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Managing fire risk during drought: the influence of certification and El Niño on fire-driven forest conversion for oil palm in Southeast Asia

Praveen Noojipady[1, 2], Douglas C. Morton[1], Wilfrid Schroeder[2], Kimberly M. Carlson[3], Chengquan Huang[2], Holly K. Gibbs[4], David Burns[5], Nathalie F. Walker[5], Stephen D. Prince[2]

[1]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[2]University of Maryland, College Park, MD 20742, USA
[3]University of Hawai'i, Honolulu, HI 96822, USA
[4]University of Wisconsin, Madison, WI 53706, USA
[5]National Wildlife Federation, National Advocacy Center, Washington, DC 20006, USA

Correspondence to: Praveen Noojipady (praveen.noojipady@nasa.gov)

Abstract. Indonesia and Malaysia have emerged as leading producers of palm oil in the past several decades, expanding production through the conversion of tropical forests to industrial plantations. Efforts to produce "sustainable" palm oil, including certification by the Roundtable on Sustainable Palm Oil (RSPO), include guidelines designed to reduce the environmental impact of palm oil production. Fire-driven deforestation is prohibited by law in both countries and a stipulation of RSPO certification, yet the degree of environmental compliance is unclear, especially during El Niño events when drought conditions increase fire risk. Here, we used time series of satellite data to estimate the spatial and temporal patterns of fire-driven deforestation in and around oil palm plantations. In Indonesia, fire-driven deforestation accounted for one quarter of total forest losses in both certified and non-certified plantations. After the first plantations in Indonesia received RSPO certification in 2009, forest loss and fire-driven deforestation declined in certified plantations but did stop altogether. Oil palm expansion in Malaysia rarely involved fire; only 6% of forest loss in certified plantations had coincident active fire detections. Interannual variability in fire detections was strongly influenced by El Niño and the timing of certification. Fire activity during the 2002, 2004, and 2006 El Niño event was similar among oil palm plantations in Indonesia that would later become certified, non-certified plantations, and surrounding areas. However, rates of fire activity were 57% and 44% lower in certified plantations than non-certified plantations during the 2009 and 2015 El Niño events, respectively. The decline in fire activity on certified plantations, including during drought periods, highlights the potential for RSPO certification to safeguard carbon stocks in peatlands and remaining forests and support legislation banning fires. However, aligning certification standards with satellite monitoring capabilities will be critical to realize sustainable palm oil production and meet industry commitments to zero deforestation.

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1 Introduction

Global production of agricultural commodities such as palm oil has risen steadily in recent decades, driven by market demand and high economic value (USDA, 2009 , 2010 , 2016). Southeast Asia's palm oil sector has grown through expansion of oil palm plantations in Malaysia, Indonesia, and more recently, Papua New Guinea (Gunarso et al., 2013; Carlson et al., 2013; Miettinen et al., 2016a; Vijay et al., 2016). By 2014, Indonesia and Malaysia accounted for nearly 69% of the global oil palm harvested area (FAO, 2016).

In the past decade, Indonesia had the highest rate of forest loss of any country in Southeast Asia (Hansen et al., 2013; Margono et al., 2014; Kim et al., 2015), spurred by rapid forest conversion for oil palm and other industrial plantations (Carlson et al., 2012; Gunarso et al., 2013; Abood et al., 2015). Between 1990-2010, more than one third of new oil palm plantations replaced forested landscapes in Southeast Asia (Gunarso et al., 2013; Gaveau et al., 2016), with rates as high as 90% in regional hotspots such as coastal West Kalimantan, Indonesia (Carlson et al., 2013). Conversion of primary and logged forests for oil palm, including vast areas with deep organic peat soils, contributed to significant greenhouse gas (GHG) emissions from decomposition, fire, and peat oxidation (Page et al., 2002; van der Werf et al., 2008; Hooijer et al., 2012; Ramdani and Hino, 2013; Field et al., 2016; Huijnen et al., 2016). Environmental concerns with palm oil production extend beyond GHG emissions, however, as forest loss threatens biodiversity (Pimm et al., 2014; Vijay et al., 2016) and particulate emissions from fires are a major public health concern in Indonesia and downwind population centers such as Singapore (Murdiyarso et al., 2004; Gaveau et al., 2014; Kunii et al., 2002; Reddington et al., 2014; Marlier et al., 2015; Chisholm et al., 2016; Johnston et al., 2015).

Palm oil is the fastest growing certified agriculture commodity, and Indonesia accounted for >50% of certified production areas in 2016 (Potts et al., 2014; RSPO, 2016). The push for certification within the palm oil industry reflects a growing consumer awareness of GHG emissions from palm oil expansion and peat oxidation and an overall rise in producer and consumer interest in "sustainable" and deforestation-free products (UNCS, 2014; Butler, 2015; McCarthy et al., 2016). The Roundtable on Sustainable Palm Oil (RSPO) certification is the most widely adopted certification standard. Worldwide, RSPO has certified 2.83 Mha in oil palm plantations that produce 10.8 million tons of palm oil, or approximately 17% of global palm oil production (RSPO, 2016). Specific principles and criteria of RSPO certification promote sustainable palm oil production and processing (Garrett et al., 2016; RSPO, 2004, 2015b). Among other provisions, RSPO certification prohibits conversion of primary and high conservation value (HCV) forests and bans fire use for land clearing in compliance with the Indonesian moratorium on fire (RSPO, 2007; RSPO, 2013 ;Edwards and Heiduk, 2015, RSPO, 2013). The RSPO does not independently monitor fire activity within member plantations, despite freely available data from NASA satellites. Recent fire activity has been assessed for a subset of palm oil concessions in Indonesia (Cattau et al., 2016a), but the use of fire for forest conversion on oil palm plantations has not previously been quantified.

Improving estimates of fire-driven deforestation is critical to assess environmental compliance by oil palm plantations, reduce uncertainties in deforestation carbon emissions (Le Quéré et al., 2015; Houghton et al., 2012; van der Werf et al.,

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2009b), and characterize ignition sources that may give rise to uncontrolled burning during drought periods (Carlson et al., 2012; Cattau et al., 2016a). The timing of GHG emissions from forest conversion to oil palm depends on the degree of fire use for deforestation (DeFries et al., 2008; Houghton et al., 2012), including the proportion of clearing activity through fire and the combustion completeness of initial or repeated burning (van der Werf et al., 2009a). Fires are common in industrial plantations and smallholder properties (Stolle et al., 2003; Austin et al., 2015; Marlier et al., 2015; Miettinen et al., 2016b; Cattau et al., 2016a), yet the link between fire activity and forest conversion is unclear. Many estimates of carbon emissions from tropical forest conversion report committed fluxes without separating fire and decomposition losses (Koh et al., 2011; Carlson et al., 2012; Austin et al., 2015). Previous studies with biogeochemical or bookkeeping models suggest that fire accounts for 30% (Houghton and Hackler, 1999) to 50% (van der Werf et al., 2009a) of carbon emissions from aboveground biomass during forest conversion in Southeast Asia—a broad range that applies to all forest conversion, not strictly to oil palm expansion. Fires are not restricted to forested areas; El Niño conditions suppress precipitation over large parts of Southeast Asia, leading to widespread fire activity during drought periods, particularly in carbon-rich peatlands (Page et al., 2002; van der Werf et al., 2008; Field et al., 2009, 2016). Understanding the contribution from fire-driven deforestation to total fire activity is therefore a critical part of mitigating fire risk during drought years (e.g., Chen et al., 2016).

Here, we combined time series of satellite data on forest loss and active fire detections with locations of oil palm plantations to assess fire-driven forest and peatland conversion in and around oil palm plantations. The combination of land management, forest loss, and active fire data provides an opportunity to evaluate the relative contributions from different fire types to spatial and temporal variability in satellite fire detections. Our study addresses three primary questions regarding oil palm expansion: 1) What fraction of forest and peat forest conversion for oil palm involves fire? 2) Does certification alter fire use for forest conversion or the frequency of management or accidental fires in plantation areas? and 3) During El Niño years, does certification reduce fire activity compared to non-certified plantations and surrounding lands? Characterizing fire-driven deforestation is critical to evaluate the influence of RSPO certification on fire activity and to improve estimates of GHG emissions from oil palm expansion.

2 Material and Methods

1.1 Oil Palm Plantations

The government of Indonesia allocates land for oil palm production to companies for a limited period of time. We separated the leases into two categories, certified and non-certified plantations. Certified plantations are properties certified by the RSPO between 2009 and April 30, 2015; non-certified plantations are properties allocated by the Indonesian government to companies but that are not certified, even if they are held by RSPO members (Carlson *et al* in review). Comparisons between certified (ever) and non-certified (never) plantations considered forest loss and fire activity preceding and following the first RSPO certificates issued to Indonesian producers starting in 2009. Boundaries of certified plantations were compiled from several sources, including boundary polygons provided by the RSPO, digitized boundaries from RSPO audit reports (Carlson et al., in review), and spatial data on plantation boundaries from RSPO member companies provided in annual communication of progress (ACOP) reports (RSPO, 2015a). Boundaries of non-certified plantations were obtained from a database of oil palm plantations published by Greenpeace (Greenpeace, 2016) and non-certified plantations held by RSPO members, as indicated in ACOP reports (RSPO, 2015a). In total, we analyzed 140 certified and 1285 non-certified plantations boundaries for Indonesia (Fig. 1). Data on certified plantations were also available for Malaysia (n =121) and Papua New Guinea (n = 10), but boundaries of non-certified plantations were not available. See Carlson et al. (in review) for a detailed description of the palm oil lease compilation.

We used maps of planted oil palm to identify established plantations within certified and non-certified plantations in Indonesia, Malaysia, and Papua New Guinea. Data on planted oil palm were available from Gunarso et al. (2013) for three years (2000, 2005, and 2010). Additional planted oil palm information was supplemented from Carlson et al. (2013) for three years (2000, 2005, and 2010) and Transparent World (TW, 2015) for year 2014. Only non-certified plantations with evidence of planted oil palm by 2014 were included in this study.

1.2 Forest definition, cover, and loss

Estimates of forested areas and forest loss fundamentally depend on the definition of forest cover (Sexton et al., 2016). The Indonesian government uses the definition of forest from the United Nations Food and Agriculture Organization (FAO) Forest Resource Assessment (FRA), i.e., canopy cover ≥ 30% (FAO, 2010; MoF, 2008). Countries may use canopy cover thresholds between 10-30% for reporting under the United Nations Framework Convention on Climate Change (UNFCCC) REDD+ framework (UNFCCC, 2002). In this study, we choose canopy cover at the top of REDD+ range (> 30%) as a conservative threshold for forest cover to reduce ambiguity associated with discriminating tropical forests from other land cover types using remote sensing data for regions with little rainfall seasonality, such as Southeast Asia.

Forest and non-forest areas were separated using Landsat-based estimates of fractional tree cover in 2000 (Hansen et al., 2013). Estimates of annual forest loss between 2002-2014 (Hansen et al., 2013) were used to identify the timing of forest conversion in and around plantations.

1.3 Active fires

We used active fire detections from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Terra and Aqua satellites. The global monthly fire location product (MCD14ML) identifies the location of actively burning fires and thermal anomalies at the time of satellite overpass at 1km nominal spatial resolution (Giglio et al., 2003). Fire pixel counts from Terra and Aqua MODIS sensors were combined using a 1km grid to evaluate monthly and annual fire activity from 2002 to 2015. Fire pixel density (km^{-2}) was used to compare certified plantations, non-certified plantations, and a 5km buffer region surrounding both certified and non-certified plantations.

For 2014 and 2015, higher spatial resolution active fire detections were used to confirm patterns in 1 km MODIS fire data. These complementary active fire detections were derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) Iband (375m) on the Suomi-National Polar orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m (Schroeder et al., 2014), and the Landsat-8 Operational Land Imager (OLI) 30 m (Schroeder et al., 2015) data sets. Finer spatial resolution fire data capture additional fire activity information that can be lost in coarse resolution data products such as MODIS, helping identify the location of active fire fronts, separate areas of flaming and smoldering fires (Elvidge et al., 2015), and improve the detection of small and/or lower intensity fires (Schroeder et al., 2015)—an important component of fire activity in agricultural landscapes (Randerson et al., 2012). In this study, the improved spatial resolution of VIIRS and OLI fire data aided the attribution of active fires to specific land management areas.

1.4 Fire-driven forest conversion for oil palm expansion

We combined satellite remote sensing data on forest cover (2000; Hansen et al., 2013), forest cover change (2002-2014; Hansen et al., 2013), and active fire detections (2001-2014; Giglio et al., 2003) to identify fire-driven forest conversion in certified and non-certified plantations. Our assessment excluded forested areas identified as oil palm (Gunarso et al. (2013); Carlson et al. (2013)). Deforestation within oil palm plantations was therefore limited to Hansen et al. (2013) tree cover loss in forested areas (tree cover >30%) outside of planted palm. Oil palm expansion into peat forests was assessed using peatland layers created by Wahyunto et al. (2003, 2004, 2006) and Wetlands International (WI, 2016). Co-located forest loss and active fire detections were considered fire-driven deforestation. Given the potential for fire activity to pre-date the detection of forest loss (Morton et al., 2008), active fire data from the year of forest loss and one year before were combined to identify fire activity associated with forest conversion.

2 Results

2.1 Certification and Fire-driven Deforestation

In Indonesia, forest loss in and around oil palm plantations reduced remaining forest cover by 28-35% between 2002-2014 (Fig. 2). Gross forest loss within plantations but outside of planted palm areas totaled 3.77 Mha (Table 1). Average annual rates of forest loss were similar in certified (1.16 yr^{-1}) and non-certified plantations (1.73% yr^{-1}) over this period. However, prior to the start of certification in 2009, rates of forest (1.66% yr^{-1}) and peat forest conversion (0.34% yr^{-1}) were higher within certified plantations than non-certified plantations (1.43% and 0.39% yr^{-1}, respectively). Given the larger extent of non-certified plantations, mean annual forest losses differed by more than order of magnitude between certified and non-certified plantations (17,256 ha yr^{-1} and 211,469 ha yr^{-1}, respectively). Temporal patterns of forest loss for buffer areas within 5 km of plantations (both certified and non-certified) were similar to non-certified plantations.

Although the use of fire for forest conversion is prohibited in Indonesia, satellite data suggest that more than one quarter of forest clearing in both certified and non-certified plantations involved fire. For certified plantations in Indonesia, the fraction of fire-driven forest loss was higher before 2008 in both lowland and peat forests (Fig. 2). The proportion of fire-driven deforestation in non-certified plantations and buffer areas was more consistent in all years. Notably, the proportion of fire-

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driven deforestation in El Niño years (2002, 2006, 2009) was similar to fire use in other years for all three management classes.

The rates of fire-driven forest loss for oil palm expansion differed between certified and non-certified plantations in Indonesia after the start of RSPO certification in 2009. Forest loss rates declined by 68% in RSPO certified plantations from 2009-2014 compared to pre-certification levels. In contrast, mean annual forest loss increased in non-certified plantations (145%) and buffer areas (128%) during this period relative to 2002-2008 (Fig. 2).

However, certification did not halt forest conversion altogether. In Indonesia, forest loss continued within certified plantations following the start of RSPO certification efforts, including fires for forest conversion, leading to an additional 7% loss of remaining forest cover between 2009-2014. Lower rates of forest loss on certified plantations are consistent with RSPO restrictions on clearing HCV forest areas and other lands deemed unsuitable for palm oil production. Declining rates of forest loss after 2009 may also reflect limited remaining forest cover on certified plantations by 2014 (13%; Fig. 2), leading to smaller clearing sizes that are more difficult to assess with remote sensing data on forest loss and fire activity (Fig. 3). In contrast, the contribution from larger clearing sizes increased over time in non-certified plantations and remained stable for buffer areas.

Patterns of fire-driven forest loss in certified plantations differed across Indonesia, Malaysia, and Papua New Guinea (Fig. 4). Overall forest loss rates were higher in Indonesia than Malaysia and Papua New Guinea (Table B1). However, large forest clearing events were more common in certified plantations in Malaysia and Papua New Guinea, with more than two-thirds of forest loss in patches > 10ha (Fig. A2). Annual forest loss rates in Malaysia remained high following certification, with little change from pre-certification patterns (Fig. 4). In Malaysia, oil palm expansion in certified plantations rarely involved fire, and only 6% of total forest loss was identified as fire-driven deforestation. Fire detections associated with forest loss declined in all three countries following the start of certification in 2008-2009.

Certification decoupled fire detections from ENSO-driven variability in fire risk. Interannual variability in regional fire activity is largely governed by the timing and magnitude of El Niño events (Fig. A1; Chen et al., 2016). Prior to certification, interannual variability in fire detections was similar for certified plantations, non-certified plantations, and buffer areas in Indonesia (Fig. 5). Mean fire rates across land management classes were also consistent during El Niño events in 2002, 2004, and 2006, with important contributions from fire-driven deforestation to total fire detections in these years. Following certification, fire activity declined in certified plantations in all years, with 67% and 44% fewer fires km^{-2} than non-certified plantations during the 2009 and 2015 El Niño events, respectively. Monthly fire counts confirm the reduction in fire activity within certified plantations during peak burning months of the 2009 and 2015 El Niño events (Fig. A3). Evidence for reduced fire activity in certified plantations highlights the potential for management of fire risk within oil palm plantations, even during strong El Niño drought conditions.

Attribution of fire activity is a critical component of satellite-based monitoring for environmental compliance. Higher resolution active fire data from VIIRS (375 m) and Landsat 8/OLI (30 m) confirm the relative decline in fire activity on certified plantations compared to non-certified plantations and buffer areas in both 2014 and 2015 (Fig. 6). The VIIRS 375 m

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fire data provide a more complete characterization of the fire perimeter than MODIS on a daily basis. Although less frequent, Landsat 8 coverage every 16 days captures the precise location of active fire fronts, small fires, and persistent smoldering in peat areas that may last for many days (Fig. 6 and Fig. A4). High-resolution fire data improve our understanding of fire use for deforestation and agricultural management, with detections that can be more definitively attributed to specific actors in support of monitoring, reporting, and verification.

3 Discussion

Following the start of RSPO certification in 2009, certified oil palm plantations in Indonesia had lower fire-driven deforestation and total fire activity during El Niño events than non-certified plantations. These reductions point to the potential for RSPO to contribute to REDD+ and to decrease fire ignitions during drought conditions. Our results direct contradict findings from Cattau et al. (2016b), likely based on the larger sample size of certified concessions in our study (N=140 compared to 28, including only 4 concessions on peat). However, certification did not halt forest losses or fire activity altogether. In addition, certified plantations currently account for a small fraction of total oil palm leases (e.g., 7% in Indonesia); non-certified plantations maintained higher rates of fire-driven deforestation and fire activity in recent years, including the 2015 El Niño. The opportunity exists, therefore, to enhance the environmental benefits of RSPO certification through expansion of certified plantations and strengthening of certification standards, including the use of satellite monitoring of fire activity and forest loss.

Our study confirms the pervasive use of fire for forest conversion to oil palm in Indonesia, with one quarter of forest loss identified as fire-driven deforestation. Fire-driven deforestation was less common on certified plantations in Malaysia and Papua New Guinea, and fire use for forest conversion declined to near zero after the start of certification in 2008-2009 in these countries. The fraction of fire-driven deforestation for different land management categories is likely conservative because satellite platforms underestimate of total fire activity. Satellite sensors may not sample at the peak of diurnal fire activity (Giglio et al., 2000), and cloud obscuration (Giglio et al., 2003) and orbital coverage (Schroeder et al., 2005) reduce the probability of fire detections, particularly for low-latitude regions with a seasonal rainfall such as Southeast Asia. New satellite products partially overcome these limitations through improvements in orbital coverage and spatial resolution (Schroeder et al., 2014), especially for detection of small and low-intensity fires in deforestation or peatland areas (Schroeder et al., 2015; Elvidge et al., 2015).

The proportion of fire-driven deforestation on oil palm plantations in Indonesia (~25%) was similar to the estimate of combustion losses in bookkeeping models (30-40%; Houghton and Hackler, 1999), but fire use was much lower in Malaysia and Papua New Guinea. However, our study only confirms the coincident timing and locations of fires and forest losses, not the combustion completeness of fires for forest conversion. Removal of forest vegetation is critical to establish an oil palm plantation, but combustion completeness may be lower for these fires, given higher fuel moisture and less need for complete combustion of aboveground biomass than for expansion of row crop agriculture (Morton et al., 2008). Fuel moisture also

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has a substantial influence on trace gas emissions from fire, including smoldering fires in peatlands (Miettinen et al., 2012; Page and Hooijer, 2016). By combining active fire detections with satellite observations of trace gas emissions, it may be possible to characterize regional GHG emissions directly associated with fires on oil palm plantations.

Several factors may account for the reduction in fire activity on certified plantations following certification. First, certification may reduce fire-driven deforestation by directly influencing land management practices. Collectively, all certified plantations in Indonesia, Malaysia, and Papua New Guinea showed declines in fire-driven forest losses after 2009. Second, declining fire activity may simply be an artifact. If companies preferentially certify older plantations (Carlson et al in review), then the reduction in fire activity may indicate an end of the expansion process rather than a change in fire-driven deforestation. Remaining forest cover was only 9-13% on certified plantations in Malaysia and Indonesia; remaining forest areas may not be suitable for oil palm or accessible based on RSPO restrictions. Similarly, a reduction in overall fire activity may be less important for GHG emissions than a reduction in peat fires (e.g., van der Werf et al., 2008; Cattau et al., 2016a; Field et al., 2016). Regardless, the potential exists for RSPO to promote fire-free management of plantations to protect high-value tree crops and remaining carbon stocks in forests and peatlands. Large labor forces needed for oil palm production (Lambin et al., 2013) may aid regional fire suppression efforts, allowing established plantations to maintain lower fire activity in and around plantations during El Niño years.

Aligning certification criteria with existing satellite monitoring capabilities could improve the transparency, accountability, and impact of RSPO and other certification efforts. RSPO certification prohibits specific categories of forest clearing that cannot be readily distinguished using satellite data. For example, total forest loss can be identified using freely available satellite data products, but high conservation value or primary forest types cannot be confirmed with Landsat or MODIS data. Changing RSPO criteria to more closely match existing products on forest cover would enable more rigorous monitoring of environmental compliance. Alternatively, public databases of set-aside areas on certified plantations (e.g., stream buffers, areas deemed unsuitable for production, or HCV) could improve transparency and support monitoring efforts without the need to derive forest conditions directly from satellite data. New, higher resolution active fire data also complement the time series of MODIS active fire observations. Landsat and VIIRS active fire data offer sufficient spatial detail to unambiguously attribute fire activity to specific land owners—an important step forward in satellite monitoring by governments, non-governmental organizations, or certification bodies such as RSPO. Fire suppression is particularly important to safeguard carbon stocks in peatlands, and Landsat resolution is particularly beneficial to identify small, smoldering fires (Schroeder et al., 2015; Elvidge et al., 2015).

By 2020, Indonesia has pledged to double its palm oil production (Maulia, 2010), and expanding production threatens remaining rainforest and peatland areas. Certification offers a path for low-carbon development of additional oil palm production, provided that certification standards are consistent with capabilities for routine satellite monitoring. RSPO certification has reduced but not eliminated forest loss and fire use on certified plantations. To realize the full potential of certification, requirements for RSPO certification must be updated to align environmental goals with objective measures of compliance. Such transparency would also provide more direct insight into the key mechanisms through which agricultural intensification and expansion contribute to feedbacks in the Earth system.

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Appendices

Appendix A Figures

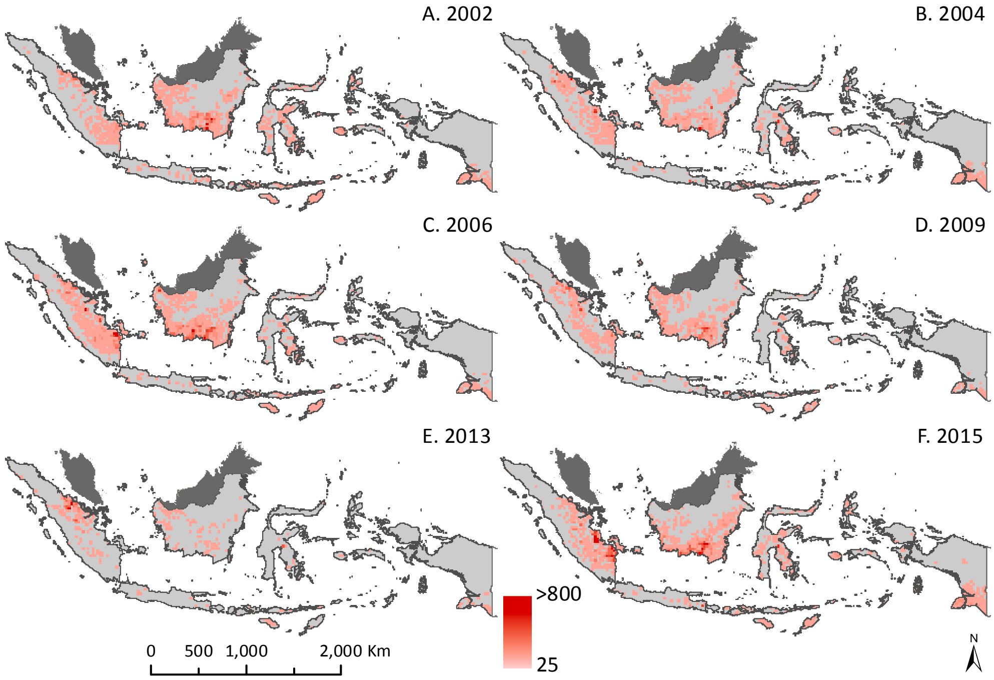

Figure A1: Density of MODIS active fire detections in Indonesia during El Niño years (A-D, F) and the June 2013 drought (E), when fires from Sumatra impacted air quality in Singapore (Gaveau et al., 2014). The spatial distribution of fire activity was consistent during El Niño years, although fire densities were highest in 2006 and 2015. Maps show annual totals of Terra and Aqua MODIS fire detections at 0.25° resolution.

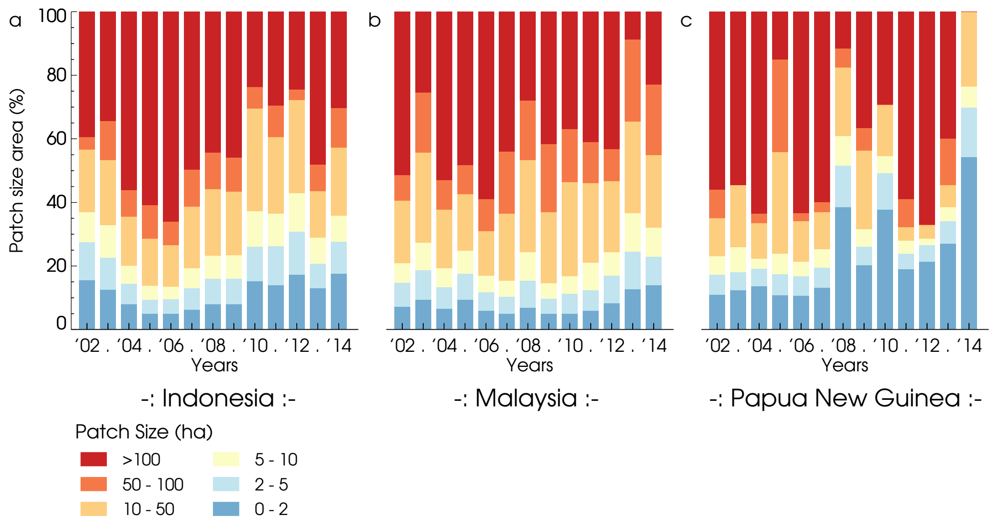

Figure A2: Forest loss patch size distribution in the RSPO Certified plantations of a) Indonesia, b) Malaysia, and c) Papua New Guinea. Patch sizes were assessed at the plantation level and summarized yearly to report between 2001-2014.

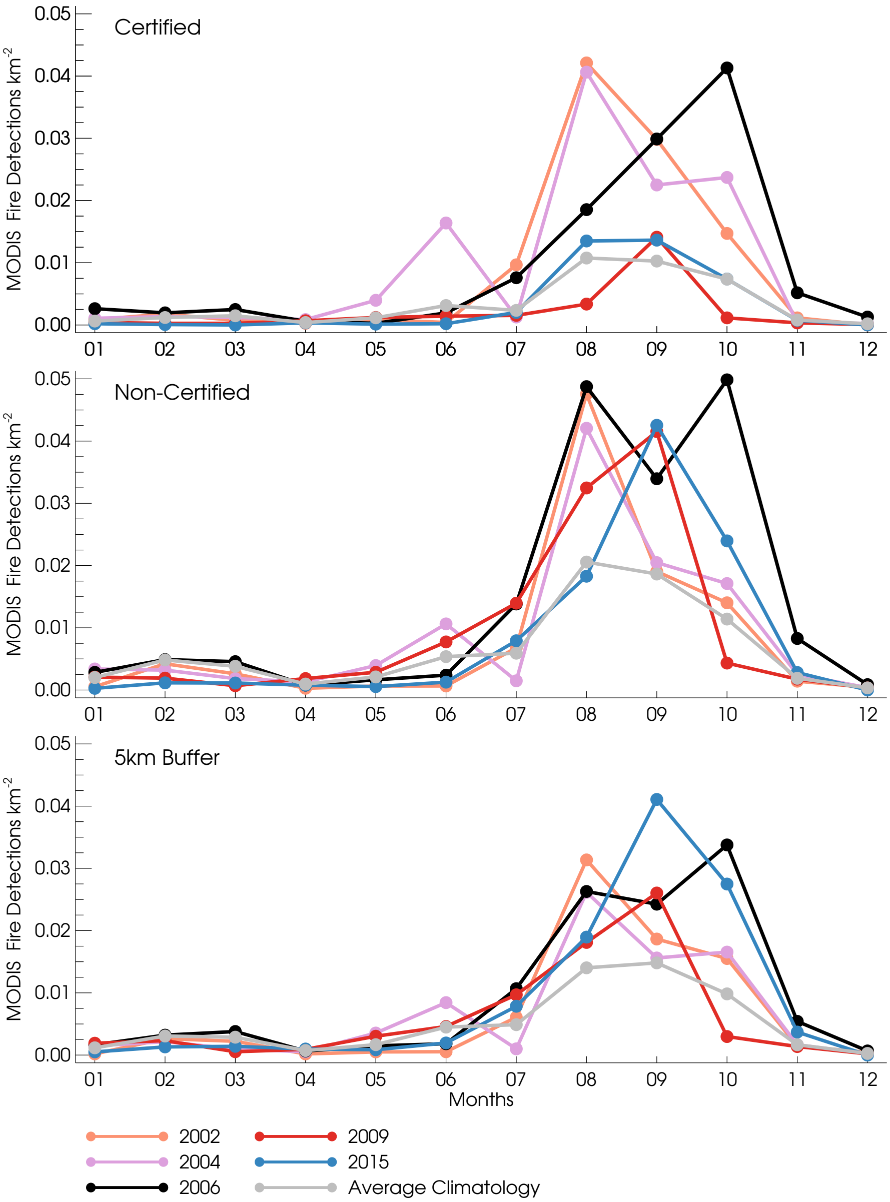

Figure A3: Monthly density of MODIS active fire detections (Terra and Aqua, combined) for certified plantations, non-certified plantations, and a 5-km buffer region surrounding plantations in Indonesia during El Niño years. A climatology of average monthly fire detections from all years (2002-2015, grey) is shown for comparison.

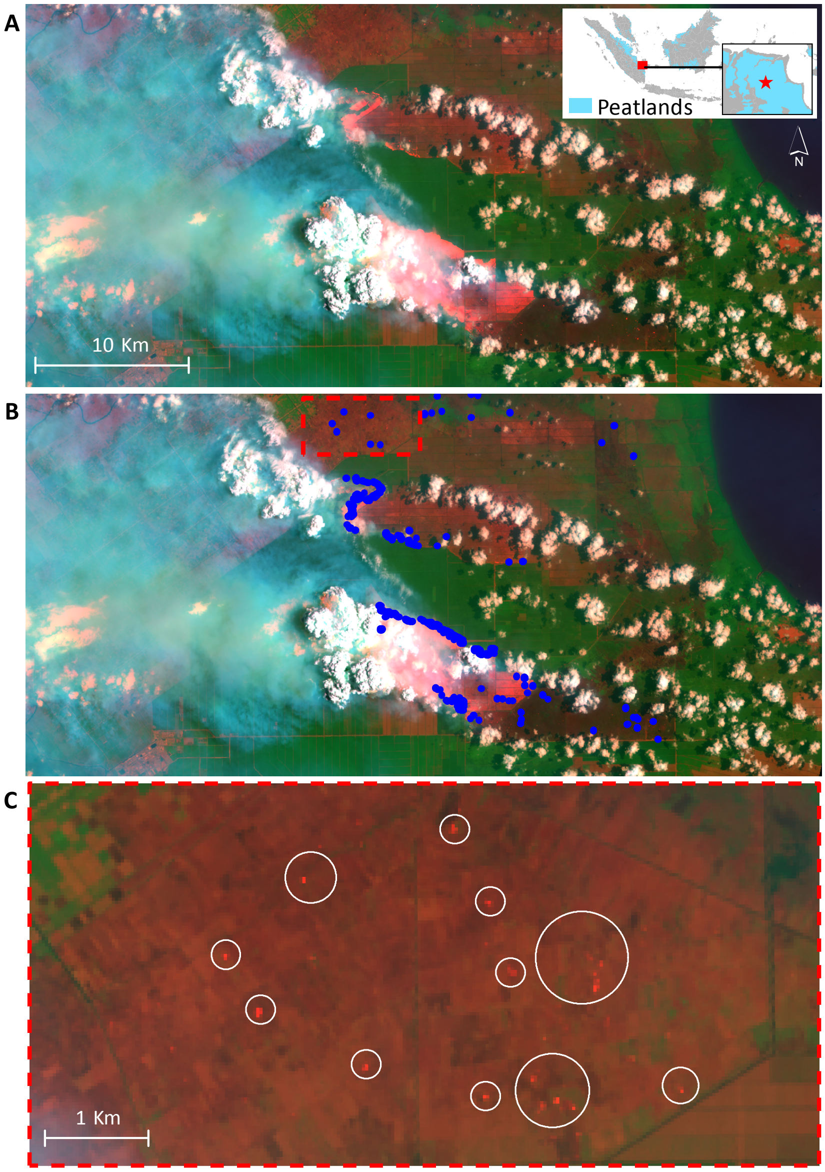

Figure A4: Landsat 8 active fire detections captured active fire fronts (B) and residual smoldering fires (C) in peatland areas of southern Sumatra on Sep. 30, 2015. White circles in panel C indicate smoldering for a subset of the image in panel B (dashed red outline). The regular grid of peatland drainage canals is visible in all panels.

Appendix B Tables

Table B1: Total and fire-driven forest loss for oil palm expansion in certified plantations in Indonesia, Malaysia, and Papua New Guinea during 2001-2014. All areas are given in hectares (ha).

	Lease area ha	Planted palm by 2010[a] ha	Forest loss ha	Peat Forest loss ha	Fire-driven loss[b] ha
Indonesia (IDN)	1,489,003	1,125,846	224,326	43,107	71,659 (27%)
Malaysia (MYS)	1,147,495	903,546	125,218	8,273	7,816 (6%)
Papua New Guinea (PNG)	174,444	94,002	21,491	-	3,860 (18%)

[a] Forest loss outside of peat areas

[b] Combined (peat and non-peat) forest loss related to fire

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Figures

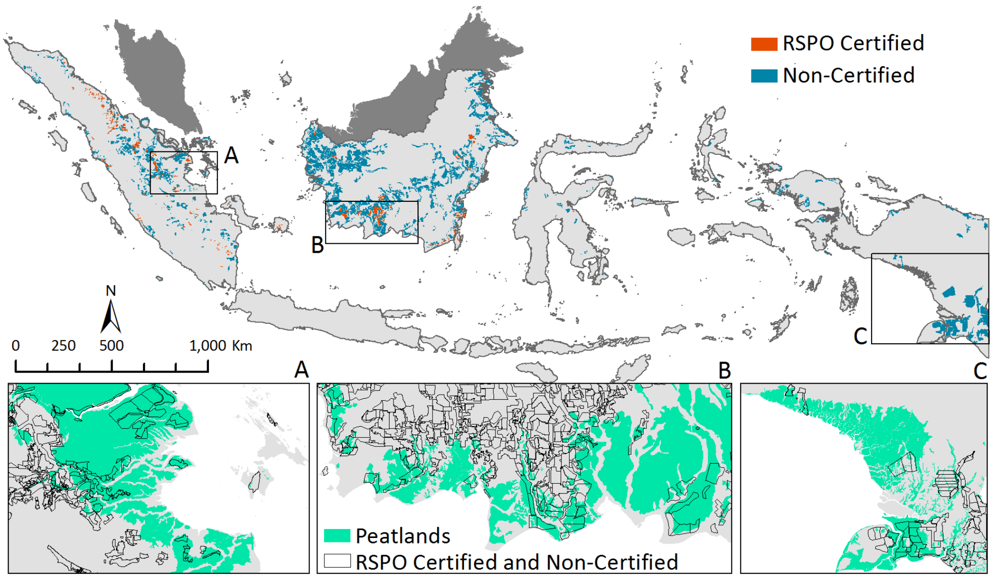

Figure 1: Extent of RSPO certified and non-certified oil palm plantations in Indonesia. Regional subsets highlight plantations (black polygons) on peatlands (green) in lowlands of Sumatra (A), Kalimantan (B), and Papua (C).

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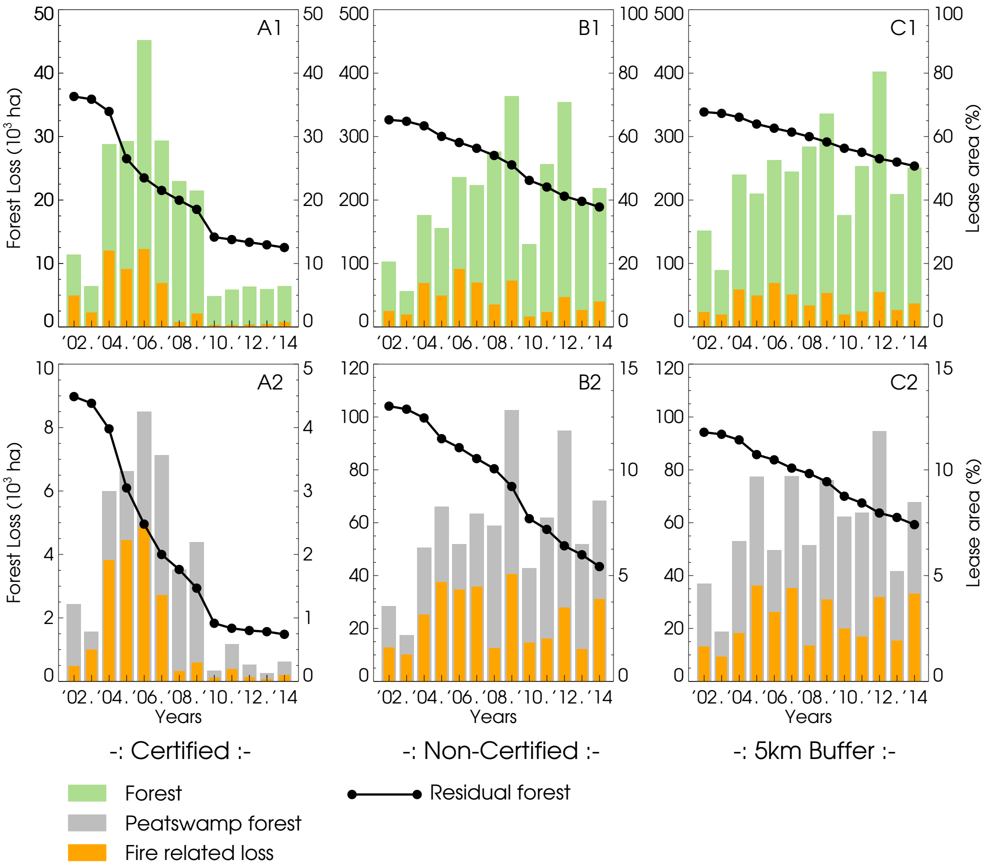

Figure 2: Forest loss within the boundaries of A) Certified plantations, B) Non-Certified plantations, and C) 5km Buffer region surrounding certified and non-certified plantations from 2001-2014. A1-C1) Fire (orange) and non-fire related (green) forest loss in non-peat areas; A2-C2) fire (orange) and non-fire related (grey) forest loss on peat. Estimates of forest loss for all management classes excluded areas of planted palm (Carlson et al., 2013; Gunarso et al., 2013). The solid black line indicates residual forest cover as a percentage of management areas.

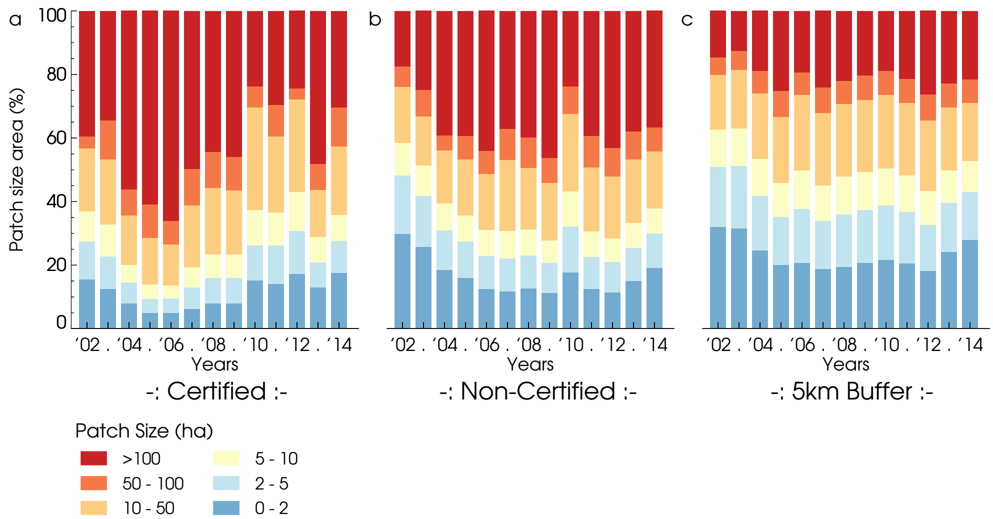

Figure 3: Forest loss patch size distribution in Indonesia within the boundaries of A) RSPO Certified plantations, B) Non-Certified plantations, and C) 5km Buffer region. Patch sizes were assessed at the plantation level and summarized yearly to report between 2002-2014.

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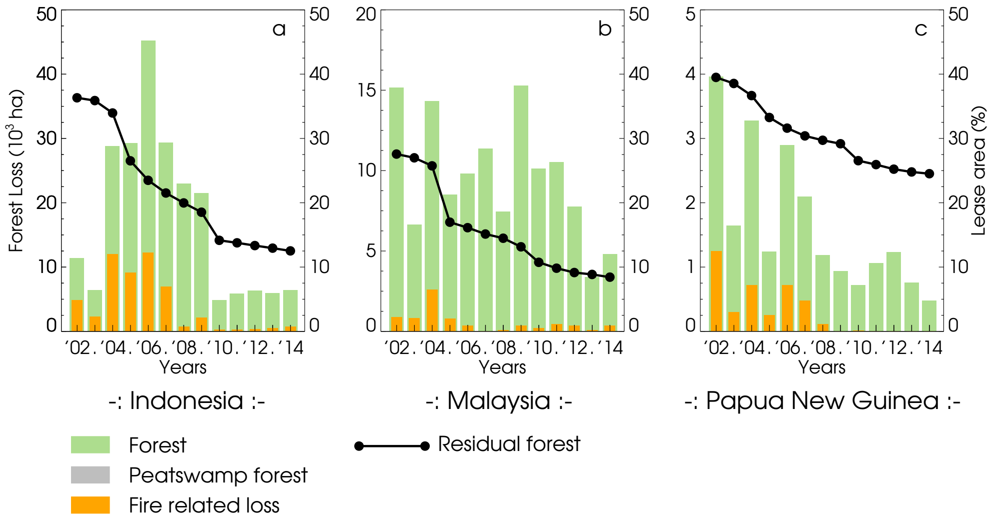

Figure 4: Total forest loss (green) and fire-driven deforestation (orange) in certified plantations in a) Indonesia, b) Malaysia, and c) Papua New Guinea. Forest loss was estimated outside of planted palm (Carlson et al., 2013; Gunarso et al., 2013). The black line indicates residual forest as a fraction of the total lease area of certified plantations in each country.

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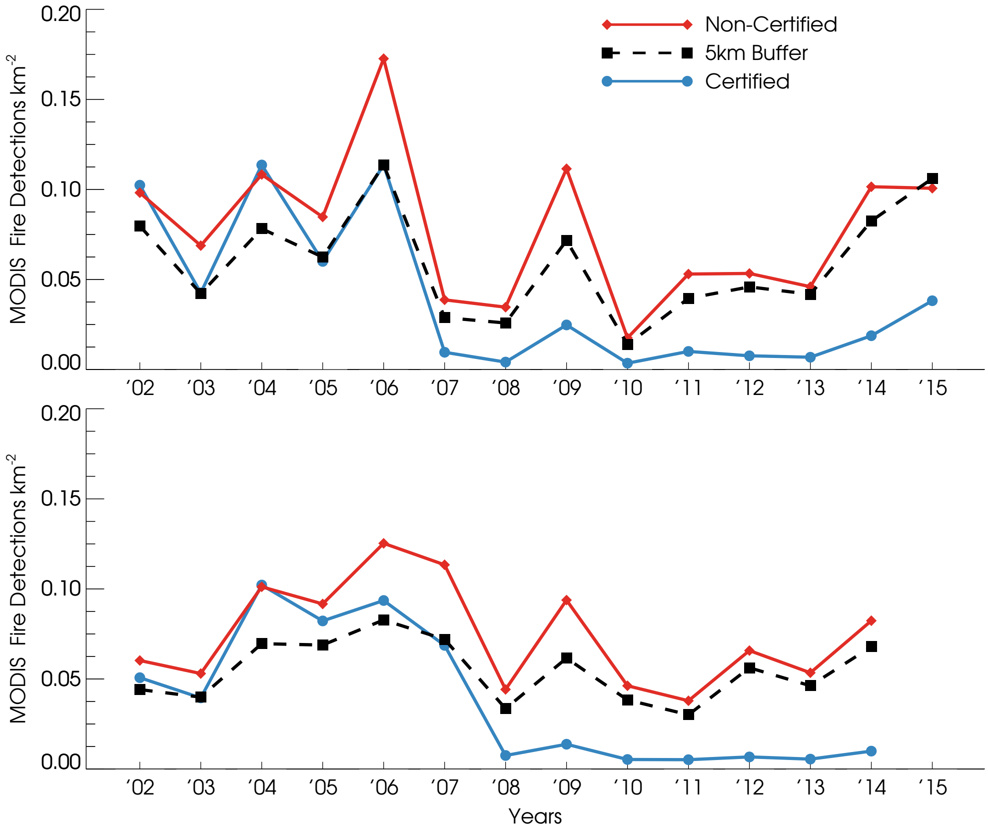

Figure 5: Density of MODIS active fire detections within certified plantations, non-certified plantations, and the 5-km buffer region around plantations from 2002-2014. A) Time series of all MODIS active fire detections; B) Time series of MODIS active fire detections associated with fire-driven deforestation.

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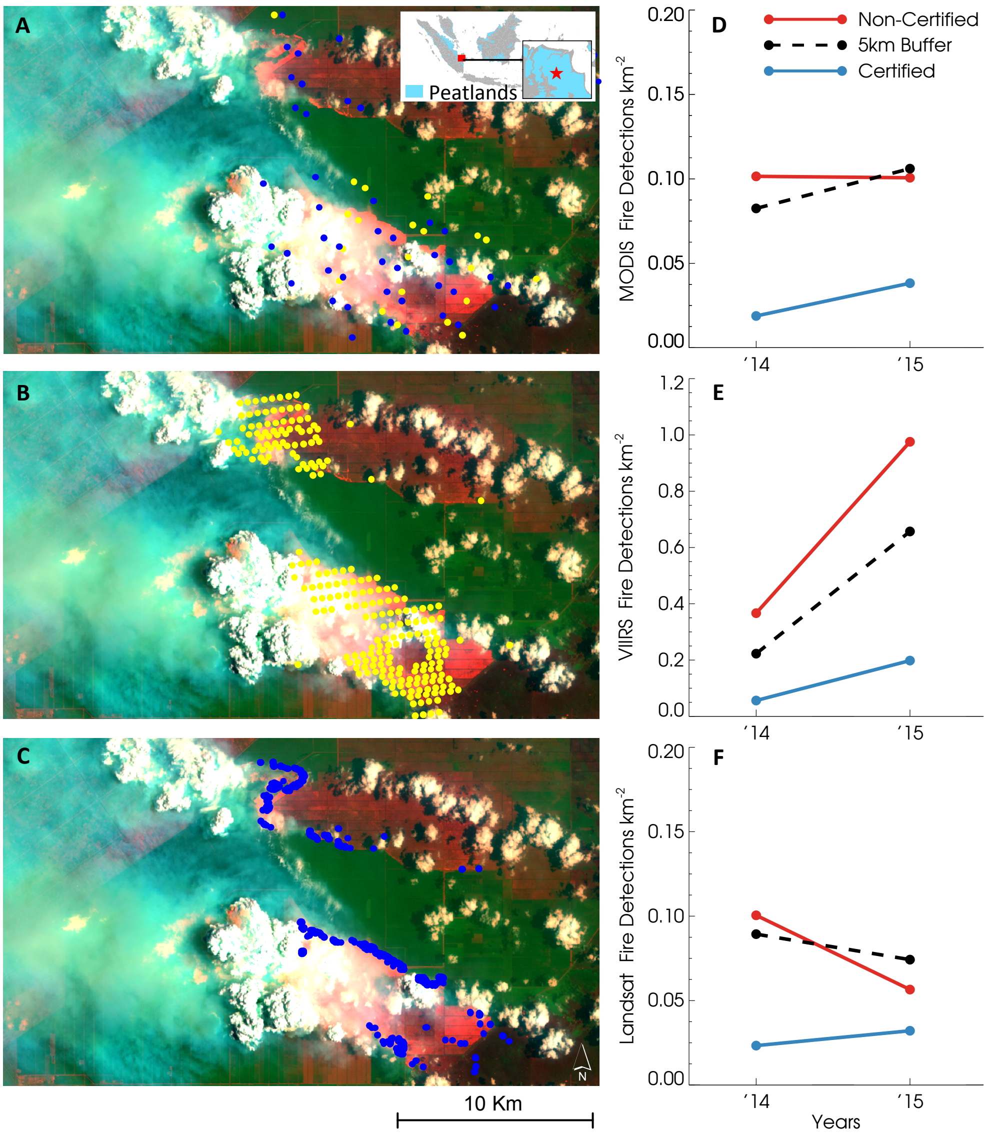

Figure 6: High-resolution active fire detections confirm lower fire activity in certified plantations during the 2015 El Niño event. Map panels show active fire detections on Sep. 30, 2015 for peat fires in southern Sumatra from A) Terra (blue) and Aqua (yellow) MODIS (1 km), B) S-NPP/VIIRS (375m), and C) Landsat-8/OLI (30m). Background images in panels A-C are a false-color composite of Landsat 8/OLI bands 7-5-3 from the same date (Path/Row: 124/62). Adjacent panels show total annual fire detections in 2014 and 2015 for certified plantations from D) MODIS, E) VIIRS, and F) Landsat 8/OLI.

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Tables

Table 1: Total and fire-driven forest loss for oil palm expansion in Indonesia from 2002-2014 within the certified and non-certified plantations.

	Lease area ha	Planted palm by 2010 ha	Forest loss[a] ha	Peat Forest loss ha	Fire-driven loss[b] ha
RSPO Certified	1,489,003	1,125,846	224,326	43,107	71,659 (27%)
Non-Certified	12,242,784	3,596,501	2,749,098	759,591	895,674 (26%)
5km Buffer	19,946,862	3,786,124	3,111,708	771,701	820,178 (21%)

[a] Forest loss outside of peat areas

[b] Combined (peat and non-peat) forest loss related to fire