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Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments

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ABSTRACT

Oil palm plantations in Indonesia have been linked to substantial deforestation in the 1990s and 2000s, though recent studies suggest that new plantations are increasingly developed on non-forest land. Without nationwide data to establish recent baseline trends, the impact of commitments to eliminate deforestation from palm oil supply chains could therefore be overestimated. We examine the area and proportion of plantations replacing forests across Sumatra, Kalimantan, and Papua up to 2015, and map biophysically suitable areas for future deforestation-free expansion. We created new maps of oil palm plantations for the years 1995, 2000, 2005, 2010 and 2015, and examined land cover replaced in each period. Nationwide, oil palm plantation expansion occurred at an average rate of 450,000 ha yr^{-1}, and resulted in an average of 117,000 ha yr^{-1} of deforestation, during 1995–2015. Our analysis of the most recent five-year period (2010–2015) shows that the rate of deforestation due to new plantations has remained relatively stable since 2005, despite large increases in the extent of plantations. As a result, the proportion of plantations replacing forests decreased from 54% during 1995–2000, to 18% during 2010–2015. In addition, we estimate there are 30.2 million hectares of non-forest land nationwide which meet biophysical suitability criteria for oil palm cultivation. Our findings suggest that recent zero-deforestation commitments may not have a large impact on deforestation in Sumatra, where plantations have increasingly expanded onto non-forest land over the past twenty years, and which hosts large potentially suitable areas for future deforestation-free expansion. On the other hand, these pledges could have more influence in Kalimantan, where oil palm driven deforestation increased over our study period, and in Papua, a new frontier of expansion with substantial remaining forest cover.

1. Introduction

Oil palm production has been under scrutiny over the past decade, due to concerns that the economic benefits of rapid plantation expansion are outweighed by the social and environmental costs. In Indonesia and Malaysia, where 87% of global palm oil is produced (USDA, 2014), plantations nearly quadrupled in extent between 1990 and 2010, from 3.5 to 12.9 million hectares (Mha) (Gunarso et al., 2013). This rapid expansion resulted in negative environmental impacts including forest loss, peatland destruction, and biodiversity degradation (Koh et al., 2011). In recognition of these consequences, dozens of multi-national retailers, consumer goods companies, and producers of palm oil made pledges to eliminate deforestation from their palm oil supply chains (United Nations, 2014). By 2015, more than 96% of internationally traded palm oil was controlled by companies with a commitment to zero-deforestation palm oil sourcing (Butler, 2015), though less than half of these companies have time bound plans to achieve compliance (Climate Focus, 2016).

Much of the research investigating deforestation due to oil palm expansion in Indonesia focused on impacts in the 1990s and 2000s. These studies report that 52%–79% of plantations nationwide (Gunarso et al., 2013; Koh and Wilcove, 2008), and 89%–90% of plantations in Kalimantan (Carlson et al., 2013), replaced forests. However, recent research suggests that the proportion of oil palm plantations driving deforestation may be declining. For example, Gaveau et al. report that more than half of oil palm plantations in Kalimantan replaced forest prior to 1990, but that approximately one-third replaced forests after 2000 (Gaveau et al., 2016). Vijay et al. also report an overall decline in the proportion of plantations driving deforestation across the tropics, and nationally in Indonesia, from 1984 to 2013 (Vijay et al., 2016). Thus, using trends from the 1990s and early 2000s to establish a baseline could result in an overestimation of the impacts of zero-deforestation pledges.

This study extends the scope of previous research by estimating oil

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palm driven deforestation across Indonesia from 1995 to 2015. We contribute new nationwide data for the 2010–2015 period, to inform how trends have shifted in the recent past. To conduct our analysis, we created new maps of oil palm plantations across Indonesia's major oil palm producing islands of Sumatra, Kalimantan, and Papua from 1995 to 2015, and tracked forest cover in these areas using data from Indonesia's Ministry of Environment and Forestry. In addition, we examined the extent to which future plantation expansion may be constrained by zero-deforestation commitments, by mapping suitable land for oil palm cultivation that could be available for future deforestation-free production.

2. Methods

2.1. Mapping oil palm plantations

We created new maps of large-scale oil palm plantations in Indonesia's major producing regions of Sumatra, Kalimantan and Papua for the years 1995, 2000, 2005, 2010, and 2015, at a resolution of 250 × 250 m. We delineated plantations by visually interpreting Landsat imagery, a method which has been successfully used to map oil palm plantations in the region (Carlson et al., 2013; Gaveau et al., 2016; Gunarso et al., 2013; Ramdani and Hino, 2013). Visual interpretation methods are valuable for identifying oil palm plantations, which have similar spectral reflectance patterns as secondary forest cover, but are frequently organized in rectilinear patterns and co-occur with context indicators such as road networks (Gaveau et al., 2016).

We mapped plantations in 1995–2010 using a combination of Global Land Survey Landsat composites and Landsat 4–5 TM imagery (USGS, 2011). We based our map for the year 2015 on a cloud-free Landsat composite (Hansen et al., 2013). In ArcGIS version 10.2, we systematically inspected across the landscape by applying a grid index with cell size 25 × 25 km. We mapped only large-scale oil palm plantations, which are frequently organized in a grid pattern, and associated with infrastructure including roads, mill facilities, and management buildings. We included recently cleared areas adjacent to existing plantations, which appeared to have been prepared for oil palm cultivation based on their grid formation.

We validated the resulting maps using the web-based validation tool Laco-Wiki, which incorporates imagery from Google and Bing Maps (http://www.laco-wiki.net/) (See et al., 2015). We constrained our validation samples to areas with high resolution ($< 5\ m^2$) imagery, which allowed us to see the crowns of individual palms. For each map we randomly selected a roughly equal number of validation points within mapped oil palm plantations, and within a 25 km buffer outside plantations. We selected this buffer to avoid inflating our accuracy estimate by including points well outside the biophysically suitable area for oil palm cultivation (SI Fig. 1). We assumed that all plantations were still observable in imagery from the years 2016 and 2017.

2.2. Assessing land cover change

To assess land cover change driven by oil palm plantation expansion, we used nation wide data on land cover for the years 1996, 2000, 2006, and 2011, provided by the Ministry of Environment and Forestry (MoEF, 2015). MoEF defines forest as land spanning an area of at least 0.25 ha, with trees higher than 5 m and canopy cover greater than 30 percent (MoF, 2004). We reclassified the Ministry of Environment and Forestry (MoEF) data into two forest cover categories- primary and secondary forest, and five non-forest categories- agriculture, timber plantation, swamp scrubland, savannah/bare land/scrubland, and other (SI Table 1). We then calculated the area of each land cover class converted to new oil palm plantations in each 5-year interval, assuming that the maps represent land cover at the start of each corresponding period.

To determine whether our results are robust to the input forest cover dataset, we repeated our analysis using forest cover in the year 2000 (Margono et al., 2014). Margono et al. define primary forest as natural forest > 5 ha that have not been cleared and re-planted, including 'intact primary forest' which have no evidence of human disturbance, and 'primary degraded forest' which have been subject to partial canopy loss due to human disturbances. We updated this map for the years 2006 and 2011 by accounting for tree cover loss from Hansen et al. (Hansen et al., 2013). The results correspond closely to those using the MoEF dataset: the proportion of plantations replacing forests using the Margono dataset is 0.2% lower than the results using the MoEF dataset in the 2000–2005 period, 1.1% higher in the 2005–2010 period, and 0.6% lower in the 2010–2015 period (SI Table 2). We additionally estimated the area of peat lands converted to oil palm plantations in each interval using data on the extent of peat soils from Indonesia's Ministry of Agriculture (MoA, 2011).

2.3. Estimating future zero-deforestation potential

We estimated the land area eligible for future zero-deforestation oil palm expansion, using a map of biophysically suitable land for oil palm cultivation across the tropics based on climate, topographic, and soil variables (Pirker et al., 2016). We combined the 'highly suitable' and 'perfect' suitability categories into one 'suitable' classification, and excluded from this class the area of oil palm plantations in 2015. We further refined this class by excluding peat lands (MoA, 2011) and protected areas (IUCN and UNEP-WCMC, 2015), which we assumed would be fully protected from future expansion. Finally, we limited expansion to areas less than 500 m elevation (Jarvis et al., 2008), in order to better reflect suitability in the Indonesian context. We used the MoEF land cover map for the year 2011 to estimate the area of potential suitability in non-forest areas. We did not consider other factors that may constrain the use of non-forest land for oil palm expansion, such as land tenure, labor availability, accessibility, or legal classification (Goh et al., 2017). Additional data collection and scale-appropriate evaluations, including for example site-level environmental and social impact assessments, free prior and informed consent, and participatory community mapping, are necessary to refine this analysis and underpin conflict-free land use planning (Gingold et al., 2012; Rosoman et al., 2017).

3. Results

3.1. Oil palm plantation expansion during 1995–2015

There were 11.1 Mha of industrial-scale oil palm plantations in Indonesia in 2015, with 5.9 Mha in Sumatra, 5.0 Mha in Kalimantan, and 0.2 Mha in Papua (Fig. 1). Plantations expanded by 9.0 Mha nationwide between 1995 and 2015 (an increase of 4.3 Mha in Sumatra, 4.5 Mha in Kalimantan, and 0.2 Mha in Papua). Prior to 2005 approximately 0.3 Mha of new plantations were established each year, while after 2005 the rate of expansion doubled to approximately 0.6 Mha annually.

Our estimates of the area of oil palm plantations correspond closely to estimates from previous studies (SI Fig. 2). The accuracies of our oil palm maps range from 89.2% to 91.5%, with roughly equal errors of commission and omission. Error matrices for all years are provided in the supplement (SI Table 3). We acknowledge that our method may incorrectly include smallholder palm in our map of large holder plantations, but that this may not be reflected in our accuracy assessment, since both categories appear as palm in high resolution imagery.

3.2. Land cover replaced by oil palm plantations

Oil palm plantations resulted in an average of 586 kha of deforestation in each five-year time step, declining from a high of 788 kha in the 1995–2000 period, to a low of 357 kha from 2000 to 2005, and then