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Effectiveness of Roundtable on Sustainable Palm Oil (RSPO) for reducing fires on oil palm concessions in Indonesia from 2012 to 2015

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Abstract

Fire is a common tool for land conversion and management associated with oil palm production. Fires can cause biodiversity and carbon losses, emit pollutants that deteriorate air quality and harm human health, and damage property. The Roundtable on Sustainable Palm Oil (RSPO) prohibits the use of fire on certified concessions. However, efforts to suppress fires are more difficult during El Niño conditions and on peatlands. In this paper, we address the following questions for oil palm concessions developed prior to 2012 in Sumatra and Kalimantan, the leading producers of oil palm both within Indonesia and globally: (1) for the period 2012–2015, did RSPO-certified concessions have a lower density of fire detections, fire ignitions, or 'escaped' fires compared with those concessions that are not certified? and (2) did this pattern change with increasing likelihood of fires in concessions located on peatland and in dry years? These questions are particularly critical in fuel-rich peatlands, of which approximately 46% of the area was designated as oil palm concession as of 2010. We conducted propensity scoring to balance covariate distributions between certified and non-certified concessions, and we compare the density of fires in certified and non-certified concessions using Kolmogorov–Smirnov tests based on moderate resolution imaging spectroradiometer Active Fire Detections from 2012–2015 clustered into unique fire events. We find that fire activity is significantly lower on RSPO certified concessions than non-RSPO certified concessions when the likelihood of fire is low (i.e., on non-peatlands in wetter years), but not when the likelihood of fire is high (i.e., on non-peatlands in dry years or on peatlands). Our results provide evidence that RSPO has the potential to reduce fires, though it is currently only effective when fire likelihood is relatively low. These results imply that, in order for this mechanism to reduce fire, additional strategies will be needed to control fires in oil palm plantations in dry years and on peatlands.

Introduction

Agricultural expansion and intensification has occurred over the last few decades and is expected to continue, especially in the tropics, in order to meet the demands of a growing global population. Oil palm (*Elaeis guineensis*), a major global commodity that dominates the vegetable oils market and is used for biofuel, is one of the world's most rapidly expanding crops. It is grown exclusively in the humid tropics. Production of oil palm and planted area have increased over the past few decades, especially in Indonesia, which is currently the largest oil palm producer (Food and Agriculture Organization of the United Nations 2015). The area under oil palm cultivation in Indonesia expanded 600% to 7.8 Mha from 1990–2000 (Indonesian Ministry of Agriculture 2010).

With land use conversion for the expansion of oil palm in Southeast Asia have come myriad environmental and social concerns, including deforestation (e.g, Carlson *et al* 2012) and land tenure and other social conflicts (e.g., displacement of local people, Colchester and Jiwan 2006). The loss of forest through oil palm expansion is a threat to biodiversity (Wilcove and Koh 2010, Koh *et al* 2011), with plantations hosting species-poor communities dominated by generalists with few forest species (Danielsen *et al* 2009). The development of oil palm plantations can also result in greenhouse emissions from the conversion process. The carbon losses from the development on peatlands are particularly high (Hooijer *et al* 2006, Koh *et al* 2011). Even when oil palm is used as a biofuel, the carbon savings from avoided fossil fuel combustion do not offset the losses in ecosystem carbon from land clearing until decades to centuries, particularly on peatlands (Gibbs *et al* 2008, Danielsen *et al* 2009), although the payback time is much shorter for previously degraded lands. However, proponents of oil palm argue that it has a much higher yield than the alternatives (e.g., soybean, sunflower, rapeseed), and with increased production efficiency, less land in cultivation is required to produce the same amount on a per hectare basis (Teoh 2010). There is also evidence that oil palm development can reduce poverty, contribute to national economies, and act as a carbon sink (relative to degraded lands) (Koh *et al* 2010, Teoh 2010).

Oil palm concession development can lead to increased fire incidence, as fire is often used to clear land prior to the initial crop planting, prior to replanting after a complete crop cycle, or to clear brush or eliminate pests mid-cycle (Simorangkir *et al* 2002). Fires that are started on oil palm concessions may escape the boundaries of the concession and burn other land cover types, including primary forest (e.g., Carlson *et al* 2012, Cattau *et al* 2016). Fires occurring within or outside of concession boundaries, particularly on peatlands, are a major cause of smog and particulate air pollution (Hayasaka *et al* 2014, Reddington *et al* 2014), habitat loss and degradation (Yule 2010, Posa *et al* 2011, Jaafar and Loh 2014), and economic costs associated with fire suppression efforts, lost timber and crop resources, and missed workdays (Ruitenbeek 1999, Barber and Schweithelm 2000, Tacconi 2003). Oil palm and timber concessions, particularly on peatlands and non-forest lowlands, contribute to emissions and hazardous regional air pollution; oil palm concessions are the largest source of concession-related emissions in Kalimantan (Marlier *et al* 2015). However, the majority of emissions can be attributed to fires outside of concessions in both Sumatra and Kalimantan (Marlier *et al* 2015).

Land use conversion can interact with climate and other biophysical factors by further increasing fire risk in conditions under which fire risk is already elevated. For example, during El Niño conditions of the El Niño Southern Oscillation (ENSO), there is increased likelihood of drought in Southeast Asia and, thus, fires are tied to ENSO cycles throughout insular Southeast Asia, including Indonesia (e.g., Deeming 1995, Kita *et al* 2000, Siegert *et al* 2001, Page *et al* 2002, Wang *et al* 2004, Fuller and Murphy 2006, Wooster *et al* 2012, Spessa *et al* 2015). In peatlands, canals drain the peat and lower the water table, improving oil palm planting conditions, but also making the peat even more susceptible to fire in the dry season, particularly during El Niño phases (Hooijer 2006, Turetsky *et al* 2015).

The land area in oil palm concession in Indonesia is projected to grow as Indonesia has pledged to double its oil palm production from 2010 to 2020 (Maulia 2010). In order to meet emissions reductions targets and improve air quality in the region, it will be critical that agricultural practices minimize fire occurrence on this land use type, either through regulatory, incentive-based, or technological mechanisms. Wilcove and Koh (2010) discuss how financial incentives can promote desirable behavior in the oil palm industry that would reduce the threats to biodiversity from land use conversion; these incentives can reduce practices that promote negative outcomes on oil palm concessions more generally, including fire. The Roundtable on Sustainable Palm Oil (RSPO) certification program, established in 2004, is one such incentive. RSPO is non-profit industry-led trade organization designed, in part, to address the growing concerns about the negative environmental impacts of palm oil. RSPO is currently the largest multi-stakeholder organization focused on sustainability within the palm oil sector and the only global sustainability standard in the edible oil sector. Thus, RSPO has a large potential to reduce the negative impacts of oil palm concession development globally. According to the RSPO Principles and Criteria, RSPO does not permit the use of fire for preparing land for new plantings or for replanting on certified plantations except 'where an assessment has demonstrated that it is the most effective and least environmentally damaging option for minimizing the risk of severe pest and disease outbreaks, and exceptional levels of caution should be required for use of fire on peat' (Roundtable on Sustainable Palm Oil 2013). Therefore, the RSPO certification mechanism has the potential to reduce fire on oil palm plantations, presuming that companies follow the RSPO Principles and Criteria. This issue is particularly critical in peatland areas, because fires in these fuel-rich systems result in high emissions from aboveground and belowground biomass burning. Approximately 46% of peatland area was designated as oil palm concession as of 2010 (World Resources Institute 2014b, 2014c). In late 2015 after the most severe fire season since 1997/98, the Indonesian president Joko Widodo, through presidential instructions, did ban clearance and conversion on peatlands, including on existing concessions (Government of

Indonesia 2015). However, this is not yet a legally binding law, though one is forthcoming. Furthermore, by targeting economic incentives, RSPO certification might result in monitoring and enforcement beyond what would exist as a result of regulatory policy alone.

Although there have been concerns that the RSPO Principles and Criteria are not sufficiently stringent, currently there is minimal evidence regarding how RSPO certification affects fire occurrence. In this research, we assess if fire activity was reduced on RSPO certified oil palm concessions in Indonesia from 2012 to 2015. We ask: (1) did certified concessions have a lower density of fire detections, fire ignitions, or 'escaped' fires compared with those concessions that are not certified? and (2) did this pattern change with increasing likelihood of fires in concessions located on peatland and in dry years?

Methods

We assess whether fire activity is reduced on RSPO certified oil palm concessions. We first identify concessions that are RSPO-certified and concessions that are not certified, and select only concessions that are already converted. We then derive three metrics of fire activity: the density fire detections, fire ignitions, and 'escaped' fires. We use nonparametric matching methods to control for bias and then determine if RSPO certified concessions have reduced fire activity, relative to the control group of non-certified concessions, in low fire-risk conditions (i.e., in wet years on non-peatlands), in intermediate fire-risk conditions (i.e., in wet years on peatlands and in dry years on non-peatlands), and in high fire-risk conditions (i.e., in dry years on peatlands). In the sections that follow, we describe the study area, concession and other datasets, remotely sensed fire observations, and our methodology to compare fire activity within RSPO-certified and non-certified concessions.

Study area

The study area consists of the island of Sumatra and of Kalimantan, the Indonesian portion of the island of Borneo (figure 1), Indonesia's largest islands, with a total area of 473481 km^2 and 544150 km^2, respectively. Both islands straddle the equator and have a hot and humid tropical climate marked by distinct wet and dry seasons. The western interior of Sumatra is mountainous and the eastern interior is lowlands and swamp. The interior of Borneo (i.e., the northern border of Kalimantan) consists of upland areas with the outer areas primarily lowlands and swamp. Both islands were once dominated by tropical rainforest, but development, illegal logging, and fire have greatly reduced the extent of that forest (e.g., 28.3% and 51.9% mature forest remained in 2012 on Sumatra and Kalimantan, respectively Margono *et al* 2014).

We focus on Sumatra and Kalimantan because over 90% of oil palm development in Indonesia occurred there over the past few decades (Rianto 2010). As of 2010, 95.8% of all the oil palm concessions in Indonesia were located in Sumatra and Kalimantan, covering 13.8% of the total land area (World Resources Institute 2014b). Industrial oil palm plantations that have already been developed cover 18.2% and 12.6% of peatlands in Sumatra and Kalimantan, respectively (Miettinen *et al* 2016).

Data and processing

We obtain oil palm concession locations in Indonesia from the Global Forest Watch portal (GFW) (World Resources Institute 2014b). Produced by the Indonesian Ministry of Forestry, these are the boundaries of the area allocated by the Indonesian government for industrial-scale oil palm plantations developed or planned by 2010. These data are known to be incomplete but are currently the best available; they do not include oil palm plantations that exist outside of the official concession boundaries. These data include the company to which each concession belongs, but not information about whether an individual concession is RSPO certified. Because spatially explicit data on the location of RSPO certified plantations is currently not publically available, we are not able to directly evaluate fire activity on all concessions that are certified versus those that are not. Instead, data on the total number of hectares of oil palm concession that each company owns and the number of hectares associated with concessions that are RSPO certified that each company owns as of 2012 is obtained from Greenpeace (Rosoman and Rahmawa 2015), and we evaluate fire activity on concessions belonging to companies that have 0% of their concession area certified (hereafter, referred to as non-RSPO certified concessions) versus concessions belonging to companies that have ⩾85% of their concession area certified (hereafter, referred to as RSPO certified concessions). There is a general lack of agreement between the oil palm concession boundary data from GFW and tabular data on certification from Greenpeace. Of the 167 concessions reported by Greenpeace to belong to companies that have ⩾85% of their concession area certified, only 58 are present in the GFW data. Of the 239 concessions reported by Greenpeace to belong to companies that have 0% of their concession area certified, only 34 are in the GFW data. Therefore, our analyses do not include all of the concessions that are RSPO certified or non-certified, but rather only the subset that are owned by companies for which data is present in both datasets.

Because fire is often used differently at different stages of plantation development, we separate concessions that were developed prior to the study period (2012–2015), during the study period, or are not yet developed. To derive the year of development for each

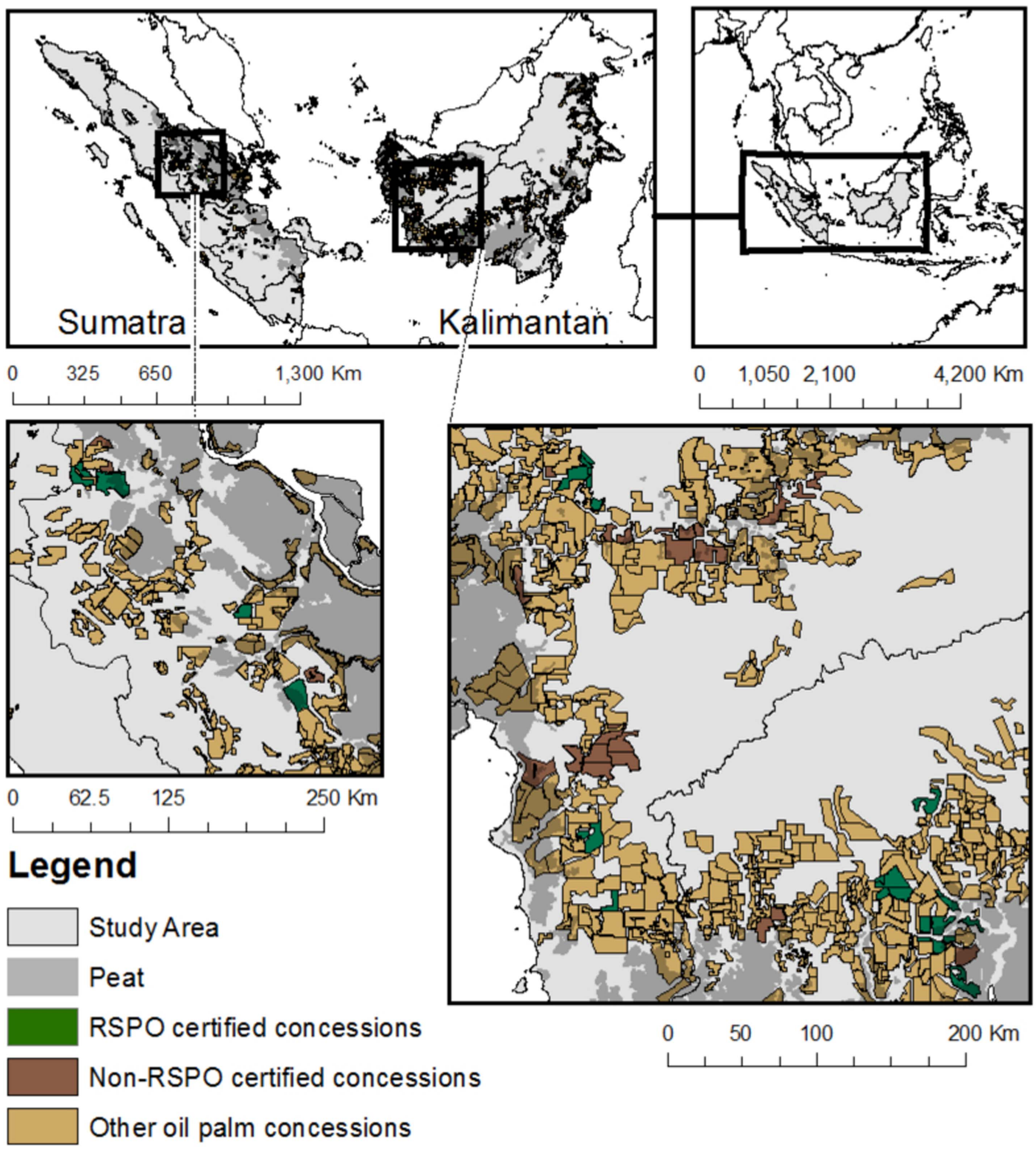

Figure 1. The study area: oil palm concessions on Sumatra and Kalimantan, Indonesia. Inset: details of two portions of the study area displaying non-exhaustive locations of oil palm concessions, including those that are RSPO certified, those that are non-RSPO certified, and those for whom certification status is unknown, as well as the distribution of peatland. See *Data and Processing* for a description of categorization of oil palm concessions into those that are RSPO certified and those that are non-RSPO certified.

RSPO certified and non-certified concession, we visually inspect Google Earth imagery for signs of clearing or planting (e.g., irrigation canals, new vegetation that is spatially ordered). We did not definitively identify any concessions that either remained undeveloped during the entire study period 2012–2015 or that were developed sometime during the study period. Thus we restrict the analysis to concessions that we determined to be already developed by 2012 (i.e., cleared or planted), including 28 RSPO certified concessions totaling 180 333 ha (4 on peatlands and 24 on non-peatlands) and 25 non-RSPO certified concessions totaling 326205 ha (11 on peatlands and 14 on non-peatlands) (detailed in figure 1). The subset of concessions used for our analyses do not show a spatial bias, as they have a representative distribution across the study area (i.e., the majority of concessions are found on Kalimantan), but may be biased in terms of size and accessibility (table A.1 in supplementary material).

We retrieve all fire detections occurring in Kalimantan and Sumatra during 2012–2015 at the nominal 1 km^2 resolution from the Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections, extracted from MCD14ML Collection 5 and distributed by NASA FIRMS. This product is considered the most accurate and complete among alternative methods for detecting fires (Langner and Siegert 2009), and correlations between the number of fire detections and the area burned on the ground is high in peatlands ($R2 = 0.75$ in Tansey *et al* 2008). We use this product to derive the metrics of fire activity on concessions: the density fire detections, fire ignitions, and 'escaped' fires. Fire detections on concessions could be associated with fires that originate outside of the concession and escape into the concession, and are thus not directly the result of activities on the concession itself. To account for this possibility, we identify fire ignitions on and escaped fires from concessions, in addition to just fire detections occurring on concessions. The MODIS fire detections indicate the center point of a 1 km^2 area in which a fire was detected, but not the location or size of the fire (Langner *et al* 2007, Miettinen *et al* 2007, Langner and Siegert 2009). Thus, depending on the location and size of the associated fires, MODIS fire detections that are temporally proximate and that represent adjacent pixels may be associated with a spatially contiguous fire event or they may represent isolated fire events. In order to identify fire ignitions, we group all fire detections into fire events (i.e., a fire with a common ignition source, which may consist of multiple fire detections) using a spatial rule that allows fire events to spread beyond their pixel of origin (i.e., neighborhood-pixel technique explained in detail in Cattau *et al* 2016). The overall accuracy of fires identified by our algorithm is 73 ($\pm$3)% when compared with finer-resolution (30 m^2) Landsat data (Cattau *et al* 2016). For each fire event, we identify the location of the ignition(s) as the earliest detection(s) associated with that fire event. For every fire whose associated pixel is bifurcated by an oil palm concession boundary, we report statistics considering that fire to occur where the majority of the pixel's area occurs (i.e., either inside or outside an oil palm concession). To account for the spatial uncertainty of fires within their associated 1 km^2 pixel, we also report the range of values derived from assigning every bifurcated pixel to 'outside of a concession boundary' (low estimate) and assigning every bifurcated pixel to 'within a concession boundary' (high estimate).

Fire activity on RSPO certified and non-RSPO certified oil palm concessions

For each oil palm concession that is identified as RSPO certified or non-certified, we identify fire detections and fire ignitions located within that concession. We also identify fires that 'escape' from each oil palm concessions into the surrounding landscape by isolating fire events whose ignition detection(s) are within that concessions and that have at least one associated detection outside the concession boundaries. For each concession, we calculate the annual density of fire detections, of fire ignitions, and of fires that 'escape' from the concession into the surrounding landscape by dividing the number of detections, ignitions, and escaped fires respectively occurring on each concession each year by the area of that concession.

We determine if the density of fire detections, ignitions, or escaped fires on RSPO certified concessions are different from that on non-RSPO certified concessions between 2012–2015 using the Kolmogorov–Smirnov (KS) test, a non-parametric test to evaluate if the distribution differs between two groups. We conduct these analyses on data stratified by whether a concession was located in peatland or non-peatland rather than grouping them all together, because the likelihood of fire is different in those classes. We obtain the location of peatlands from the Global Forest Watch portal (World Resources Institute 2014c), which is a layer of peat depth at the sub-meter resolution from the atlas of peat land distribution Kalimantan originally derived from remotely sensed data validated with field data (Wahyunto and Suryadiputra 2008). We further separate the data by wet years (2012 and 2013) and dry years (2014 and 2015). In the wet years, the 3-month running mean of SST anomalies in the Niño 4 region never surpassed a threshold of +0.5 °C. In the dry years, it surpassed the threshold in 6 months in 2014 and 12 months in 2015 (figure A.1 in supplementary material).

Because our data are observational, we improve causal inferences by controlling for bias (i.e., factors that may have an influence on whether a concession is RSPO certified and thereby affecting comparability with non-certified concessions). We conduct propensity score matching using the 'MatchIt' package in R (Ho *et al* 2011), which uses nonparametric matching methods to match samples of the treated (i.e., RSPO certified) and control (i.e., non-RSPO certified) groups with similar covariate distributions in order to improve statistical models. For each concession, we calculate the following covariates: concession area in hectares and mean road density (i.e., access to infrastructure) (see figure A.2 in supplementary material for covariate distributions). Road density is derived from a layer of road locations, including both paved and unpaved roads, obtained from WRI (Minnemeyer *et al* 2009). We estimate propensity scores (i.e., the probability that a concession is RSPO certified) using a generalized linear model with a logit link, and match samples on propensity scores using nearest neighbor matching. We then determine if the distributions of the density of fire detections, ignitions, or escaped fires on RSPO certified concessions are different from that on non-RSPO certified concessions using KS tests on matched samples.

Results

In the study area, the intra-annual pattern of fire activity from 2012 to 2015 peaks during the dry season months (August–October) both within all concessions in the study area (i.e., all concessions in the GFW dataset) and outside of concessions (figures 2(a) and (b), respectively). The inter-annual pattern of fire

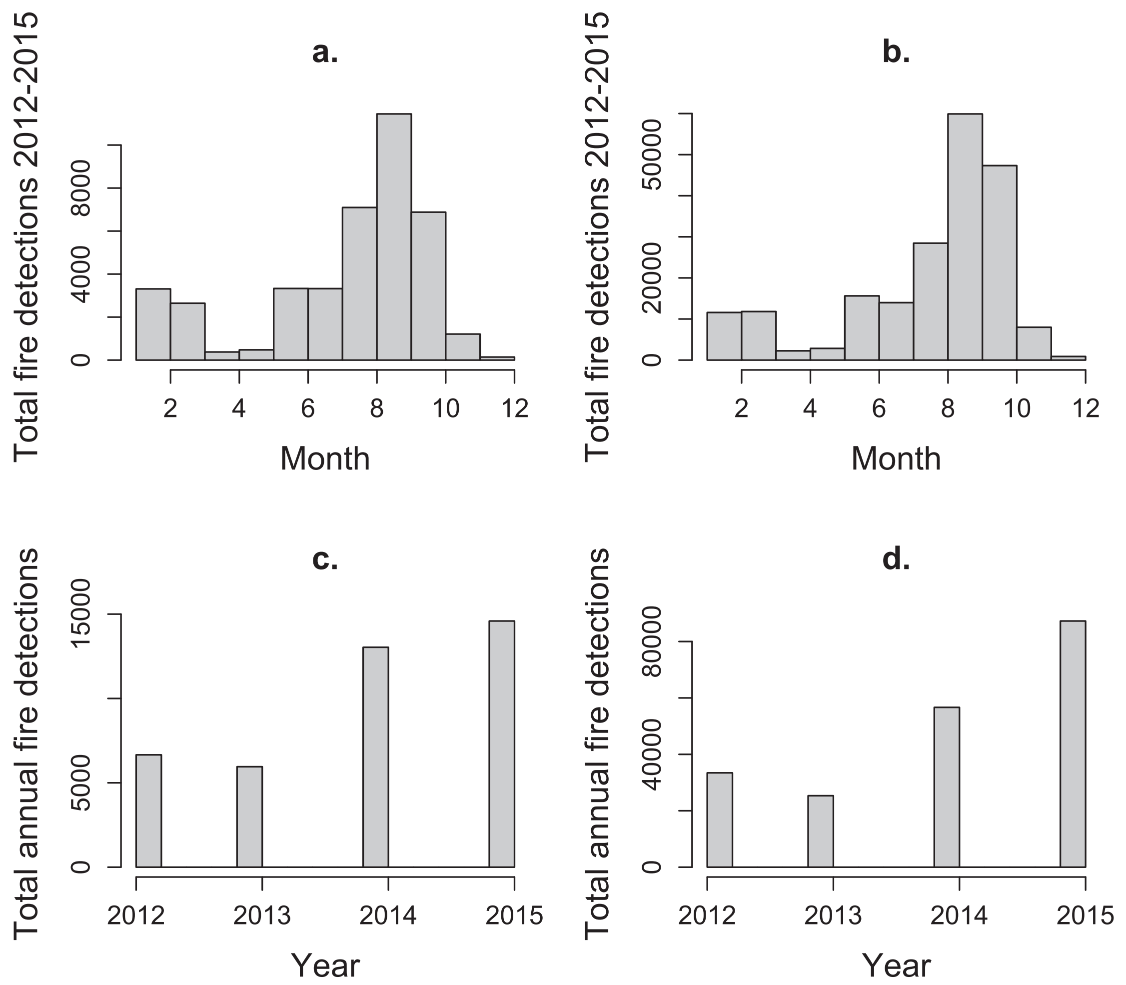

Figure 2. Temporal pattern of fire in the study area 2012–2015: the number of MODIS fire detections within the study area (total *N* fire detections = 242957: 110884 on Kalimantan and 132073 on Sumatra) that occur per month (a) on all oil palm concessions in the study area (*N* concessions = 1764) and (b) outside of oil palm concessions, and that occur per year (c) on all oil palm concessions in the study area and (d) outside of oil palm concessions. Fire activity peaks during the dry season months (August–October) both within and outside of concessions. Fire activity was higher in dry years 2014 (Mean 3 month average Niño 4 Index: 0.50 ± SD 0.27) (28.7% of fire detections) and 2015 (1.21 ± SD 0.28) (41.9% of fire detections) than wet years 2012 (−0.01 ± SD 0.47) (16.5% of fire detections) and 2013 (0.08 ± SD 0.10) (12.9% of fire detections), both within and outside of concessions. Note differences in scale.

activity within all concessions in the study area is also similar to that outside of concessions across the years 2012–2015 (figures 2(c) and (d), respectively). Although most fire activity in the study area occurs outside of oil palm concessions, a substantial percentage (16.6 (12.8–20.3)%) of all the fire detections during the study period are located within oil palm concessions (figure 3), distributed among 70.4 (63.3–70.5)% of the total concessions. During the study period, a disproportionate percentage of the total fire detections (52.3%) occur on peatlands (figure 3), considering peatlands cover approximately 13.7% of the land area in Sumatra and Kalimantan.

Propensity scoring

On peatlands, concession area does not differ between RSPO certified and non-certified concessions, but road density does (figure A.2 and table A.2 in supplementary material). We thus conduct propensity scoring using just road density to improve inference on peatlands. Propensity scoring resulted in one-to-one matching of 4 RSPO certified concessions with 4 non-certified concessions and a 79.7% balance improvement on mean road density, meaning that the mean of that measured covariate is more similar between the RSPO certified and non-certified concessions after matching than prior to matching (table A.2 in supplementary material). On non-peatlands, concession area and road density differ between RSPO certified and non-certified concessions (table A.2 in supplementary material); we thus conduct propensity scoring using both covariates to improve inference on non-peatlands. Propensity scoring resulted in matching with replacement of 24 RSPO certified concessions with eight non-certified concessions and a 25.5% balance improvement on mean road density and a 96.4% balance improvement on concession area (table A.2 in supplementary material).

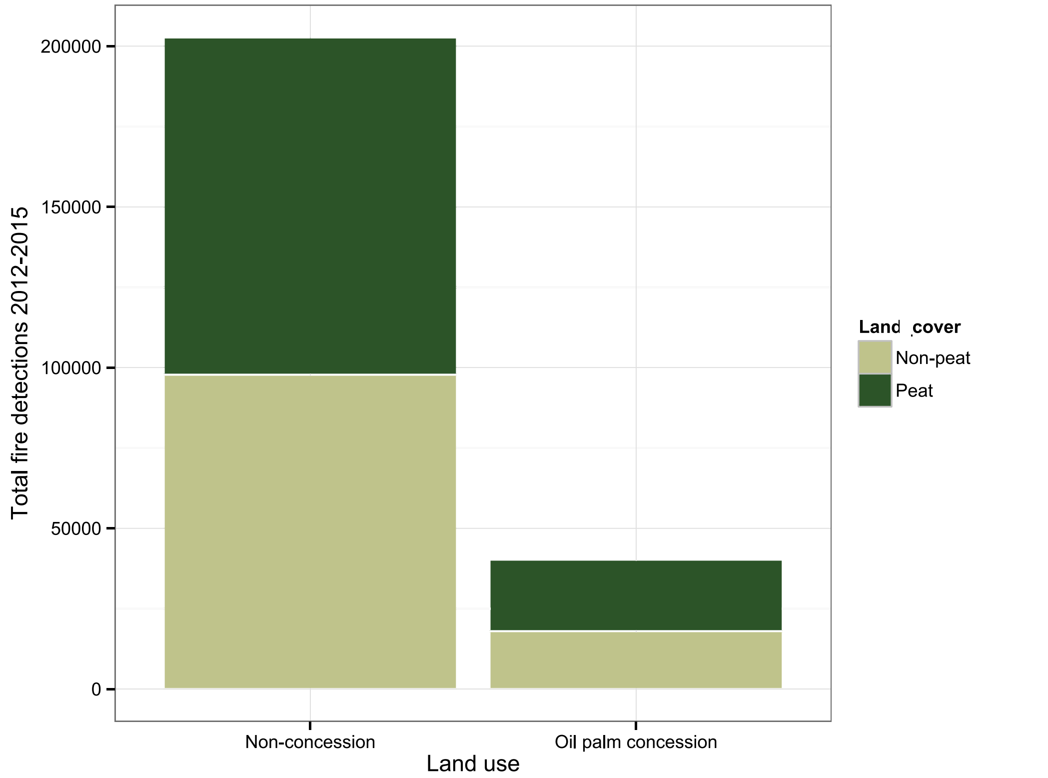

Figure 3. The total number of fire detections ($N = 205\,749$) on Kalimantan and Sumatra 2012–2015 located outside of oil palm concession boundaries and within concessions boundaries. 16.6% of all the fire detections during the study period are located within oil palm concessions. These detections are divided into peatlands (13.7% of the land area) and non-peatlands (86.3% of the land area). A disproportionate percentage of the total fire detections (52.3%) occur on peatlands considering the percent land area in peatland (13.7%).

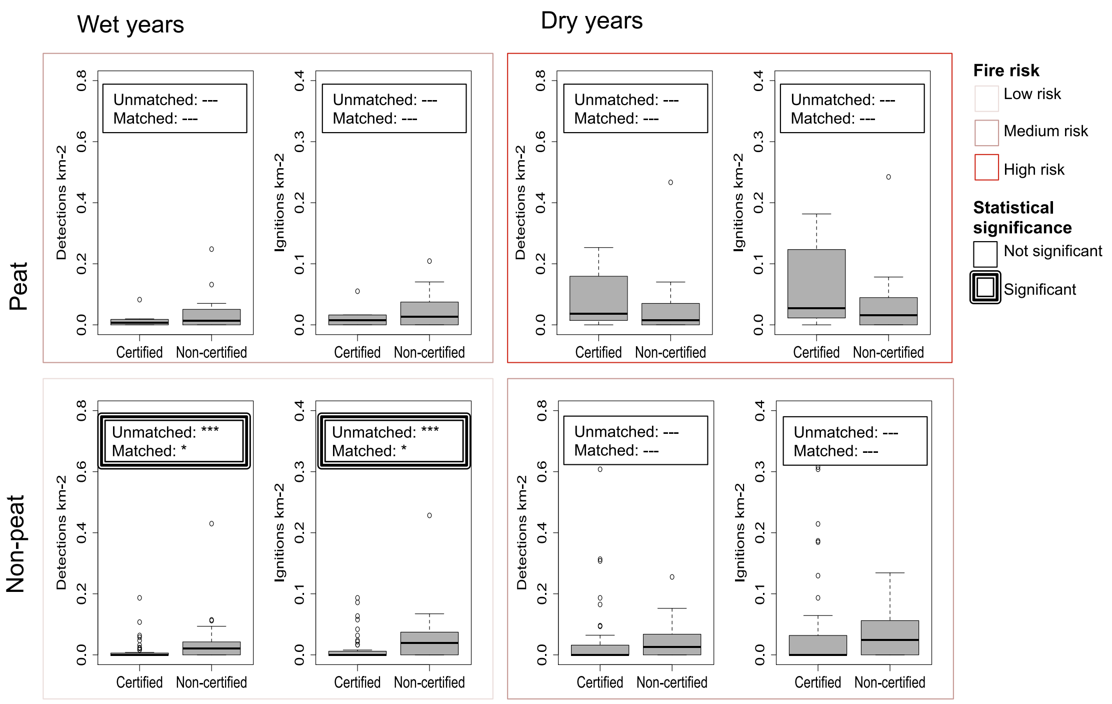

Figure 4. Density of fire activity, including the density of fire detections and density of fire ignitions on non-peatlands for RSPO certified concessions ($N = 24$) and non-certified concessions ($N = 14, N = 8$ after matching) and on peatlands for RSPO certified concessions ($N = 4$) and non-certified concessions ($N = 11, N = 4$ after matching), divided into wet years (2012–2013) and dry years (2014–2015). Differences in fire activity between RSPO certified and non-certified concessions before and after matching tested using KS-tests are shown with the following significance codes: >0.10, *<0.10, **<0.05, ***<0.01. See table A.3 in supplementary material for data on fire activity on RSPO certified concessions compared with non-certified concessions both on peatlands and on non-peatlands divided into wet and dry years.

Fire activity on RSPO certified and non-RSPO certified oil palm concessions

During the study period, fire activity—including the density of fire detections and fire ignitions—is not significantly different between RSPO certified and non-certified concessions on peatlands for matched or unmatched samples (figure 4 and table A.3 in supplementary material). This result is consistent in wet years (2012–2013) and dry years (2014–2015) for both the high and low estimates of fire activity within concessions (table A.3 in supplementary material). Fire activity is significantly lower on RSPO certified concessions compared with non-certified concessions on non-peatlands in wet years, for both the high and low estimates of fire activity within concessions. Fire activity is not significantly different between RSPO certified and non-certified concessions on non-peatlands in dry years, except for the low estimate of fire activity within concessions. During the study period, only eight fires escaped from inside the boundaries of a developed concession included in our analysis into other land use classes; five from certified concessions and three from non-certified concessions. Thus, we do not consider escaped fires further in our analysis.

Discussion and conclusion

We find that, from 2012–2015, fire activity (i.e., the density of fire detections and fire ignitions) is significantly lower on RSPO certified concessions than non-RSPO certified concessions when the likelihood of fire is low (i.e., on non-peatlands in wet years), but not statistically different when the likelihood of fire is high (i.e., on peatlands in all years or on non-peatlands in dry years). Our results provide evidence that RSPO has the potential to reduce fires, but is currently only effective when fire likelihood is relatively low and thus fewer fires occur and are presumably more easily controllable; during the study period, only 16.3% of fire detections on RSPO certified and non-certified concessions occurred on non-peatlands in wet years. This result implies that, in order for this mechanism to reduce fire, greater efforts may be needed to control fires in dry years and on peatlands.

The potential for RSPO certification to further reduce environmental impacts, including fire, may depend in part upon further clarification of what is required under the RSPO Principles and Criteria. A few relatively new initiatives may strengthen the RSPO; the Palm Oil Innovation Group and The Sustainable Palm Oil Manifesto have been developed to provide additional clarification and criteria above and beyond what is required by the RSPO, and the Indonesian Sustainable Palm Oil standard introduces accountability for domestic growers.

Fire activity on RSPO certified concessions may also be reduced with improved monitoring and enforcement. A single, undisputed set of map data containing the location of Indonesian oil palm concessions, including RSPO certified plantations, is not currently publically available. Because of these data constraints, our sample size was reduced to the concessions that belong to companies for which the percent of their holdings that are RSPO certified are known to be either 0% (for non-certified concessions) or over 85% (for certified concessions). This issue is the major limitation of this study. RSPO members were required by General Assembly Resolution in November 2013 to submit their concession maps to RSPO. However, Indonesia and Malaysia questioned the legality of this (e.g., Directorate General of Plantation M O A 2015), resulting in a freeze of the implementation of this resolution and of the release of these data since 2013. However, this issue limits the ability not only of independent researchers to evaluate the effects of RSPO certification, but also of RSPO to monitor its members. The RSPO monitors fire hotspots through the GFW platform (World Resources Institute 2014a); if a fire detection is located within a RSPO certified concession, the RSPO member must provide evidence of what the situation is on the ground and report back to RSPO with the results of the actions they have taken to remediate the situation (Roundtable on Sustainable Palm Oil 2015a, 2015b). These concession maps are often different than the boundary maps that the oil palm companies hold. Without an undisputed map of certified concessions, RSPO cannot hold its members accountable. Although RSPO indicates it will publish its members' oil palm concession maps during the second quarter of 2016 (Roundtable on Sustainable Palm Oil 2015a, 2015b), this will be map data disclosed primarily by the RSPO member companies that hold the concessions themselves. In order to comprehensively evaluate if fire activity is reduced on RSPO certified concessions, as well as to accurately assign responsibility for fires in order to hold RSPO members and other concession owners accountable, spatially explicit data that are publically accessible, accurate, current, exhaustive, and recognized by all parties is essential.

We recognize some important limitations in assessing fire activity using MODIS-derived active fire detections, including the relatively large and variable MODIS pixel size and the spatial uncertainty of the fire size and fire location within the MODIS pixel. However, the average concession that we used for our analyses is 96 km^2; thus, the percent of all fires along the concession boundaries that are misattributed to either the area inside a concession or outside a concession is likely to be only a small percent of all fires and not biased in one direction. When we address the issue of the uncertainty of the fire location within the associated pixel by assigning all fire pixels bifurcated by a concession boundary to 'outside of a concession' (low estimate) and to 'within a concession' (high estimate), we find that the results are consistent with assigning each fire pixel based on the majority area of that pixel;

fire activity is significantly different between certified and non certified concessions only on non-peatlands in wet years (with the exception of the low estimate of fire activity also being significantly different between certified and non certified concessions on non-peatlands in dry years). Although using moderate resolution data to map burned area might allow us to more accurately identify the spatial location and size of fires, there is a paucity of available moderate resolution data that is relatively cloud-free during the study period (e.g., only four images with 10% or less cloud cover are available for Path 118 Row 62 from Landsat 7 during the entire study period). Furthermore, the temporal resolution is too coarse to identify ignitions, escaped fires, or repeat fires at a return interval more frequent than concurrent cloud-free images.

We acknowledge several limitations in our study that may result in under- or overestimating fire activity and/or the effect of RSPO on fire activity. Our estimate that 16.6% of fire detections are located within oil palm concessions includes fires that occurred during the study period on all concessions. However, our estimates for fire activity on RSPO certified and non-certified concessions were limited to concessions that were already developed by the beginning of the study period in 2012 because there were insufficient data to include concessions developed during the study period. Thus, we do not capture fire related to the clearing stage, and our estimates of fire activity are therefore conservative. When more data become available, the effect that RSPO certification has on reducing fire activity will be substantially improved by evaluating conversion fires. The subset of concessions used for our analyses may be biased, as they are larger and more accessible than the average concession in Sumatra and Kalimantan. However, this bias is unlikely to affect the results, as the concessions are still representative of the larger landscape (i.e., well within a standard deviation for size and accessibility of all concessions) and there is no clear relationship between either the size of a concession and fire activity on that concession or between road density around a concession and fire activity on that concession (figure A.3 in supplementary material). We control for concession size and accessibility when matching certified and non-certified concessions, but more research is needed to identify if additional factors affect the relationship between certification status and fire activity. These covariates may include biophysical factors (e.g., slope), anthropogenic factors (e.g., land use history), as well as complex interactions between these factors (e.g., the climatological conditions in the year of initial clearing). Additionally, the omission rate for MODIS active fire detections in Kalimantan and Sumatra is estimated at 34%–60% (Liew *et al* 2003, Miettinen *et al* 2007, Tansey *et al* 2008). Fire detection density therefore likely underestimates fire activity, especially in areas with high tree cover including mature plantations, though we do allow for missed detections when we cluster fire detections into fire events to derive ignition density (see Cattau *et al* 2016 for further explanation). Finally, we include only legal, agro-industrial oil palm concessions, though smallholders are eligible for RSPO certification. The effect of RSPO on fire activity or the trends of fire activity more generally may be different on smallholder plantations than on agro-industrial concessions, but data are not currently available to evaluate this issue.

Financial mechanisms (e.g., RSPO certification) used in tandem with regulatory approaches (Wilcove and Koh 2010) may be effective for reducing fire. There have been previous attempts to reduce fire in Indonesia through national and international regulatory mechanisms (e.g., ASEAN Agreement on Transboundary Haze Pollution, Singapore's Transboundary Haze Pollution Act, and Indonesia's national law (Act No 41/1999) banning corporations from using fire to clear land for palm-oil plantations), but with limited success. The presidential instructions banning clearance and conversion on peatlands, including on existing concessions (Government of Indonesia 2015) may prove effective if it becomes legally binding law. Furthermore, the effectiveness of regulatory approaches to reducing fire on oil palm will depend, in part, upon the capacity for enforcement. In a clear demonstration of regulatory enforcement, the Indonesian government is currently taking legal recourse on companies responsible for fires associated with the 2015 haze crisis, most of which are in pulp and paper, by revoking or suspending their licenses (Butler 2015).

Protecting high carbon value areas, particularly peatlands, from fire activity will be essential in reducing concessions-related emissions. During the study period, a disproportionate percentage of the total fire detections (52.3%) occur on peatlands, which cover approximately 13.7% of the land area in Sumatra and Kalimantan. Furthermore, fires in peatlands have higher emissions potential because of the high fuel loads in belowground biomass. Nearly half of all peatland area is designated as oil palm concession, and so the management of those concessions will have a large influence on fire activity on peatlands and the integrity of peatland ecosystems at the national scale. The relevant management includes not only direct burning, but also whether canals are dug, which can alter the hydrology of these systems and make them more susceptible to ignition and burning (e.g., critical threshold of groundwater depths below which fire is very likely Usup *et al* 2004, Wosten *et al* 2006).

We find that RSPO does have a limited potential to reduce fires on agro-industrial concessions in Indonesia. More research is needed to understand if and in what capacity fire activity is reduced on RSPO certified smallholder plots in Indonesia and on smallholder and agro-industrial plantations in other countries. Given the global reach of the association, the capacity for this mechanism to result in oil palm production that is more sustainable is considerable.

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References

Barber C V and Schweithelm J 2000 *Trial by Fire: Forest Fire and Forestry Policy in Indonesia's Era of Crisis and Reform* (Washington, DC: World Resources Institute) (www.wri.org/sites/default/files/pdf/trialbyfire.pdf)

Butler R A 2015 50+ companies being investigated or punished for Indonesia's haze crisis Mongabay

Carlson K M, Curran L M, Ratnasari D, Pittman A M, Soares-Filho B S, Asner G P, Trigg S N, Gaveau D A, Lawrence D and Rodrigues H O 2012 Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia *Proc. Natl Acad. Sci.* **109** 7559–64

Cattau M E, Harrison M E, Shinyo I, Tungau S, Uriarte M A and DeFries R 2016 Sources of anthropogenic fire ignitions on the peat-swamp landscape in Kalimantan, Indonesia *Glob. Environ. Change* **39** 205–19

Colchester M and Jiwan N 2006 *Ghosts on Our Own Land: Indonesian Oil Palm Smallholders and the Roundtable on Sustainable Palm Oil* (Moreton-in-Marsh/Bogor: Forest Peoples Programme/Perkumpulan Sawit Watch) (www.forestpeoples.org/topics/palm-oil-rspo/publication/2011/ghosts-our-own-land-oil-palm-smallholders-indonesia-and-roundt)

Danielsen F *et al* 2009 Biofuel plantations on forested lands: double jeopardy for biodiversity and climate plantaciones de biocombustible en terrenos boscosos: doble peligro para la biodiversidad y el clima *Conservation Biol.* **23** 348–58

Deeming J E 1995 *Development of a Fire Danger Rating System for East-Kalimantan, IFFM Short Term Report GTZ Document No.* 08 Eschborn

Directorate General of Plantation Ministry of Agriculture 2015 Letter No. 120/HM.230/02/2015 to the Indonesian Growers Caucus of the RSPO on provision of Indonesian plantation maps to the RSPO and NGOs

Food and Agriculture Organization of the United Nations 2015 *FAOSTAT: FAO Statistical Databases* (http://faostat3.fao.org/)

Fuller D O and Murphy K 2006 The ENSO-fire dynamic in insular Southeast Asia *Clim. Change* **74** 435–55

Gibbs H K, Johnston M, Foley J, Holloway T, Monfreda C, Ra-mankutty N and Zaks D 2008 Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology *Environ. Res. Lett.* **3** 034001

Government of Indonesia 2015 Instruksi Presiden Republik Indonesia nomor 11 tahun 2015 tentang peningkatan pengendalian Kebakaran hutan dan lahan (http://luk.staff.ugm.ac.id/atur/sda/Inpres%2011-2015PengendalianKebakaranHutan.pdf)

Hayasaka H, Noguchi I, Putra E I, Yulianti N and Vadrevu K 2014 Peat-fire-related air pollution in Central Kalimantan, Indonesia *Environ. Pollut.* **195** 257–66

Ho D E, Imai K, King G and Stuart E A 2011 MatchIt: nonparametric preprocessing for parametric causal inference *J. Stat. Softw.* **42** 1–28

Hooijer A 2006 Tropical peatlands in Southeast Asia *The Biology of Peatlands* ed H Rydin and J K Jeglum (Oxford: Oxford University Press) pp 233–9

Hooijer A, Silvius M, Wösten H and Page S 2006 PEAT-CO_2 *Assessment of CO_2 Emissions From Drained Peatlands in SE Asia, Delft Hydraulics*(https://inis.iaea.org/search/search.aspx?orig_q=RN:42022627)

Indonesian Ministry of Agriculture 2010 *Area and Production by Category of Producers: Oil Palm 1967–2010* (Jakarta, Indonesia: Indonesian Ministry of Agriculture)

Jaafar Z and Loh T-L 2014 Linking land, air and sea: potential impacts of biomass burning and the resultant haze on marine ecosystems of Southeast Asia *Global Change Biology* **20** 2701–7

Kita K, Fujiwara M and Kawakami S 2000 Total ozone increase associated with forest fires over the Indonesian region and its relation to the El Niño-Southern oscillation *Atmos. Environ.* **34** 2681–90

Koh L, Miettinen J, Liew S and Ghazoul J 2011 Remotely sensed evidence of tropical peatland conversion to oil palm *Proc. Natl Acad. Sci.* **108** 5127–32

Koh L P, Ghazoul J, Butler R A, Laurance W F, Sodhi N S, Mateo-Vega J and Bradshaw C J A 2010 Wash and spin cycle threats to tropical biodiversity *Biotropica* **42** 67–71

Langner A, Miettinen J and Siegert F 2007 Land cover change 2002–2005 in Borneo and the role of fire derived from MODIS imagery *Global Change Biol.* **13** 2329–40

Langner A and Siegert F 2009 Spatiotemporal fire occurrence in Borneo over a period of 10 years *Global Change Biol.* **15** 48–62

Liew S C, Shen C, Low J, Lim A and Kwok L K 2003 Validation of MODIS fire product over Sumatra and Borneo using high resolution SPOT imagery *Proc. 24th Asian Conf. on Remote Sensing and 2003 Int. Symp. on Remote Sensing*

Margono B A, Potapov P V, Turubanova S, Stolle F and Hansen M C 2014 Primary forest cover loss in Indonesia over 2000–2012 *Nat. Clim. Change* **4** 730–5

Marlier M E, DeFries R S, Kim P S, Koplitz S N, Jacob D J, Mickley L J and Myers S S 2015 Fire emissions and regional air quality impacts from fires in oil palm, timber, and logging concessions in Indonesia *Environ. Res. Lett.* **10** 085005

Maulia E 2010 *Indonesia Pledges to 'Feed the World'* (Jakarta: Jakarta Post) (www.thejakartapost.com/news/2010/01/30/indonesia-pledges-feed-world039.html)

Miettinen J, Andreas L and Siegert F 2007 Burnt area estimation for the year 2005 in Borneo using multi-resolution satellite imagery *Int. J. Wildland Fire* **16** 45–53

Miettinen J, Shi C and Liew S C 2016 Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990 *Global Ecol. Conservation* **6** 67–78

Minnemeyer S, Boisrobert L, Stolle F, Muliastra Y I K D, Hansen M, Arunarwati B, Prawijiwuri G, Purwanto J and Awaliyan R 2009 *Interactive Atlas of Indonesia's Forests (CD-ROM)* (Washington, DC: World Resources Institute)

Page S E, Siegert F, Rieley J O, Boehm H-D V, Jaya A and Limin S 2002 The amount of carbon released from peat and forest fires in Indonesia during 1997 *Nature* **420** 61–5
Posa M R C, Wijedasa L S and Corlett R T 2011 Biodiversity and conservation of tropical peat swamp forests *BioScience* **61** 49–57
Reddington C L, Yoshioka M, Balasubramanian R, Ridley D and Toh Y Y 2014 Contribution of vegetation and peat fires to particulate air pollution in Southeast Asia *Environ. Res. Lett.* **9** 094006
Rianto B 2010 *Palm Oil Plantation: Industry Landscape, Regulatory and Financial Overview* (Jakarta, Indonesia: Pricewaterhouse Coopers Indonesia) pp 1–16 (www.pwc.com/id/en/publications/assets/palm-oil-plantation.pdf)
Rosoman G and Rahmawa A 2015 Oil palm growers
Roundtable on Sustainable Palm Oil 2013 *Principles and Criteria for the Production of Sustainable Palm Oil 5.5 and 7.7* (www.rspo.org/file/RSPO%20Principles%20&%20Criteria%20Document.pdf)
Roundtable on Sustainable Palm Oil 2015a Palm oil concession maps of RSPO members to become publically available, Kuala Lumpur (www.rspo.org/news-and-events/news/palm-oil-concession-maps-of-rspo-members-to-become-publicly-available)
Roundtable on Sustainable Palm Oil 2015b RSPO statement on the Indonesian forest fires (www.rspo.org/news-and-events/news/rspo-statement-on-the-indonesian-forest-fires)
Ruitenbeek J 1999 *Indonesia. Indonesia's Fire and Haze: The Cost of Cataptrophe* ed D Glover and T Jessup (Ottawa: Institute of Southeast Asian Studies (ISEAS)/International Development Research Centre (IDRC))
Siegert F, Ruecker G, Hinrichs A and Hoffmann A A 2001 Increased damage from fires in logged forests during droughts caused by El Nino *Nature* **414** 437–40
Simorangkir D, Moore P, Haase N and Ng G 2002 Workshop Report: Land clearing on degraded lands for plantation development *A Workshop on Economics of Fire Use in Agriculture and Forest Plantations* (Kuching: Fire Fight South East Asia, IUCN, and WWF) (https://cmsdata.iucn.org/downloads/ff_workshop_economics.pdf)
Spessa A C, Field R D, Pappenberger F, Langner A, Englhart S, Weber U, Stockdale T, Siegert F, Kaiser J W and Moore J 2015 Seasonal forecasting of fire over Kalimantan, Indonesia *Nat. Hazards Earth Syst. Sci.* **15** 429–42
Tacconi L 2003 *Fires in Indonesia: Causes, Costs, and Policy Implications* (Jakarta, Indonesia: Center for International Forestry Research) (www.cifor.org/publications/pdf_files/OccPapers/OP-038.pdf)
Tansey K, Beston J, Hoscilo A, Page S E and Paredes Hern·ndez C U 2008 Relationship between MODIS fire hot spot count and burned area in a degraded tropical peat swamp forest in Central Kalimantan, Indonesia *J. Geophys. Res.* **113** D23112
Teoh C H 2010 *Key Sustainability Issues in the Palm Oil Sector* (Washington, DC: World Bank) (http://siteresources.worldbank.org/INTINDONESIA/Resources/226271-1170911056314/Discussion.Paper_palmoil.pdf)
Turetsky M R, Benscoter B, Page S, Rein G, van der Werf G R and Watts A 2015 Global vulnerability of peatlands to fire and carbon loss *Nat. Geosci* **8** 11–4
Usup A, Hashimoto Y, Takahashi H and Hayasaka H 2004 Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia *Tropics* **14** 1–19
Wahyunto and Suryadiputra I N N 2008 *Peatland Distribution in Sumatra and Kalimantan—Explanation of its Data Sets Including Source of Information, Accuracy, Data Constraints and Gaps* (Bogor, Indonesia: Wetlands Internationa) (www.wetlands.or.id/PDF/Atlas%20Review.pdf)
Wang Y H, Field R D and Roswintiarti O 2004 Trends in atmospheric haze induced by peat fires in Sumatra Island, Indonesia and El Nino phenomenon from 1973–2003 *Geophys. Res. Lett.* **31** L04103
Wilcove D S and Koh L P 2010 Addressing the threats to biodiversity from oil-palm agriculture *Biodiver. Conservation* **19** 999–1007
Wooster M J, Perry G L W and Zoumas A 2012 Fire, drought and El Nino relationships on Borneo (Southeast Asia) in the pre-MODIS era (1980–2000) *Biosciences* **9** 317–40
Wosten J H M, van den Berg J, van Eijk P, Gevers G J M, Giesen W B J T, Hooijer A, Idris A, Leenman P H, Rais D S and Siderius C 2006 Interrelationships between hydrology and ecology in the fire degraded tropical peat swamp forests *Water Resour. Dev.* **22** 157–74
World Resources Institute 2014a Active fire *Global Forest Watch* Open Data Portal (http://data.globalforestwatch.org/)
World Resources Institute 2014b Oil palm *Global Forest Watch* (http://data.globalforestwatch.org/)
World Resources Institute 2014c Peatlands *Global Forest Watch* (http://data.globalforestwatch.org/)
Yule C 2010 Loss of biodiversity and ecosystem functioning in Indo-Malayan peat swamp forests *Biodiver. Conservation* **19** 393–409