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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

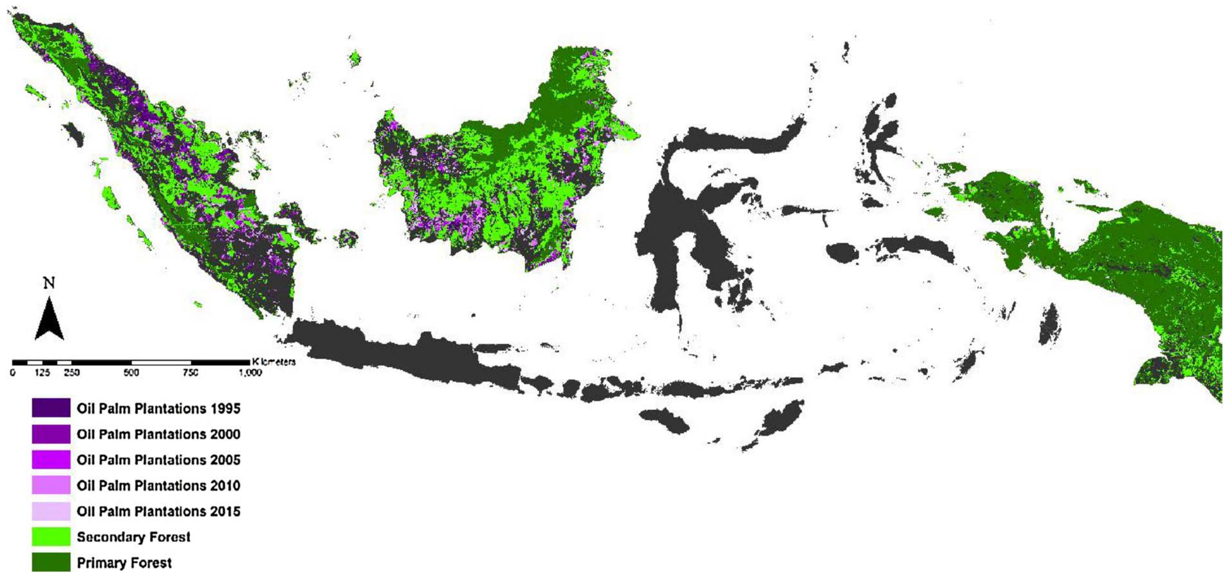

Fig. 1. Industrial-scale oil palm plantations 1995–2015, and forest cover in the year 1996 from the Ministry of Environment and Forestry.

rebounding to 616 kha and 585 kha during the 2005–2010 and 2010–2015 periods, respectively (Fig. 2A, SI Table 4). Most this forest loss occurred in secondary (94.9%) rather than primary (5.1%) forest categories. At the same time, the proportion of new plantations causing deforestation decreased from more than half, or 53.9%, during 1995–2000, to 18.0% during 2010–2015 (Fig. 2B). On the other hand, the proportion of plantations derived from non-forest land increased, including notably the proportion from agriculture land, which increased from 22.1% in the 1995–2000 period to 37.9% in the 2010–2015 period.

Nationwide approximately one-fifth of oil palm plantations in each period expanded on peat lands, and this proportion remained stable across the study period (SI Table 4). As the total area of expansion increased, the total area of expansion onto peat doubled, from 305 kha during 1995–2000, to 619 kha during 2010–2015. Most the peat areas converted to oil palm were in the secondary forest, swamp, and swamp scrubland classifications, according to the MoEF data.

The oil palm plantation establishment patterns differ among the three islands of Sumatra, Kalimantan, and Papua (Fig. 3, SI Table 5). Sumatra was responsible for 669 kha (or 84.9%) of national

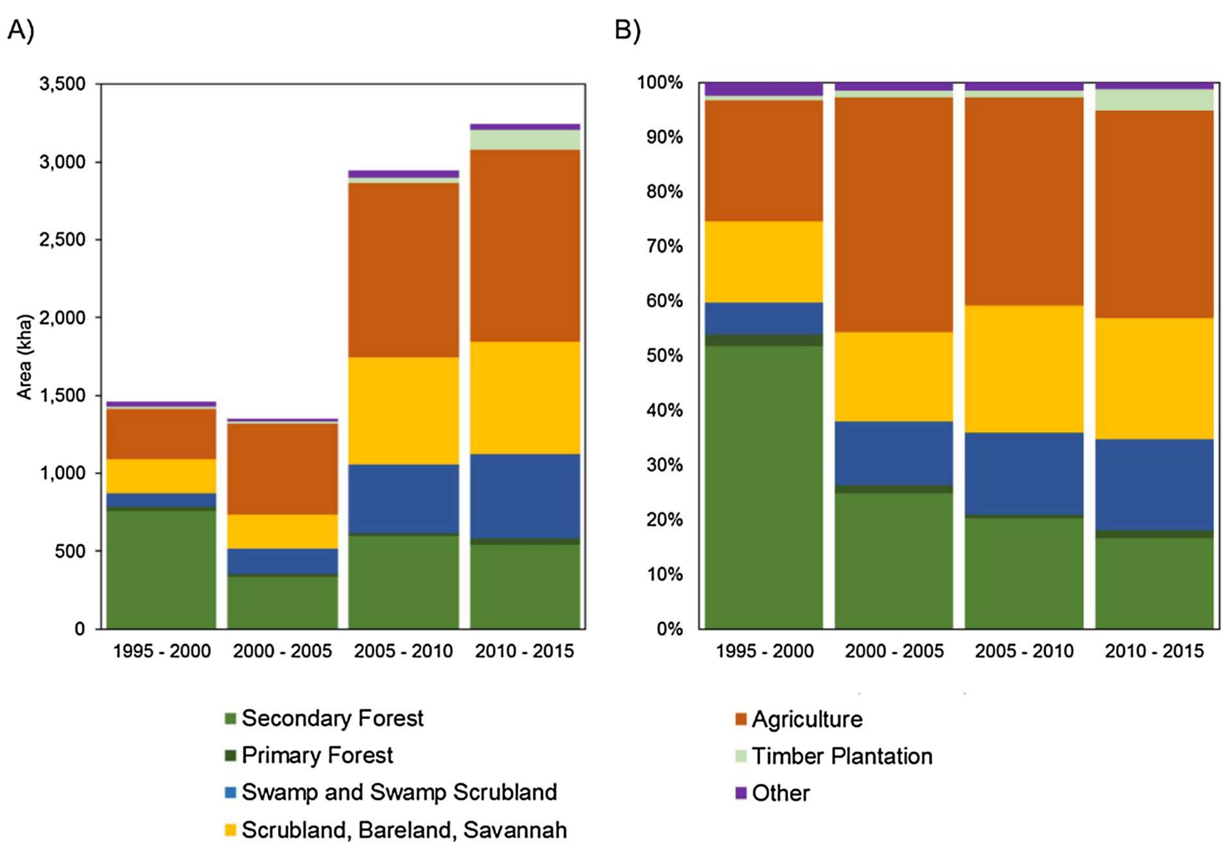

Fig. 2. A) Area and B) Proportion of each land cover category converted to oil palm plantations in each time period, across all three study islands.

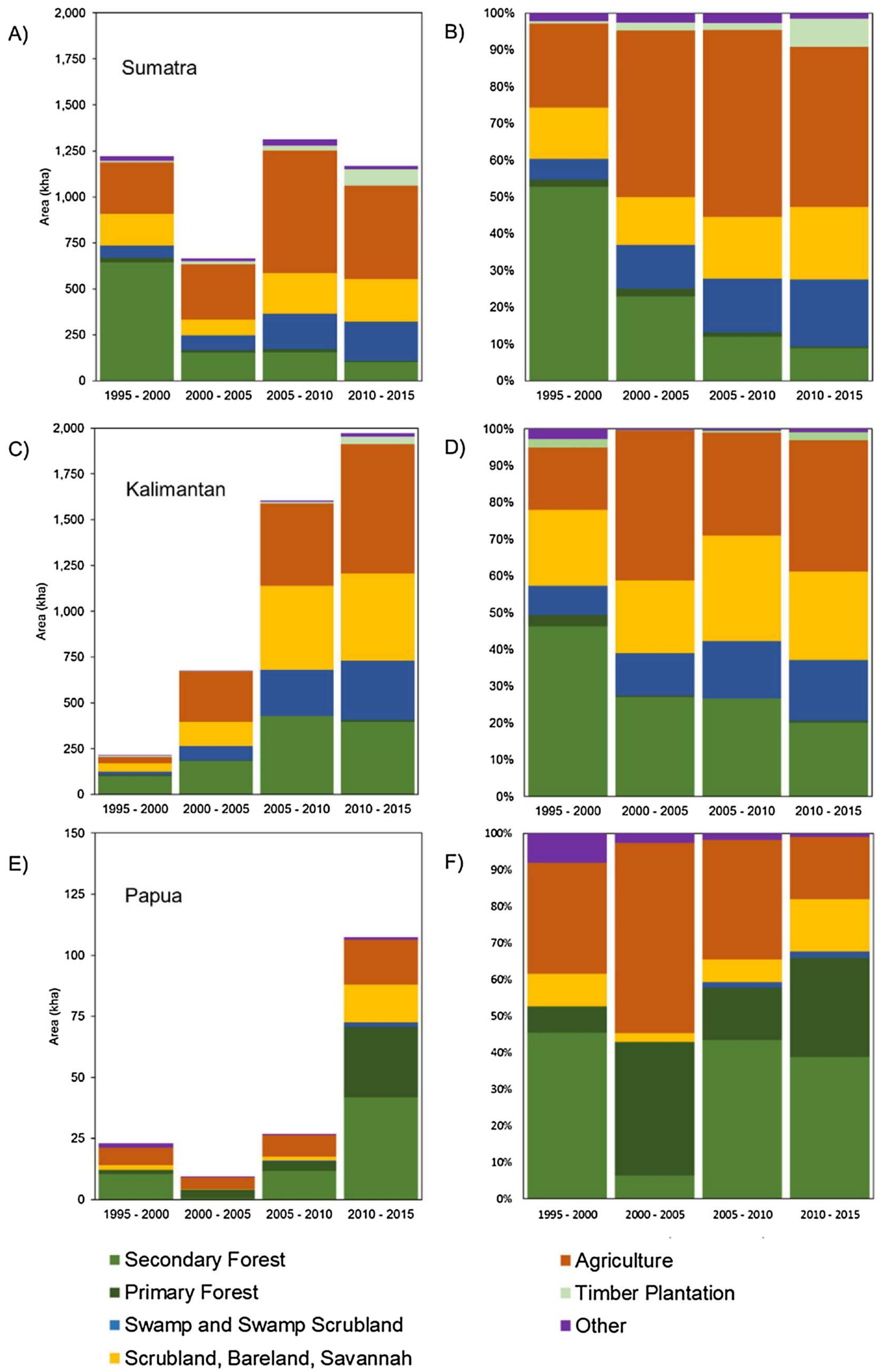

Fig. 3. A) Area and B) Proportion of each land cover category converted to oil palm in Sumatra. C) Area and D) Proportion of each land cover category converted to oil palm plantations in Kalimantan, and E) Area and F) Proportion of each land cover category converted to oil palm plantations in Papua. Note the scale of the y-axis is different for Papua.

deforestation due to oil palm in the 1995–2000 period, but just 107 kha (or 18.3%) in the 2010–2015 period (Fig. 3A). On the other hand, Kalimantan was responsible for 107 kha (or 13.6%) of national deforestation due to oil palm in the 1995–2000 period, and 407 kha (or 69.6%%) in the 2010–2015 period (Fig. 3C). The proportion of oil palm plantations replacing forests in both Sumatra and Kalimantan declined over the twenty-year study period. However, the decline in Sumatra, from 54.7% of plantations replacing forest from 1995 to 2000, to 9.2% from 2010 to 2015 (Fig. 3B), is more pronounced than in Kalimantan, where the proportion declined from 49.3% to 20.6% at the same time (Fig. 3D).

In Papua, which hosts just 2% of all oil palm plantations nationwide in 2015, we observe a divergent trend. While on a relatively smaller scale than elsewhere in the archipelago, the amount of deforestation driven by oil palm expansion increased five-fold in Papua, from 12 kha in the 1995–2000 period to 71 kha in the 2010–2015 period (Fig. 3E). The proportion of new plantations replacing forests is also substantially larger than in Sumatra and Kalimantan, and increased over the study period, reaching a high of 66.0% from 2010 to 2015 (Fig. 3F).

3.3. Suitability for future zero-deforestation oil palm

There are 48.5 Mha of biophysically suitable land for oil palm cultivation across Indonesia, with a roughly even distribution across the archipelago (16.5 Mha in Sumatra, 19.4 Mha in Kalimantan, and 12.5 Mha in Papua) (Fig. 4). Nationwide more than half of this suitable area (30.2 Mha) was not forested in 2011. However, non-forest land suitable for oil palm production is not evenly distributed across the archipelago; 15.2 Mha is found in Sumatra, 13.0 Mha in Kalimantan, and just 2.0 Mha in Papua. Except for West Sumatra, more than 80% of the biophysically suitable land in all Sumatran provinces is not forested (SI Fig. 3). More than 80% of the suitable land in South and West Kalimantan is also non-forest. On the other hand, less than 50% of the suitable land in Central and East Kalimantan, and less than 20% of the suitable land in the provinces of Papua and West Papua, is non-forest.

4. Discussion

4.1. Policy context

Government regulations designed to reduce the impacts of oil palm agriculture on forests have thus far had limited success in Indonesia. The 2011 moratorium on new permits for oil palm expansion in primary forests and peatlands is one notable example (Murdiyarso et al., 2011). The modest impact of the moratorium on slowing deforestation may be due to the partial protection of forests by the policy (Busch et al., 2015), poor dissemination of information about the moratorium to local implementing agencies (Austin et al., 2014), weak law enforcement, and local vested interests (Pirard et al., 2017). In recognition of these challenges, non-governmental organizations and advocacy groups have increasingly focused on market-based conservation strategies, including certification schemes and commodity roundtables, which rely on consumer pressure to incentivize companies to improve their social and environmental performance (Lambin et al., 2014). More recently, advocacy organizations have called for strengthened standards with respect to oil palm driven deforestation than under previous market-based approaches (Climate Focus, 2016). These campaigns highlighted deforestation as a reputational risk and a threat to market access, and prompted more than 400 companies to commit to zero deforestation supply chains (Donofrio et al., 2017).

Ex-post assessments have documented significant impacts of pledges to eliminate deforestation in other regions and commodity supply chains. This includes for example the timber industry in Chile (Heilmayr and Lambin, 2016) and Indonesia (Miteva et al., 2015) and in the soy and beef industries in Brazil (Gibbs et al., 2016; Macedo et al., 2012). However, these and other studies have also noted several limitations to these commitments that could reduce or neutralize their effectiveness. These include leakage, in which expansion onto existing agricultural land shifts agriculture to the forest frontier (Arima et al., 2011), laundering, where commodities causing deforestation are sold through a compliant property (Gibbs et al., 2016), market segmentation, when producers sell non-compliant products to consumers with lower environmental standards (Heilmayr and Lambin, 2016), and the absence of legal and legislative support to implement zero-deforestation commodity production (Streck and Lee, 2016).

In the following sections we discuss the heterogeneous patterns of oil palm driven deforestation across Indonesia, to provide a more refined understanding of the potential impact of zero-deforestation pledges on regional rates of deforestation. We additionally highlight key implementation challenges that companies and government agencies may consider as these commitments are put into practice.

4.2. Regional patterns

The observed pattern in oil palm driven deforestation nationwide is

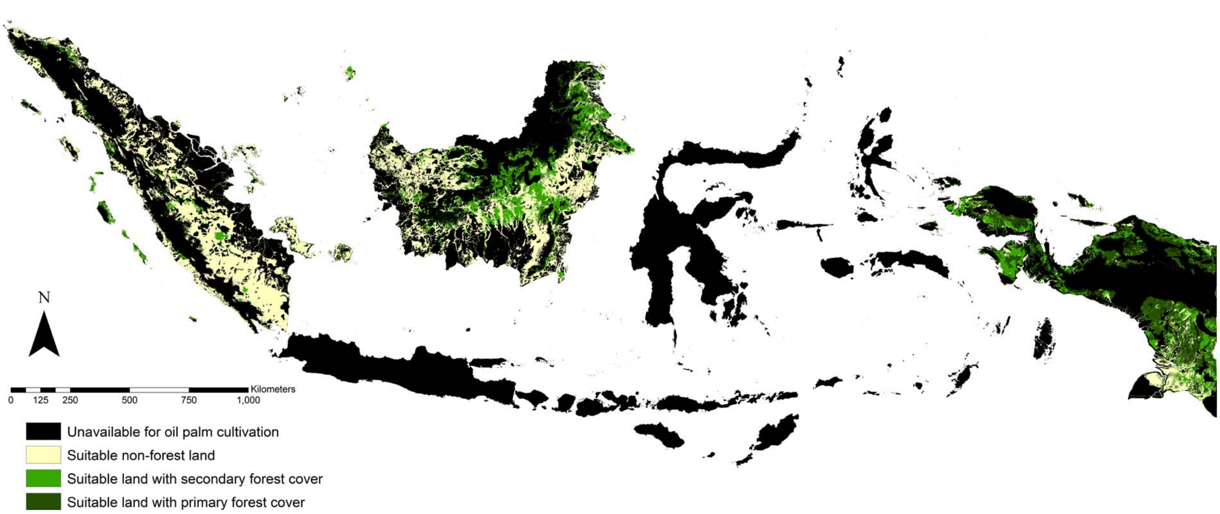

Fig. 4. Biophysically suitable land for oil palm cultivation. Yellow represents suitable non-forest areas, while green represents suitable secondary and primary forested areas. Black areas are not suitable for oil palm cultivation, or are peat lands, protected areas, above 500 m elevation, or existing oil palm plantations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the result of opposing trends in Sumatra and Kalimantan over the study period. While the rate of plantation expansion levelled off and the area of oil palm driven deforestation declined in Sumatra, production shifted to Kalimantan, where it drove increasing deforestation. In both regions the proportion of oil palm expansion resulting in forest loss declined from 1995 to 2015. Expansion patterns therefore increasingly resemble patterns documented in South and Central America, where the majority of recent oil palm expansion occurred on non-forest land made available due to a long history of export-oriented commodity agriculture and ranching (Furumo and Aide, 2017; Vijay et al., 2016).

In Sumatra, plantation expansion plateaued after 2005, and we observed a marked decline in both the total amount of deforestation driven by oil palm, and the proportion of expansion resulting in deforestation. Less than one-quarter of plantations after 2000, and less than 10% of plantations from 2010 to 2015, replaced natural forest land. This trend is likely due to Sumatra's relatively long history of plantation agriculture and higher population density, which made large non-forest areas available for deforestation-free expansion. However, this non-forest area includes planted forest, including pulp and paper and rubber plantations, which may not be considered eligible for zero-deforestation production according to recent consensus mapping approaches (Rosoman et al., 2017). We estimate that more than 90% of the more suitable land for oil palm cultivation in Sumatra is no longer covered by natural forest, suggesting that future oil palm expansion will continue predominantly in non-forest areas even in the absence of policy interventions.

The expansion of oil palm plantations in Kalimantan accelerated after 2000 due to policy reforms in the late 1990s which facilitated a favorable investment climate and attractive leases (Bissonnette and De Koninck, 2015). The resulting rapid plantation expansion caused an increase in deforestation due to oil palm, even as the proportion of plantations replacing forests declined from almost half in 1995–2000, to approximately one-fifth in the 2010–2015 period. Our results for Kalimantan are consistent with those of Gaveau et al., who also report to a steady decline in the proportion of new plantations replacing forests. Two-thirds of the suitable land for oil palm cultivation is not forested across the island of Kalimantan, and sufficient to accommodate substantial future deforestation-free expansion. However, less than 50% of the suitable land is non-forest in Central and East Kalimantan, suggesting that zero-deforestation commitments may be more constraining in those provinces.

There has been relatively little expansion of plantations in Papua up to present, though the region is seen as a new frontier for future oil palm development (Kesaulija et al., 2014). Due to high remaining forest cover and low historic rates of deforestation, more than two-thirds of plantations in Papua replaced forest land from 2010 to 2015. In addition, while the region hosts large areas of suitable land for oil palm cultivation, just 16% of this area, or 2.0 Mha, was non-forest in 2011. As companies begin take deforestation risk into account, this could result in less investment in the region. The same may be true in other frontiers of oil palm expansion with extensive remaining forest cover, including for example many countries in Central Africa (Austin et al., 2017).

4.3. Indirect land use change

Natural forest cover loss increased in Indonesia since at least the year 2000, reaching 839,000 ha in 2012 (Margono et al., 2014). Over the same period, we estimate that oil palm driven deforestation decreased, contributing approximately 14% of national deforestation from 2010 − 2015. However, it is possible that expansion onto non-forest land, particularly agriculture land in Sumatra and Kalimantan, could have resulted in the displacement of less profitable agricultural activities to the forest frontier, indirectly driving deforestation (Gatto et al., 2015).

Leakage of deforestation due to voluntary sustainability commitments made by commodity producers has been documented in other contexts. For example, after the implementation of the soy moratorium in the Brazilian Amazon, Macedo et al. reported that soy increasingly expanded onto existing agricultural and pasture lands, resulting in a substantial decrease in direct deforestation (Macedo et al., 2012). However, Arima et al. demonstrated that soy expansion onto pasture lands indirectly drove deforestation elsewhere, calling into question the effectiveness of the anti-deforestation strategy (Arima et al., 2011).

Importantly, the types of agricultural land replaced by large scale oil palm plantations may include smallholder oil palm agriculture. Smallholder oil palm comprises more than one-third of Indonesia's national production (Rist et al., 2010), but small farms have not been mapped nationally and are not distinguished by the MoEF land cover maps. Mosnier et al. estimate that one of the impacts of industry zero-deforestation commitments will be to increase smallholder cultivated area, resulting in higher rates of deforestation attributable to small-scale oil palm (Mosnier et al., 2017). Additional research to determine the specific land uses which were replaced by oil palm plantations, and whether leakage occurred using statistical analyses, e.g. via economic simulation models (Meyfroidt et al., 2013), is a priority.

4.4. Regulatory obstacles

We find that Sumatra and Kalimantan host substantial non-forest areas which are potentially suitable for oil palm cultivation. However, the extent to which companies will be able to take advantage of these landscapes is limited by several factors (Goh et al., 2017). Key among these obstacles are spatial plans for oil palm expansion developed by government planning and permit granting agencies. These agencies wield considerable influence in determining where oil palm is legally allowed to expand, and the considerable area of forest land within the current portfolio of permits suggests that they do not yet reflect the private sector zero deforestation agenda (Carlson et al., 2013). In addition, the legal mechanisms for a company to protect forests within the boundaries of an existing permit are limited, and the mechanisms enabling a company to swap an existing permit in a forested area for an equivalent permit in a non-forest location are complex and costly (Rosenbarger et al., 2013). The lack of a supportive legal and regulatory framework for zero-deforestation commitments may hinder their implementation and ultimately their effectiveness (Streck and Lee, 2016).

4.5. Other considerations

Our analysis is based on land cover data from the Ministry of Environment and Forestry, which is largely consistent with data on forest cover from Margono et al., 2014. However, both products use a definition of forest which does not include secondary forest cover that is regenerating from a previous clearing. Protecting regenerating forests could support valuable biodiversity resources and provide carbon sequestration services, and has been proposed for inclusion in the definition of 'forest' underpinning zero-deforestation commitments (Rosoman et al., 2017). Improved maps of areas of forest regrowth will enable the incorporation of this land cover category in future analyses.

This study does not consider areas hosting exceptional levels of biodiversity, significant ecosystem services, important values for local communities, or other high conservation value (HCV) attributes. Elsewhere, there is a risk that zero-deforestation commitments could shift expansion into non-forest areas that are also HCV, including native grassland and savannah habitats (Austin et al., 2017). As maps of HCV land characteristics are developed in Indonesia, it will be important to examine whether shifting plantation away from forest land results in an increase in the conversion of non-forest HCV areas.

We note that the proportion of plantations expanding on peat lands remained steady at approximately 20% across our study period, and the total area of plantations expanding on peat lands increased at the same time, to more than 600 kha in the 2010–2015 period. However, we do not consider whether the areas of peat converted to oil palm plantations had been previously drained or degraded for other uses. Most zero-deforestation commitments include provisions to avoid conversion of peat lands as well as forests. Given that the proportion of plantations expanding on peat lands has not declined in the same pattern as we observe in forest areas, it is possible that these pledges could have a substantial impact on rates of peat land conversion and degradation. Improved maps of peat extent, depth, and management status will enable more detailed evaluation of this potential.

5. Conclusion

Zero-deforestation commitments are now commonplace among oil palm growers and consumer goods companies. There is growing interest in assessing the extent to which these commitments will address a key driver of deforestation in Indonesia (Bregman et al., 2016; McCarthy, 2016; Mosnier et al., 2017). This study provides the most up to date nationwide data on trends in oil palm driven deforestation, informing the potential effectiveness of these pledges. We find that oil palm production continues to be a notable driver of deforestation in Indonesia, and the rate of oil palm driven deforestation has remained relatively stable since 2005, averaging 117,000 ha annually. We also note that the proportion of oil palm expansion resulting in forest loss declined over our study period, reaching less than one-fifth by 2015. This suggests that oil palm expansion increasingly occurred in non-forest areas even in the absence of zero-deforestation commitments. In addition, we find that there is a large area of potentially suitable land for oil palm that is not forested in Sumatra and Kalimantan, suggesting that zero-deforestation pledges may not constrain future plantation expansion in these regions. However, these commitments have the potential to accelerate an ongoing transition towards 100% deforestation-free oil palm nationwide, and may prevent future expansion from shifting to areas with high remaining forest cover and historically low rates of deforestation, such as Papua.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2017.08.036.

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