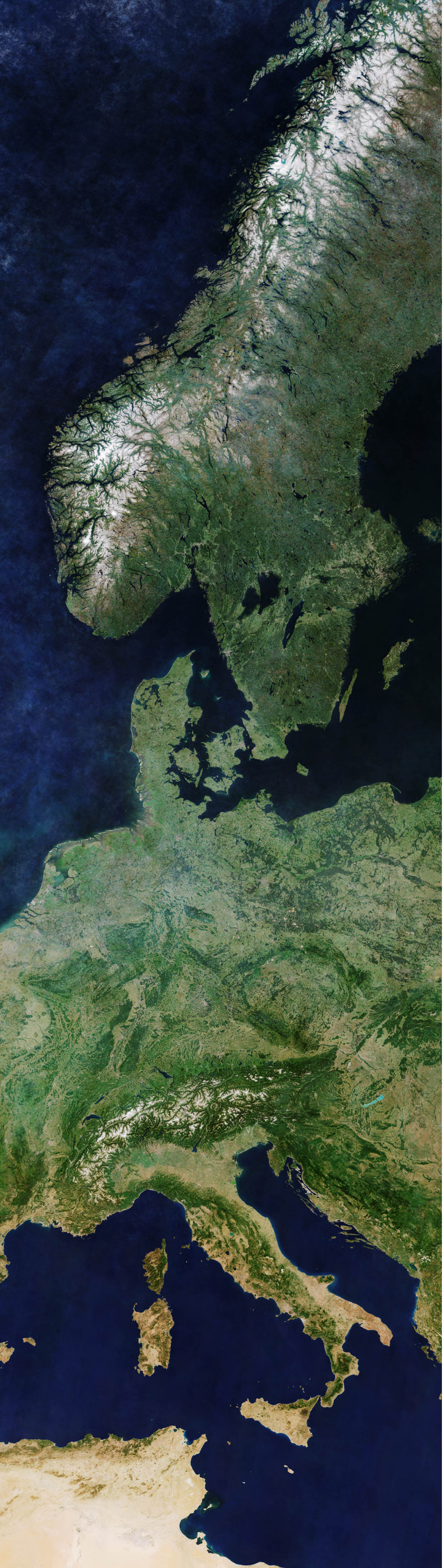

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remote sensing technologies supporting
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Session Remote Sensing for Agricultural Applications: from regional to local scale
Thursday, 5 July 2018 (17:00 -18:30)
Congress Hall - Chairman: Mirko Boschetti, Enrico Borgogno Mondino

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Detection and Characterization of Palm Oil Plantations through MODIS EVI time series

1. Introduction

Elaeis guineensis Jacq. is a palm species of the Arecaceae's family commonly called Oil palm; it is planted extensively in South-East Asia, especially in Indonesia, Malaysia, and Thailand. Palm oil is the world highest yielding oil crop. In Indonesia plantations showed an increasing linear trend that brought the 4 million hectares in 2000 up to 11 in 2015. The consumption of palm oil over the world is growing through the years: 50 Million tons in 2012-2013, over 60 Million tons in 2015-2016. According to FAO in 2007 the two largest oil palm producing countries are located in Southeast Asia: Indonesia (4.1 million ha) and Malaysia (3.6 million ha). Oil palm well fits the humid tropical climate with a high precipitation rate, high solar radiation and warm temperature (24–32 °C). Oil palm is a perennial tree. Plantations generally have a triangular pattern (9 m row spacing), to optimize sunlight penetration. The majority of planted oil palms are a small mixture of hybrid clones (i.e. Dura X Pisifera), resulting in a uniform pattern at the ground; this makes oil palms different from other trees or forest in satellite imagery. Cultivation of oil palm in tropical countries, on one hand is an important economic factor, but, on the other hand, it endangers biodiversity and degrades the environment with a global impact. These regions, in fact, represent the 11% of the world's remaining tropical forests, containing numerous endemic or rare species, many of which are restricted to forest habitats. Furthermore, logged-over forests often are seen by governments as degraded habitats, only waiting for farm practices. This fact, has encouraged the conversion of secondary (logged) forests to oil palm plantations in Malaysia and Indonesia. From this point of view remote sensing can support a more efficient plantation management that takes into account their effects over environment. Plantations monitoring by remote sensing well fits requirements of precision farming that many stakeholders are currently approaching. Private owners and local farmers are interested in assessing crop conditions; differently, governmental institutions and environmental associations long for the possibility of continuously monitoring the state of the national natural/crop capital. In this work a time series of EVI maps obtained from the MODIS Vegetation Index products (MOD13Q1) for the period 2000–2018 was processed to automatically detect new oil palm plantations, giving an estimate of both ages and productions.

2. Materials and Methods

2.1 Study Area

The study area is sited in the South of Kalimantan Tengah (Central Kalimantan), a province of Indonesia located on Borneo island (5°00'43.92"S 115°41'04.92"E, WGS-84). Area edges were determined on landscape markers basis (rivers, coast, etc.) resulting in about 2947219 ha. According to Köppen classification, local climate is Tropical rainforest. It is dominated by low-pressure system all over the year generating no thermal and moisture seasonality. According to USDA (United States Department of Agriculture) Soil Taxonomy, local soil is labeled as Oxisol with a high aluminum and low phosphate content that could hinder plant growth. Morphology is generally flat without significant reliefs; even if some existing local microsites conditions could affect vegetative vigour of plantation, edaphic conditions of area can be retained constant at the small scale.

2.2 Available data

An EVI (Enhanced Vegetation Index) image time series, composed of 415 images, and covering a period between 18/02/2000 at 18/02/2018 was generated from the MOD13Q1 (version 5) dataset available from the NASA LPDAAC collection.

A vector map of Indonesian Oil palm concessions was obtained from the Global Forest Watch (GFW) archive. Map was produced by the Indonesia Ministry of Forestry; it is dated 2010 and its nominal scale is not declared. Map reports the boundaries of current (or planned) oil palm plantations in Indonesia. The map is known to be incomplete, but it is currently the only available one.The adopted reference system for all the images is the WGS-84 UTM 49 S. All data were processed by free GIS software (QGIS 2.18.4 and Saga GIS 6.2).

2.3 Mapping Oil Palm Plantations

Starting from the EVI time series a new methodology for oil palm detection and characterization was developed

and implemented in the IDL 8.0 programming language based on temporal profile analysis of each pixel. Pixel EVI temporal profile proved to be effective in describing dynamics of vegetation cover and detecting the moment when an abrupt change occurs along the considered period (18 years).
Candidate pixels possibly representing oil palm fields planted in the analyzed period, were detected with reference to the 1st order polynomial approximating EVI local values in the whole reference period; in particular gain value of the local line was assumed as predictor of new oil palm plantations and saved in a new image layer. The latter was then thresholded to separate potential oil palm pixels from the others. In this work and for the study area authors used a threshold value for line gain of 2.0.
Theoretical assumption is that, in tropical areas palm cover shows a gain higher than natural vegetation, being the EVI values of the new cover significantly higher than the one ordinarily expressed by natural vegetation. In general, can be observed that when natural vegetation is present, yearly EVI trend is slightly varying with no remarkable profile steep trait, determining gain value close to zero. Differently, if a new plantation occurs, EVI temporal profiles suddenly decreases at the moment of forest cut, but after a transitional period, it reaches a new state of vigour corresponding to higher EVI values.
Classification refinement was achieved using the above mentioned Indonesian Oil palm concessions map. It was used to mask out from classification those pixels falling outside the polygons. A further refinement was operated by deleting all those areas smaller than 100 ha, being plantation average size in general higher and higher.
Accuracy assessment was achieved by photo-interpretation of 25 random areas that were selected from those labeled as “oil palm” in the classification step. The 2018 Landsat true color image available from Google Earth website was used as ground truth reference dataset.

2.4 Estimating starting date and age of plantations

Time distribution of changes in the area was analyzed, focusing on the selected pixels from the previous step. Analysis was achieved exploring the local EVI temporal profile with a sliding window (kernel) running along the time and including 11 images preceding and 11 following the middle one. At each position of the window a local linear interpolation (1st order polynomial) was performed and the gain value archived for further investigations. Being 415 the available EVI images, 415 were the gain values archived at each position. It was found that the minimum gain value of the local series was a reasonable indicator of the time of changes for that pixel. According to this minimum value criterion, for each candidate oil palm pixel, an estimate of the year when the new plantation started was computed. Estimated starting date was saved for each pixel and a new image layer generated, finally giving a representation of new plantation trends and spatial distribution in the investigated period.
Accuracy assessment was achieved by photo-interpretation of Landsat true color images available for the period 1984-2016 from Google Earth website. A Landsat image per year was selected focusing on 25 random areas extracted from those labelled as “oil palm” in the previous step, looking for the moment when new palm plantation appears. Estimated and observe dates of changes in vegetation cover were compared and Mean Absolute Error (MAE) computed.
The age of oil palm plantation is an important parameter for crop management: it is a good predictor of yearly yield and conditions the quality and quantity of the fresh fruit bunches (FFB). The age of plantations from available data was computed by comparing (by differencing) the estimated planting year with the present (2018). This operation was performed for the whole “oil palm” class.

2.5 Estimating oil palm production

Oil palms produce FFB that represent the raw material for palm oil mills. Oil is extracted from the pulp of the fruit. Production can be affected by various internal and external factors. Internal factors include age and oil palm breeds/variety; external factors include rainfall, drought, disease, soil fertility and moisture, harvesting efficiency. Thus, to give an estimate of production, all the above mentioned factors would have to be taken into consideration. Nevertheless, a good synthetic predictor of yield is the age of plantation itself.
Palms can be classified in 5 farming classes determining different production: a) “seedling” from 0 to 3 years; b) “young” from 4 to 8 years; c) “teen” from 9 to 14 years; d) “mature” from 15 to 25 years; e) “old” from 25 to 32 years.
Azman et al. (2002) proposed a time dependent unitary production (UP) curve for oil palm, relating FFB yearly yield (tons·ha-1×yr-1) with the age of plantation (annual basis). The curve is not defined by a mathematical formula, but through an empirical table. Consequently, authors used it as a look up table relating the estimated age of plantation to the expected UP in 2018. To give an estimation of local production (LP) UP was multiplied by the area of each MOD13Q1 pixel. A map of expected LP was, therefore, generated for the year 2018. Presented results must be considered purely indicative. In fact, they can be highly moved from the expected value if unknown plant diseases or unfavorable microsite conditions are present in the area.

3. Results and Discussion

Classification showed that in the area about 632585 ha of new oil pam plantations were found in the reference period (21.46% of the whole study area). Classification accuracy (oil palm, not-oil palm), computed referring to the above mentioned 25 check areas, was 92%. The area of new plantations stared in each investigated year are respectively: 17695 ha in 2000,17604 ha in 2001, 70423 ha in 2002, 36480 ha in 2003, 123804 ha in 2004, 25122 ha in 2005, 122739 ha in 2006, 22881 ha in 2007, 13631 ha in 2008, 14203 ha in 2009, 32385 ha in 2010, 11443 ha in 2011, 17816 ha in 2012, 18113 ha in 2013, 23188 ha in 2014, 38817 ha in 2015, 20799 ha in 2016, 5441 ha in 2017.

The estimate of the year when the new plantation started, according was computed with a MAE of 2.27 years corresponding to a percentage error of 11% in respect of the whole period.

Concerning oil palm plantations production in respect of the 5 above mentioned age classes, the proposed methodology found that:

For the whole study area, the total estimate of FFB yield produced only by those plantations started within the investigated period (2000-2018) is, at February 2018, 10 Million tons. Age class contributions to the total are: about 0.093 Million tons· yr-1 for "Seedling" plantations (61436 ha); about 1.36 Million tons· yr-1 for "young" plantations (97493 ha); about 6.58 Million tons· yr-1 for "teen" plantation (363103 ha); about 1.96 Million tons· yr-1 for "mature" plantation (110553 ha). No "old" plantation was detected since the investigated period is shorter than 25 years.

4. Conclusions

MODIS derived EVI time series proved to be effective to map and characterize new oil palm plantations. Detection of new plantations based on local temporal profile analysis revealed to be accurate enough (overall accuracy = 92 %), suggesting that time discriminant is basic in assessing vegetation cover. It also proved to make possible give an approximate estimation of the starting date of new plantations and, consequently, of new productions in the area if a unitary production curve is available.

Many limitations, at the moment, still persist: a) detected changes in vegetation cover can be also related to abiotic or biotic disturbance like wildfire, plant diseases, human clear cut. Auxiliary data from other map or institutional source could help to make result more reliable from this point of view; b) production estimates are based on a literature-derived curve of UP. It is not clear if this curve must be better calibrated according to ground data specifically referring to the explored area; c) production estimates are strictly related to the estimate of the date of beginning of plantations. At the moment, the approximation in this estimate is too large (± 2.27 years) to be reliable enough; d) future experiences trying to apply the same methodology are expected to be based on MOD13Q1 version 6 datasets, since the version 5 is going to be dismissed from LPDAAC.

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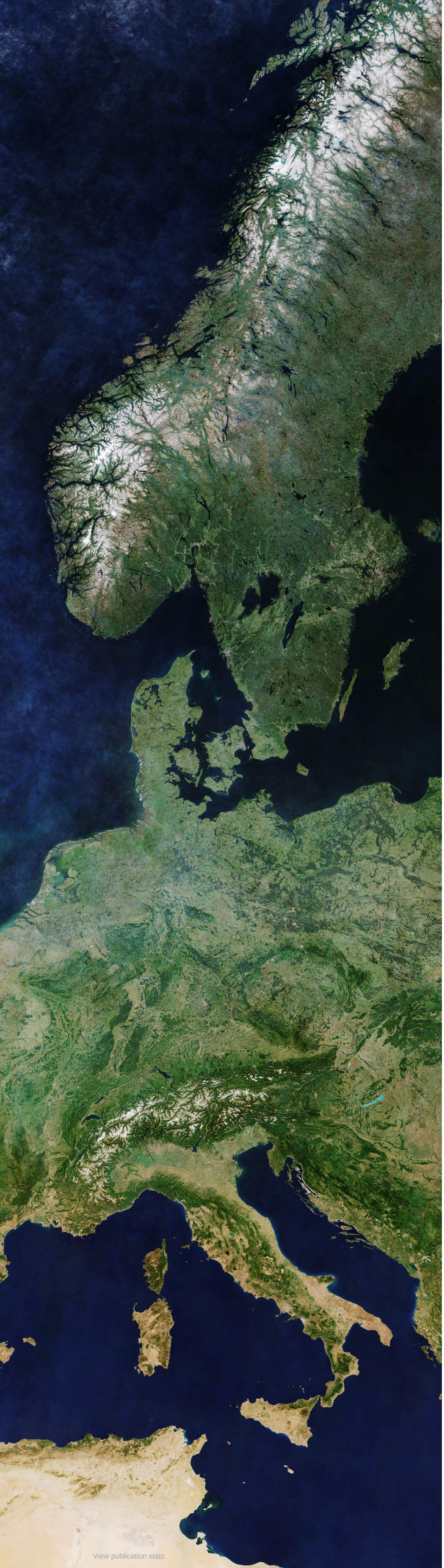

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