National Statistical Bureau (2011) Indonesian oil palm statistics. Sub Directorate of Estate Crops Statistics. Statistics-Indonesia
Corley RHV, Tinker PB (2003) The Oil Palm, 4th edn. National Academy Press. Blackwell Science, British
Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Bruhl CA, Donald PF, Phalan B (2008) How will oil palm expansion affect biodiversity? Trends in Eco & Evo 23(10):538–545. doi:10.1016/j.tree.2008.06.012
Foster WA, Snaddon JL, Turner EC, Fayle TM, Cockerill TD, Ellwood MDF, Broad GR, Chung AYC, Eggleton P, Khen CV, Yusah KM (2011) Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. Phil Trans R Soc B 366:3277–3291. doi:10.1098/rstb.2011.0041
Georgescu M, Lobell D, Field C (2011) Direct climate effects of perennial bioenergy crops in the United States. Proc Natl Acad Sci U S A 108:4307–4312
Gibbs HK, Ruesch AS, Achard F, Clayton MK, Holmgren P, Ramankutty N, Foley JA (2010) Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. Proc Natl Acad Sci U S A 107: 16732–16737. doi:10.1073/pnas.0910275107
Ho C.-H, Park S.-J, Jeong S.-J, Kim J, Jhun J.-G (2012) Observational evidences of double cropping impacts on the climate in the northern China plains. J Climate 25:4721–4728. doi:10.1175/JCLI-D-11-00224.1

Koh LP, Wilcove DS (2008) Is Oil palm agriculture really destroying tropical biodiversity? Conserv Lett 1(2):60–64

Koh LP, Levang P, Ghazoul J (2009) Designer landscapes for sustainable biofuels. Trends Ecol Evol 24:431–438. doi:10.1016/j.tree.2009.03.012

Koh LP, Miettinen J, Liew SC, Ghazoul J (2011) Remotely sensed evidence of tropical peatland conversion to oil palm. Proc Natl Acad Sci U S A 108(12):5127–32. doi:10.1073/pnas.1018776108

Luskin MS, Potts MD (2011) Microclimate and habitat heterogeneity through the oil palm lifecycle. Basic and Appl Ecol 12(6):540–551

Loarie SR, Lobell DB, Asner GP, Mu Q, Field CB (2011) Direct impacts on local climate of sugar-cane expansion in Brazil. Nat Clim Chang 1:105–109. doi:10.1038/NCLIMATE1067

Moffiet T, Armstonb JD, Mengersenc K (2010) Motivation, development and validation of a new spectral greenness index: A spectral dimension related to foliage projective cover. ISPRS J Photogramm Remote Sens 65:26–41

Park C-E, Ho C-H, Jeong S-J, Kim J, Feng S (2012) The potential of vegetation feedback to alleviate climate aridity over the United States associated with a 2xCO2 climate condition. Clim Dyn 38:1489–1500. doi:10.1007/s00382-011-1150-x

Ramdani F (2011) Changes in land use due to development of oil palm plantation in Sumatera and Kalimantan Island, under economic globalization. Thesis, Tohoku University

Ramdani F (2012) Analysing variety of vegetation indices values using different methods for mapping oil palm closed-canopy composition in southern Riau Province, Indonesia. Geoscience and Remote Sensing Symposium (IGARSS), IEEE International, 22–27 July 2012, Munich, Germany. pp 6032–6034. doi:10.1109/IGARSS.2012.6352232

Ramdani F, Hino M (2012) Combining remote sensing information and policy changed to monitor oil palm expansion in tropical country, Indonesia. G-COE Final Symposium, Achievements of the Global-COE program for Earth and Planetary Dynamics and the Future Perspective. 25–28 September 2012, Sendai, Japan. pp 263–264.

Ramdani F, Hino M (2013) Land use changes and GHG emissions from tropical forest conversion by oil palm plantations in Riau Province Indonesia. PLoS ONE 8(7):E70323. doi:10.1371/journal.pone.0070323

Susanti A and Burgers p (2012) European Report on Development. http://erd-report.eu/erd/report_2011/documents/researchpapers_susanti-burgers.pdf. Accessed 18 March 2013

Turner E, Foster WA (2006) Assessing the influence of bird's nest ferns (Asplenium spp.) on the local microclimate across a range of habitat disturbances in Sabah, Malaysia. Selbyana 27:195–200

Whitten AJ (1987) Indonesia's Transmigration Program and Its Role in the Loss of Tropical Rain Forests. Conserv Biol 1(3):239–246