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Application of Sentinel-1 satellite to identify oil palm plantations in Balikpapan Bay

M Lazecky*[1], S Lhota[2], T Penaz[3] and D Klushina[4]

[1] IT4Innovations, VSB-TU Ostrava, 17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic
[2] Czech University of Life Sciences, Kamýcká 961/129, 165 00 Praha-Suchdol, Czech Republic
[3] Institute of Geoinformatics, VSB-TU Ostrava, 17. listopadu 15, 70833 Ostrava-Poruba, Czech Republic
[4] Nanotechnology center, VSB-TU Ostrava,17. listopadu 15, 708 33 Ostrava-Poruba, Czech Republic

milan.lazecky@vsb.cz

Abstract. Satellite remote sensing has proved to be efficient for monitoring of canopy changes. In tropical areas, optical or multispectral satellite images are very often negatively affected by cloud cover, on the other hand satellites with polarimetric radars have a great advantage given their ability to penetrate clouds, smoke and atmospheric haze. Copernicus Sentinel-1 radar constellation offers both vertically co-polarized and cross-polarized imagery in a relatively high revisit time and resolution. This work describes an approach to identify selected palm oil plantations in Balikpapan Bay, East Kalimantan (Borneo). It gives an overview about advantages for monitoring temporal changes in the tropic environment using radar imagery but also constraints due to ambiguity of canopy type identification. The paper shows a brief comparison with application of multispectral Copernicus Sentinel-2 data and points a roadmap towards a practical application of the technologies.

1. Introduction

1.1. Palm plantations in Indonesia

Until recently, tropical rainforest covered a major proportion of the Indonesian Archipelago, including almost whole island of Borneo. In past several decades, more than half of the Bornean rainforest was lost. Indonesia has entred the Guiness Book of World's Records as the country with the fastest rate of deforestation in the history of mankind [1]. The major single cause of deforestation in Borneo is palm oil [2]. Prior to 1990, more than half of oil palm plantations in Kalimantan (Indonesian Borneo) replaced forest; since then, more plantations have been established on the agricultural or degraded land, however even after 2000, one-third of the plantatiins still replaced forests [3]. Although the plantations managed by the RSPO (Roundtable on Sustainable Palm Oil) member companies experience reduced rate of deforestation, the difference is not great compared to the conventional plantations [4]. The ongoing expansion of oil palm plantations leads to enormous loss of biodiversity.

It is one of the major reasons of the loss of 100,000 Bornean orangutans over past 16 years [5], Indonesia covers only 1 % of the total land surface, yet it hosts approximately one tenth of all flowering plant species, one eight of all mammalian species and one sixth of all amphibians, reptiles and birds [6]. Although none of these species became extinct in recent years, the expansion of oil palm plantation can be undoubtedly viewed as one of the major threat for the global biodiversity in near future. Furthermore, the loss of the tropical raiforests means a loss of vitel environmental services that this ecosystem provides. It has been demonstrated that the the biomas of trees in the undisturbed Bornean rainforests increases over past 20 years, which means that these forests act as a sing of the carbon sink [7], which may slow down the current increase of carbon dioxide concentration in atmosphere. Rainforests are also vital for maintaining water regime and may influence local climate [8]. Oil palm plantations play none of these ecological roles.

Besides the above written risks for the ecosystem it is necessary to mention the risks of exponentially growing intake of palm oil for human health. Palm oil low in Free Fatty Acids (FFAs), impurity content and with good bleaching is considered of high quality and used in the edible oil industry; low-quality oils are used in non-edible industry such as biofuel, cosmetics and soap production [9]. Because of the texture, the fragrance and the neutral taste the palm oil application in food industries has highly grown in the last decades. Palm oil can be used in different ways depending on its fraction - from preparation of mayonnaise to creation of candles. It can be generally found in majority of modern consumer products (e.g. cheese analogs, chips, chocolate, confectionery fats, cookies, cooking oil, crackers, doughnuts, frozen meals etc.). There is a number of scientific works which makes to think of fat-rich diet as one of the factors of some metabolic diseases such as obesity [10], obesity-related diseases such as hyperlipidemia, hypertension and type 2 diabetes mellitus (T2DM) and some types of cancer [11]. Several observations [12, 13, 14] support an opinion that an excessive consumption of palm oil in the diet causes changes in gut microbiota components and is associated with lipid accumulation. Also, there is an evidence, that the intake of palm oil and inter-esterified fat (IF) present in processed foods during pregnancy and lactation period affects the offspring and leads to the development of obesity in adult life [15]. Another research of Central Nervous System (CNS) on mice shows that high-doses of palmitic acid (main constituent of palm oil) induce pro-inflammatory responses and leptin resistance, similarly to obesogenic-diets [16].

Finally, we can admit that the rapidly rising level of world consumption of palm oil and the expansion of palm oil plantations are interrelated and its character of a very questionable sustainability induce a warning to human-natural well-being on the planet.

1.2. Oil palm tree detection with remote sensing methods

Knowledge of oil palm plantations geographical distribution and changes in their occurrence is a necessity for better environmental protection. The requirement for defining the boundaries as accurately as possible and to determine the extent of oil palm areas is an opportunity for mapping via remote sensing. To this end, methods of image classification are used for landcover evaluation. By performing classification of multi-temporal images it is possible to identify the changes of the spatial delimitation of the plantations. The possibility of oil palm plantations evaluating from optical imagery is significantly limited by weather. Oil palm plantations occurrence is bound to the tropical areas with intense cloudiness. As clouds cover a significant part of the territory, appropriate images of some areas are very difficult to obtain. Oil palm trees counting applications based on the processing of very high resolution multispectral QuickBird images are described for example in [17]. However, this is a detailed mapping of individual trees, which is not suitable for assessing the occurrence of oil palm plantations and evaluating the changes of their extension in large areas. In addition, QuickBird data is a paid product.

Another option is to evaluate the spatial delimitation of oil palm plantations from the microwave remote sensing. These data are not affected by the weather or daylight conditions. Some studies [18, 19] have verified the use of synthetic aperture radar (SAR) for mapping oil palm plantations. The basis of processing lies in identification of polarization changes of the radar microwave that occurs by scattering from palm leaves. Interesting and effective are approaches which combine multidimensional data from multisensor images [20]. In addition to intensity information, SAR data also carries texture information and can therefore be complementary to image data from optical sensors [21]. Using this approach, scientists were able to significantly improve and refine the classification results [20, 22, 23, 24].

1.3. Study area of Balikpapan Bay
Balikpapan Bay represents one of the last remaining complex and relatively undisturbed coastal ecosystems of the Indonesian province of East Kalimantan. The area of interest includes more than 450 km^2 of high conservation value habitats, including primary dipterocarp rainforest, regenerating second-growth forests, mangrove swamp forest, limestone outcrops, coral reefs, sea grass beds and shallow seas. Semi-continuous second-growth forests connect this forest block with other important areas, including Bukit Soeharto conservation area to the north-east and Meratus mountain range to the south-west, while the marine ecosystem connects with the Makassar Strait on the east. Within this extensive area, the total more than 170 km^2 represents an important proboscis monkey habitat. It hosts one of the world's largest populations of proboscis monkeys – 1400-2000 individuals, which represent more than 5% of the known overall population estimate. Other fauna of Balikpapan Bay and the surrounding forests include more than 100 mammalian species including the Bornean orangutan (*Pongo pygmaeus*) and other endangered species. Scattered along its coast there are still several traditional fishing villages (Gersik, Jenebora, Pantai Lango, Maridan, Mentawir). The income of several thousand fishermen still depends on the preservation of the rich natural resources in Balikpapan Bay. As the ecosystem degrades, the fishermen are unable to find an alternative income, often narrow-sighted selling their land to developers and shifting to illegal logging or other criminal activities. They also go bankrupt after unsuccessful attempts to start unsuitable alternative businesses such as shrimp farming or agriculture, and the degree of rural poverty is thus increasing. In a wider perspective, Balikpapan Bay provides invaluable ecosystem services to the fast-developing cities of Balikpapan and Penajam. Some of the river systems provide vital sources of surface fresh water – notably Wain River, which serves as the major source of water for the Balikpapan oil refinery, which in turn represents the most vital industry for the whole area. Semoi and Lawe-Lawe Rivers are also planned as future reservoirs whilst others such as Riko and Tempadung Rivers, provide major sources of underground water.

2. Input data and processing methodology

2.1. Applied datasets
Data of Copernicus Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 multispectral instrument satellite constellations are used for the study. Sentinel-1 SAR images are being acquired in a revisit frequency of an Interferometric Wide Swath (IW) image per 12 days and are available under a free and open access policy. Data were acquired after a Level-1 processing level known as GRD (Ground Range Detected) where they are resampled to the resolution of 20x22 m. Sentinel-2 multi-spectral data with 13 bands in the visible, near infrared, and short wave infrared part of the spectrum are acquired. Data are provided in free and open access policy. From 2015 to 2017 the data were acquired in a revisit time of 10 days. Using special averaging mechanism offered by Google Earth engine service, it was possible to prepare a non-cloud average Sentinel-2 image from 2015-2017 in a 50 m resolution. These data were used for a visual interpretation of identified plantations. As the only

found public available source, geodata from GlobalForestWatch.org were used for a results verification. However these data are not precise and up-to-date enough to provide a suitable source of information. Plantations can be further identified using a visual interpretation. For these purposes, Google Earth dataset has been used. Areas of interest are covered by satellite imagery from not later than 2014.

2.2. Classification of plantations using Sentinel-1

Sentinel-1 is a dual-polarization radar mission. Data are achieved by transmitting a vertically polarized microwave signal, afterwards the satellite detects the reflection in both Vertical Plane (VV) and Horizontal Plane (VH). Physical changes in VV and VH reflection are dependent on various factors, see [25]. For the purposes of vegetation studies in tropical areas the theory can be simplified to the key factor that intensity of VV reflection would be increasing with the size of reflecting objects (e.g. a tree trunk) while a cross-polarization effect VH would occur by scattering within objects of size comparable to or smaller than the radiation wavelength and with regards to their orientation towards the inbound electromagnetic wave. Since Sentinel-1 uses signal of a carrier wavelength 5.55 cm, its VH backscatter would be maximized by reflection from tiny and dense leaves of oil palms or acacias rather than from larger leaves of mangroves - see illustration at Figure 1. Using a VV/VH ratio, the difference between reflection signature of mangroves and palms would increase [26].

Figure 1. Illustrative images of three plant families of the main interest within the study

A typical issue of SAR satellites is a sensitivity of reflection to the direction of the transmitted electromagnetic beam. Terrain-induced intensity variation can be removed using a terrain simulation by processing of a digital elevation model (DEM) [27]. An SRTM global DEM in the resolution of approx. 30 m has been used for this correction. Another issue is a frequent occurrence of reflection noise known as a speckle [28]. Because the phenology of oil palms are relatively unchanging during the course of a year, it is possible to effectively reduce the speckle and other temporary contributions by averaging a number of SAR images (taken from the same orbital track). Using a number of SAR images, it is possible to apply also sophisticated multitemporal speckle filters available in SNAP. In our case, both approaches were applied in order to achieve an annual map of plantations.

For the purposes of identification of oil palm plantations using Sentinel-1, an open-source tool by ESA: Sentinel Application Platform (SNAP) has been used for following workflow in Figure 2 that includes above-mentioned corrections. A powerful 24 cores computer node of a high performance computing (HPC) facility has been used for a full scale data analysis.

After the processing, data are converted to logarithmic scale (dB) and translated to WGS-84 coordinate system using precise Sentinel-1 ephemerides. The resulting GeoTIFF file can be afterwards visualized in a GIS environment using RGB false colour composition or can be further processed using specific spatial analyzes. For our cases, a polygon GIS layer corresponding to plantation borders has been selected as the most suitable result. In order to achieve such layer, the average VV/VH ratio image has been thresholded by value of VV/VH>5. Residual noise and non-palm areas between the palm trees has been removed using 3 iterations of Majority filter by SAGA GIS (radius 5 or 10 pixels, depending on scale of focus). The output has been vectorized and the resulting vector simplified using GDAL tools implemented in Quantum GIS. Finally only polygons covering area larger than 1 km^2 were saved as an extracted GIS layer of plantations. A general overview of larger palm plantations (area around 0.02°N, 117.01°E) using this approach is demonstrated on Figure 3.

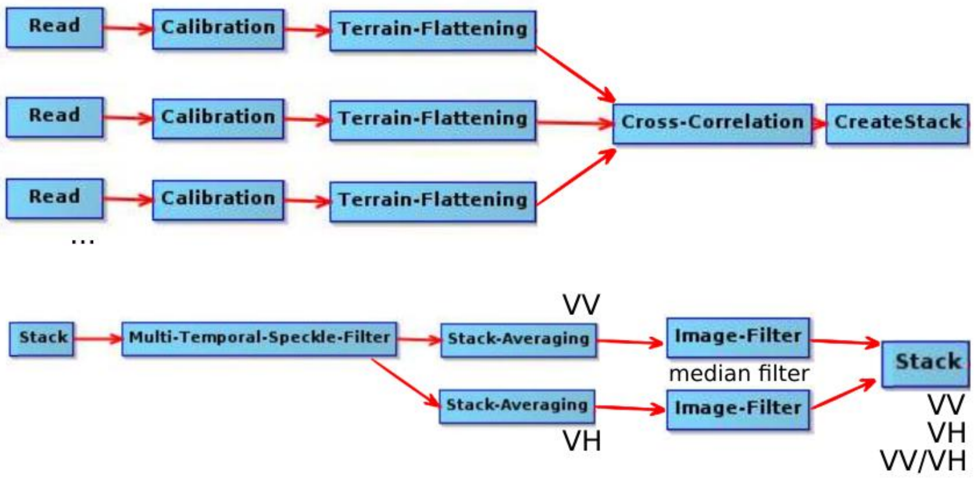

Figure 2. Sentinel-1 data processing workflow using SNAP

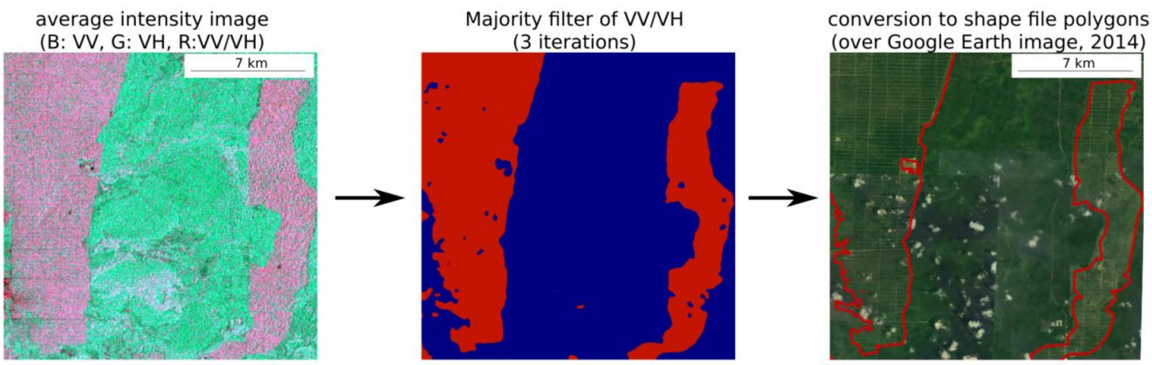

Figure 3. Demonstration of SAR processing steps towards generation of polygons of identified plantations

3. Application to Balikpapan Bay area

The described approach has been adopted to the Balikpapan Bay. In this case, palm plantations are distributed into scattered smaller areas. In order to keep balance between noise and resolution, a multilooking of radar images has been performed before further analysis, decreasing amount of noise but causing a resolution drop down to 50x50 m cell. This approach may lead to neglect very local plantation areas. However the performance showed more suitable than using the original data. The result is visible in following Figures 5-7. Figure 4 shows areas of potential plantations over Balikpapan Bay of size larger than 10 ha as detected by proposed Sentinel-1 processing methodology.

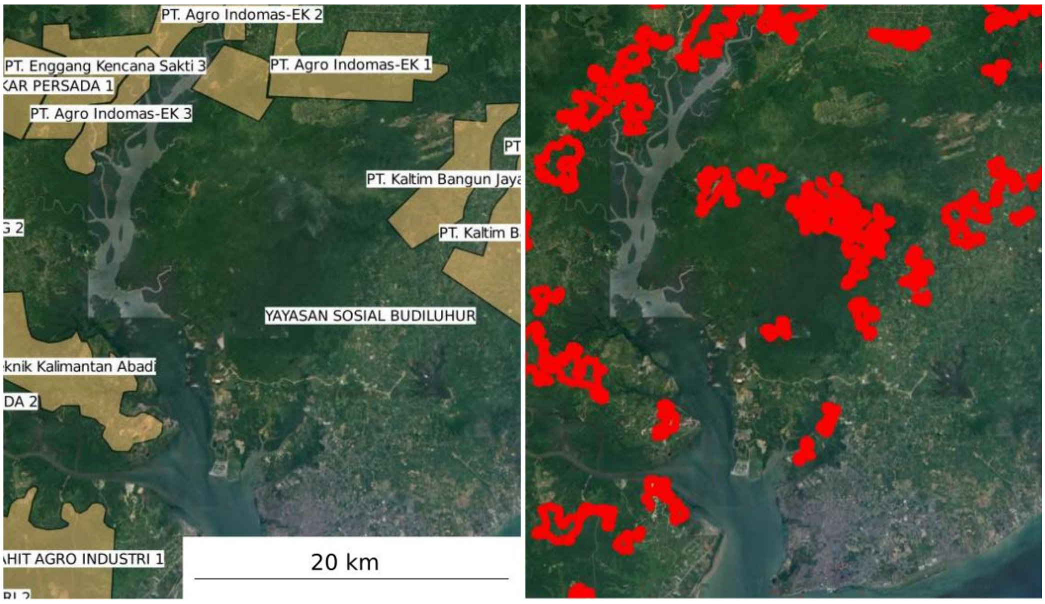

Figure 4. Map of Balikpapan Bay area (background: Google Earth, 2014): GlobalForestWatch map of oil palm concessions (left), map of potential plantations growing in 2017 based on proposed Sentinel-1 methodology (right).

Figure 5 represents a small area processed by proposed methodology. Though a lower resolution of 50x50 m cell, the palm plantation in this area has been well identified - the contour lines of 2017 fit with palm plantation that is well visible in the background Google Earth high resolution image from 2014 (palms are easily distinguishable here for their typical texture, being planted regularly in approx. 3 m distance within each other).

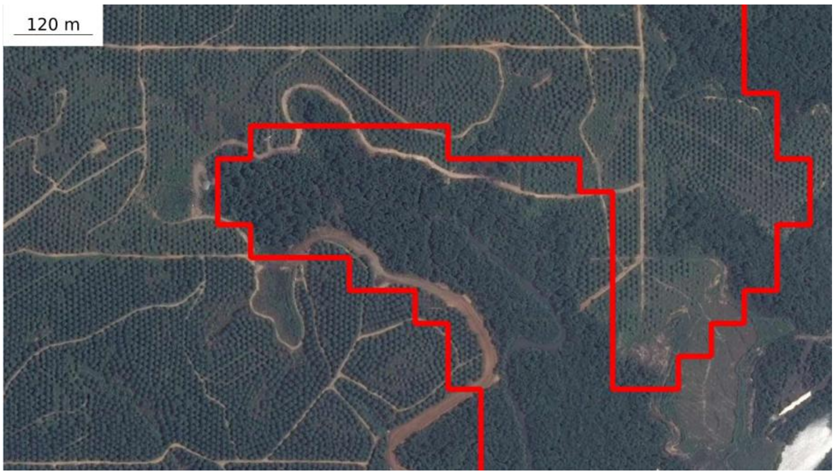

Figure 5. A detailed view of Sentinel-1 processing result (red contour) at a selected plantation.

A spectral response of palm plantations in both multispectral and radar satellite date are visible in Figure 6 - plantations and forests (red in Figure 6a) are easily distinguishable from mangroves using Sentinel-2 where palm plantations are observable mainly using band 8 where their spectral response (from 38% to 48%) is a little higher than spectral response of natural vegetation (from 29% to 37%) in surroundings. Typical leaves of palms change polarization of the radar signal making them distinguishable from surrounding vegetation as seen in Fig. 6b, however the polarization can be changed also by other types of vegetation, being a cause of possible misinterpretation. A map of potential palm plantations differ from official information sources as GlobalForestWatch.org (see Fig. 6c). Identified plantation areas are pictured as red contours in Fig. 6d.

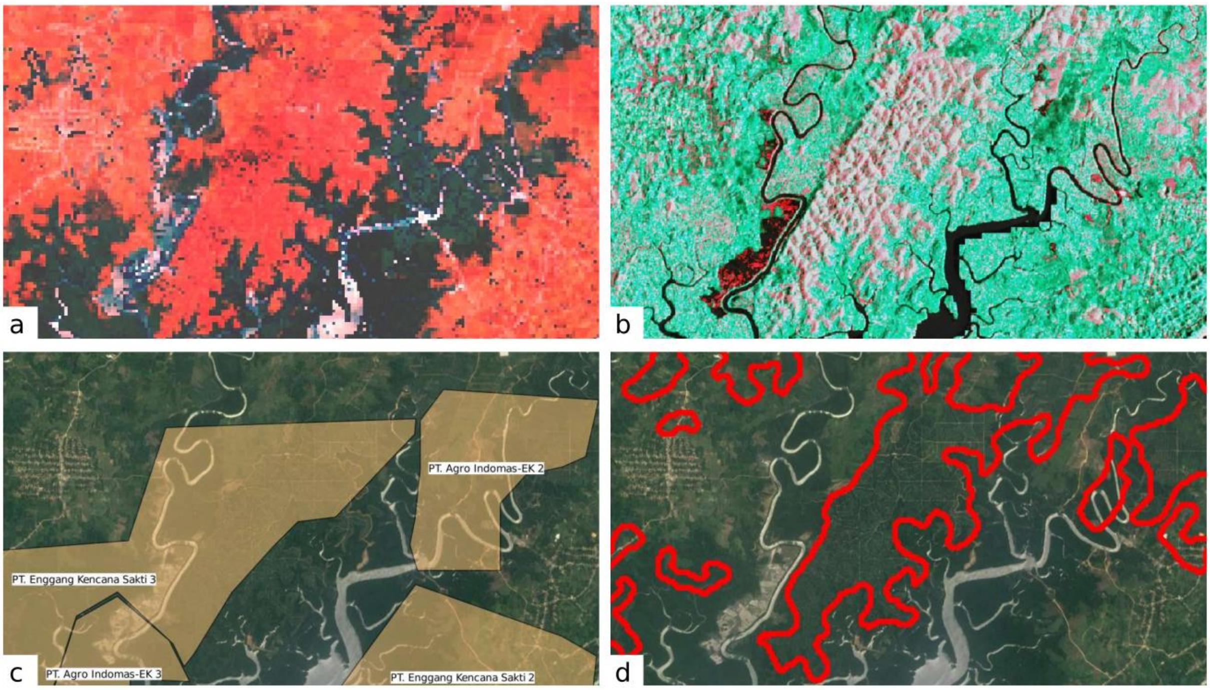

Figure 6. Northern part of Balikpapan Bay: a) RGB composite of Sentinel-2 cloud-filtered map 2015-2017 (B:band 3, G:band 4, R:band 8), b) RGB composite of Sentinel-1 average map 2017 (B:VV, G:VH, R:VV/VH), c) map of palm concessions, d) output of proposed methodology

4. Discussion and conclusions

Plantations were identified using both Sentinel-1 SAR and Sentinel-2 multispectral data in the manner of annual averages, with the main focus into applicability of SAR data. In case of Sentinel-2 images, only few images over 2015-2017 could have been used for the analysis due to persistent cloud coverage. Sentinel-1 data proved its cloud penetrating abilities but generally its only two bands failed in detailed distinguishing between an oil palm and acacia, deforested areas or other main land use classes. As seen on Fig. 4, the automatic processing identifies areas further from official concessions and should be properly interpreted before raising a false classification as a plantation. It should be noted that not only palms would show a significant VV/VH signature of the signal. The information should be dealt as very preliminary and must be further assessed by other methods - either classification by multispectral satellite data or different SAR (e.g. ALOS-2 [24]), local monitoring or an advanced way of Sentinel-1 processing. However the results especially demonstrated by Figures 5 and 6 show a good potential of using dual-polarization mid-resolution Sentinel-1 SAR data for identification of palm plantations. It is planned to apply an updated proposed methodology to perform a multi-temporal investigation in order to capture growth of palm plantations over Balikpapan Bay, as future works. The work should aim towards establishing a methodology for application to a continuous monitoring of semi-illegal growth of plantations over endangered areas in larger scales and higher frequency than it would be possible by local patrols. This would achieve a local impact in areas affected by especially illegal expansion of palm plantations often to protected natural areas.

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