WHITE PAPER

JULY 2016

ECOLOGICAL IMPACTS OF PALM OIL EXPANSION IN INDONESIA

Chelsea Petrenko, Julia Paltseva, and Stephanie Searle

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

ACKNOWLEDGEMENTS

This work was generously supported by the Packard Foundation.

International Council on Clean Transportation
1225 I Street NW Suite 900
Washington, DC 20005 USA

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

The high yields, low cost, and stability of palm oil makes it the most widely used vegetable oil in the world, and global production of the commodity is steadily rising in response to population growth and policies that promote the use of palm and other oils in biofuels. Indonesia is the world's leading producer of palm oil, supplying approximately half of the commodity globally, and is itself driving increased palm oil consumption through a domestic biofuel policy. While the oil palm is a highly efficient crop, there are severe environmental and social consequences of the rapidly expanding industry.

Given that global land area for agriculture is limited, increasing demand for palm oil leads to expansion of this industry onto other cropland, secondary forests already logged for timber, and native tropical forests. Business-as-usual oil palm expansion, which increasingly replaces tropical forests with monoculture crop systems, depletes biodiversity, destroys old growth rainforest, and causes air pollution. Furthermore, much of the rainforest in Indonesia grows on carbon-rich peatland, the destruction of which adversely affects both biodiversity and the climate.

Southeast Asia overlaps with four of the world's distinct "biodiversity hotspots," each of which has unique geological history and biota. Unfortunately, tropical forests in Southeast Asia are being destroyed at a faster pace than other regions in the world. Indonesia lost an estimated 0.84 Mha of primary forest per year from 2000 to 2012, totaling over 6.02 Mha, and significantly outpacing deforestation rates in Brazil; half of this forest loss has been attributed to oil palm expansion. The consequences of this loss to biodiversity are devastating, as a single hectare of tropical rainforest in Indonesia harbors over 200 plant species. Furthermore, more than 60% of Indonesian rainforest species are endemic to that region. Iconic species such as the orangutan, found only on Sumatra and Borneo, are rapidly declining in numbers due to forest loss. Unique fishes living in peat swamp forests are also as risk from habitat degradation. Additionally, pests and alien species such as rats tend to thrive in plantation environments. Although not all biodiversity loss in the region is directly attributable to oil palm plantations, palm production has been found to reduce biodiversity more than other type of crop plantations.

Land-use change in the tropics accounts for 10-20% of total global greenhouse gas (GHG) emissions, making it the second largest GHG source in the world. The carbon footprint of the palm oil industry has two components: emissions from deforestation, and emissions from the processing of palm oil. Converting forests to oil palm plantations results in the loss of large amounts of carbon from biomass and from the disturbed soil. In particular, drainage of peat swamps for oil palm establishment is associated with extremely high CO_2 emissions when organic matter that has accumulated over millennia is allowed to decompose. Because of the extensive emissions associated with palm oil expansion, the carbon savings are far outweighed by the losses. It is estimated that it would take between 75 and 600 years for the carbon savings of petroleum displacement by palm oil biofuel to balance the carbon lost during the growth and manufacturing of the product.

Wildfire smoke is a major source of air pollution that adversely affects human health and productivity in Southeast Asia. Despite regulations against land-clearing fires, "slash and burn" agriculture is a common occurrence in the dry season. In Katapang, Indonesia, fire was the cause of 90% of deforestation between 1989 and 2008, and 20% of wildfires across Indonesia can be attributed directly to oil palm plantation practices. Wildfire smoke can cause respiratory and cardiovascular disease and even death. In addition to devastating health effects, wildfires have adverse economic effects. Closed businesses, schools, and limited transportation can bring economies to a halt, and the effects of fires spread far beyond the geographic region where they originate.

Pollutants from agrochemicals associated with palm oil production (fertilizers, pesticides, and rodenticides) have harmful impacts on terrestrial and aquatic ecosystems. Palm oil mill effluent, which is microbially digested in open ponds, often overflows into waterways during heavy rains. The use of dangerous herbicides and pesticides also directly affects the health of workers who handle these chemicals.

Some stakeholders experience significant gains from the burgeoning global palm oil trade (growers, investors, and employees), but other groups, such as traditional landowners, experience land losses and restrictions on land use rights. Native Customary Rights are often ignored when plantations are established, leading to conflicts between indigenous peoples and palm oil companies and sometimes serious human rights abuses.

It is clear that business-as-usual expansion of the Indonesian palm oil industry will come at a great environmental cost. In order to meet Indonesia's greenhouse gas reduction goals, protect biodiversity, and reduce air and water pollution, stricter law enforcement is needed and new development must be diverted from primary and secondary forests. New oil palm plantations sited on degraded or *Imperata* grasslands could realize significant carbon savings with low biodiversity impacts. However, the limited area of these land types will not support all future growth of the palm oil industry if demand continues to increase in line with expectations. Policies that continue to promote growing for the use of palm and other oils in biofuel will thus likely exceed the capacity of the industry to expand sustainably. The use of available palm and other agricultural residues in biofuel are more effective solutions for meeting climate and other environmental goals.

TABLE OF CONTENTS

INTRODUCTION

Palm oil has risen in global importance in the past several decades, with world production of palm oil rising from 13.5 million tonnes in 1990, to 155.8 million tonnes in 2014 (FAOSTAT, 2016). The efficiency of its production, low cost, and stability of the oil make it the most attractive and widely used vegetable oil in the world. Palm oil is ubiquitous in global products, including food, cosmetics, detergents, plastics, industrial chemicals, and biofuels. The oil palm yields more oil per land area than any other tropical or temperate oil crop (Sheil, 2009), but there are severe environmental and social consequences of the rapidly expanding industry, particularly for those countries producing the product.

Indonesia is the world's leading producer of palm oil, supplying approximately half of the commodity globally (FAOSTAT, 2015). Together with Malaysia, the two countries account for more than 80% of global production (Pittman, 2013). In 2014, Indonesia produced 32.5 million tonnes of crude palm oil and exported 80% of it, earning USD$18.6 billion (Indonesia-Investments, 2016). Palm oil is the largest agricultural industry in Indonesia (Indonesia-Investments, 2016), and its production is expected to continue to expand at 10% per year (Gunarso et al., 2013). Total harvested oil palm area in Indonesia grew from 4.1 million ha in 2006 (Obidzinski et al., 2012) to an estimated 8.9 million ha in 2015 (Wright and Rahmanulloh, 2015), and is projected to reach 17 million ha by 2025 (Figure 1; Sung, 2016). The palm oil industry directly employs 7.5 million people (Sung, 2016), making it an important source of income for many Indonesians.

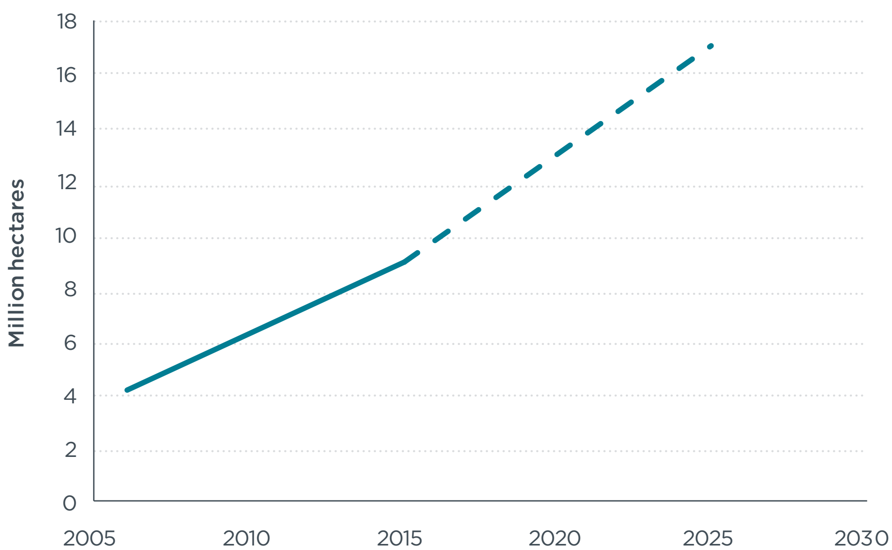

Figure 1. Historical and projected oil palm plantation area in Indonesia

Palm oil is produced from a tropical palm, *Elaeis guineensis*, which is native to West and Central Africa. It grows in tropical rainforests with high annual rainfall and temperatures in the range of 24-30° C (Sheil et al., 2009). Oil palm is cultivated on a range of soil types in monoculture plantations. The size of the plantations ranges from personal smallholdings to large private estates up to 20,000 ha in area (Sheil et al., 2009). Large private enterprises account for approximately half of production, while smallholdings account for 35% (Indonesia-Investments, 2016).

Given that global land area for agriculture is limited (Tilman et al., 2001), the rapid expansion of the oil palm industry comes at the expense of other cropland, secondary forest, and native tropical forest. Most (96%) of palm oil production occurs on the island of Sumatra and in Kalimantan (Indonesian Borneo), where crops such as cacao and rubber are also grown. Early palm plantations were thought to be replacing existing croplands and utilizing degraded land (Gibbs et al., 2010), but evidence has accumulated to show that intact tropical forests have been, and will continue to be, a major source of new land for palm plantations (Gibbs et al., 2010; Koh and Wilcove, 2008). Oil palm expansion directly accounted for 11% of Indonesian deforestation between 2000 and 2010 (Abood et al., 2014). However, deforestation is also linked to palm oil through several indirect pathways: (i) replacement of forests that were previously degraded by logging or fire; (ii) joint economic ventures that first clear land for timber and then install palm plantations; (iii) increasing access to remote forests through road infrastructure; and (iv) displacement of food crops into forests (Fitzherbert et al., 2008). Forests that are harvested for wood products should be left to regenerate, as 84% of forest species can be recovered within 30 years of deforestation (Koh & Wilcove, 2008); palm expansion into these areas prevents such regeneration. Including these indirect effects, Fitzherbert et al. (2008) estimate that 1.7–3 million ha of Indonesian forest were lost to palm plantations between 1990 and 2005, accounting for more than 50% of total deforestation during that time period.

Business-as-usual (BAU) oil palm expansion increasingly replaces tropical forests with monoculture crop systems, depleting biodiversity, destroying old growth rainforest, and causing air pollution. Furthermore, much of the rainforest in Indonesia grows on carbon-rich peatland (RFA, 2010), the destruction of which adversely affects both biodiversity and climate (Danielsen et al., 2009).

The staggering amount of land required for oil palm plantations translates into competing uses of land, and in most cases, the destruction of ecologically valuable tropical forests. Losses of endemic species, foregone carbon sequestration, forest fires, and negative impacts to human health and welfare are all consequences of this phenomenon. This report addresses environmental and social impacts of the palm oil industry in Indonesia. We cover the rich biological diversity of Indonesian tropical forests, the carbon balance of intact forest versus plantations, air and water pollution from the palm oil industrial process, and impacts on native Indonesians. Finally, we summarize solutions that have been offered from a range of science, policy and economic experts.

BIODIVERSITY

Southeast Asia overlaps with four of the world's distinct "biodiversity hotspots," each of which has unique geological history and biota (Sodhi et al., 2004). Biological diversity provides cultural, environmental, and financial benefits locally and globally. Species variety improves ecosystem function through seed dispersal, nutrient cycling, and pollination. Preserving biodiversity maintains other ecosystem services such as water filtration and carbon storage (Koh et al., 2011). Biodiverse regions also support a variety of human lifestyles and recreations. Thus, biodiversity affects natural resource availability and human welfare on a range of spatial and temporal scales.

However, tropical forests in Southeast Asia are being destroyed at a faster pace than other regions in the world, and three-quarters of this area could be lost by 2100 (Sodhi, 2004). It is estimated that up to 42% biodiversity in Southeast Asia could be destroyed in the same time period (Sodhi, 2004). Agricultural expansion is the leading cause of biodiversity loss (Tilman et al., 2001; Yaap et al., 2010), and in Indonesia it is directly tied to deforestation.

Understanding the implications of palm oil production in Indonesia is critical, as the country has both the highest rate of deforestation and the highest plant species richness in the world. Indonesia lost an estimated 0.84 Mha of primary forest per year from 2000 to 2012, totaling more than 6.02 Mha and significantly outpacing deforestation rates in Brazil (0.46 Mha yr^{-1}; Margono et al., 2014). The consequences of this loss are devastating, as a single hectare of tropical rainforest in Indonesia harbors more than 200 species and 500 stems (Uryu et al., 2008). Furthermore, more than 60% of Indonesian rainforest species are endemic to the region (Sodhi et al., 2004). The region is home to a variety of unique ecological processes, such as the masting of *Dipterocarpaceae* (synchronized fruiting of tall tropical trees) and the blooming of the *Rafflesia* and titan arum flowers. Indonesia is also home to large charismatic fauna, such as the Sumatran tiger (*Panthera tigris sumatrae*), Sumatran elephant (*Elephas maximus sumatranus*), and Orangutang (*Pongo* spp.).

DEFORESTATION EFFECTS ON BIODIVERSITY

There is paucity of information on how palm plantations in particular affect biodiversity. However, studies are in agreement that forest clearing for any reason has strong, negative impacts on biodiversity. Three plant and eight animal species have already been listed as "extinct" in Southeast Asia, and many native species are not expected to persist in the face of mass deforestation (Sodhi et al., 2004). Given that large-scale deforestation has only occurred in the region for the past two centuries, it is likely that the full effects of such practices have yet to be measured (Sodhi et al., 2004).

Deforestation decreases population density and species richness of all animal groups studied, including birds (Sodhi, 2002), mammals (Heydon & Bulloh, 1997; O'Brien et al., 2003; Meijaard & Nijman, 2001), bees (Liow et al., 2001), butterflies (Sodhi et al., 2004), moths (Beck et al., 2002), termites (Gathorne-Hardy et al., 2002), dung beetles (Davis et al., 2001), and ants (Bruhl et al., 2003). Iconic species such as the orangutan, found only on Sumatra and Borneo, are rapidly declining due to forest loss (Robertson & Van Schaik, 2008; Meijaard et al., 2011). Unique fishes living in peat swamp forests are also as risk from habitat degradation (Ng et al., 1994). In Riau, Sumatra, Sumatran elephants have declined by up to 84%, from >1000 in 1984, to approximately 210 in 2007 (Uryu et al., 2008). Sumatran tiger populations declined by 70% in a similar timespan, from 640 in 1982, to 192 in 2007 (Uryu et al., 2008).

Forest clearing causes high rates of conflict between humans and elephants on Sumatra (Uryu et al., 2008), and similarly, alarmingly high rates of orangutan killings and human-orangutan conflicts may be linked to deforestation (Meijaard et al., 2011). Orangutans are endemic to the lowland rainforests and peat forests of Borneo and Sumatra, which are prime regions of oil palm expansion. Much of the orangutan's native habitat is cleared for expanding plantations, hastening the iconic ape's extinction in the wild and curtailing conservation attempts (Meijaard & Wich, 2007; Nantha & Tisdell, 2009). By surveying local residents in Kalimantan, researchers estimated that between 1950 and 3100 Orangutans are killed annually. The primary reasons given for killing the animals are: for food (54%), and self-defense (11%) (Meijaard et al., 2011).

BIODIVERSITY ON PLANTATIONS

Although not all biodiversity loss in the region is directly attributable to oil palm plantations, palm production has been found to reduce biodiversity more than other types of crop plantations. Fitzherbert et al. (2008) found that oil palm supports fewer species than rubber, cocoa, or coffee plantations, although all plantation types decrease species richness when compared to intact forest. For example, the conversion of rubber plantations to oil palm resulted in a 14% decline in bird diversity (Peh et al., 2006). The severity of palm plantations' impact is driven by a number of factors, including changes in the forest structure, use of dangerous chemicals, frequent human disturbance, and increasing habitat fragmentation.

Plantations are markedly less complex than natural forests, as they have a uniform tree age structure, lower canopy height, and sparse undergrowth (Yaap et al., 2010). The aboveground biomass of mature palm trees is less than 20% of the original forest (Saxon and Roquemore, 2011), which has consequences for microclimate and shade-adapted species (Danielsen et al., 2009; Yaap et al., 2010). In general, the conversion of complex native forest to an *Elaeis guineensis* monoculture results in the local removal of the majority of specialized species. The resulting biological community reflects the available habitat: simpler, species-poor communities dominated by a few generalist species (Danielsen et al., 2009).

All vertebrate species–birds, lizards, and mammals–decline in number when forests are converted to plantations. As such, plantations support only between 15 to 23% (Fitzherbert et al., 2008 and Danielsen et al., 2009, respectively) of primary forest species (Figure 2). The species lost include those with specialized diets, those requiring specialized habitat features such as large trees, those with small ranges, and those of highest conservation concern (Fitzherbert et al., 2008). Large, iconic mammals, such as the Sumatran tiger and clouded leopard, are absent from plantations; instead, the wild pig is the most common large mammal present on plantations in Sumatra (Maddox et al., 2007). Peh et al. (2006) found a 77% decline in bird species richness when primary forests were converted to plantations, and a 73% decline when selectively harvested secondary forests were converted. Aratrakorn et al. (2006) found a shift from high conservation value, forest-dwelling species, such as woodpeckers, barbets and babblers, to lower conservation, non-forest species on palm plantations in Thailand. Water pollution from palm oil mill effluent (POME), insecticides, rodenticides, and herbicides negatively impacts aquatic biodiversity such as fishes, amphibians and reptiles (Fitzherbert et al., 2008).

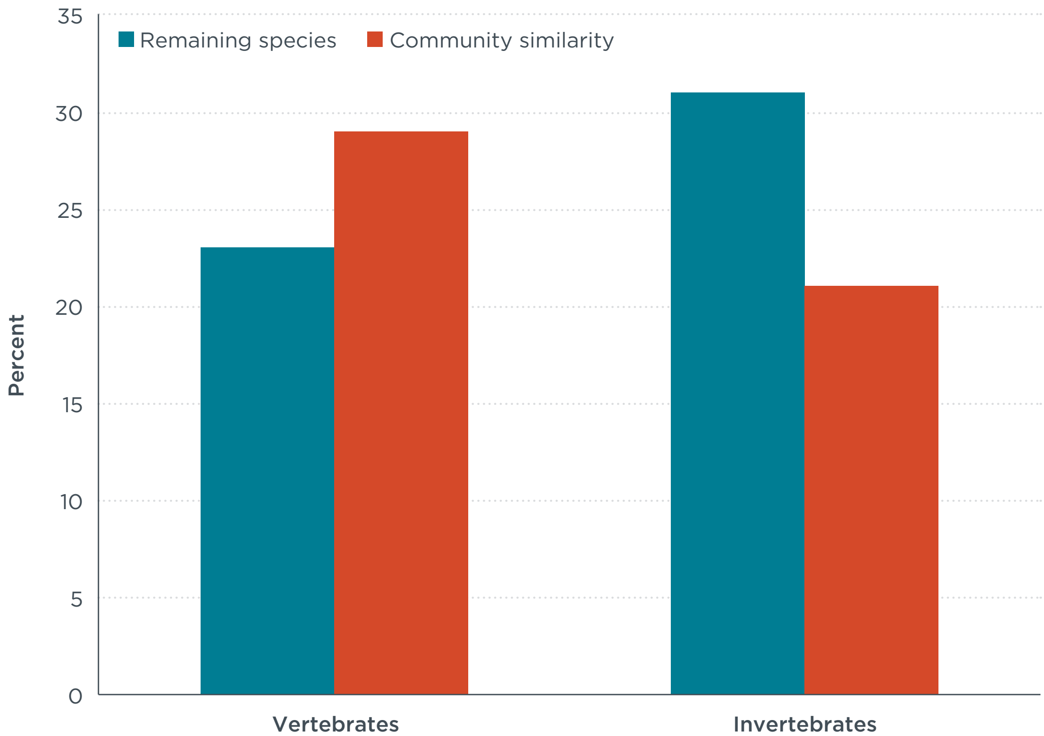

Figure 2. Percent of species remaining in palm plantations as compared to native forest, and species community similarity between forests and plantations. Note: The figure was produced from the findings of Danielsen et al. (2009).

Palm oil plantations also adversely affect invertebrate species. Senior et al. (2013) concluded that ant and beetle species richness declined by 61% and 52%, respectively, following conversion to oil palm plantations. Forest butterfly species richness declines by 83% and 79% with conversion of primary forest and secondary forest, respectively (Koh and Wilcove, 2008). Invertebrate species, although not as visible on the world stage, play an integral role in ecosystem functioning, and their decline may have a cascading effect through higher trophic levels. For example, Larsen et al. (2005) found that large-bodied dung beetles decreased with habitat loss, leaving only their smaller-bodied, less efficient counterparts in the ecosystem. Because dung beetles help maintain soil nutrients and organic matter, their absence was a detriment to the ecosystem function.

The flora of tropical forests not only serve as the lattice for a complex ecosystem, but constitute a major source of biodiversity. Oil palm plantations lack forest trees, lianas (woody climbing vines), epiphytic orchids and indigenous palms (Danielsen et al., 2009). Furthermore, a decreased abundance of fruit-eating birds and mammals greatly reduces seed dispersal, while a decline in bee abundance reduces pollination; both dispersal and pollination are necessary for maintaining plant variety (Senior et al., 2013). Prescott et al. (2015) found 58 epiphytic species recolonizing palm plantations after deforestation, which are then typically removed in order to protect the intended crop. However, the study found that epiphytes did not affect crop yield and suggests that native biodiversity should not be removed from plantations. Oil palm plantations do appear to host more mosses and ferns than old growth forests, but the species are those that commonly colonize disturbed areas (Danielsen et al., 2009).

In place of the rich biological diversity of Indonesian forests, a narrow range of species with certain functional traits thrives in the plantation habitat. Present species tend to be smaller-bodied, from lower trophic levels and not found in high numbers in the forest (Senior et al., 2013). Monocultures providing an overabundance of a certain resource (e.g., palm fruit and palm fronds) promote the hyper-abundance of the few species exploiting that resource (Senior et al., 2013). Ghazali et al. (2016) found that, while arthropod diversity was significantly greater in native forests than in plantations, arthropod abundance was similar. The same was true for butterflies, whose diversity was lower but abundance > 3.5 times greater on plantations compared to native forest (Lucey & Hill, 2012). Additionally, pests tend to thrive in plantation environments. Rat population densities can reach 600 ha^{-1} (Wood & Chung, 2003). Pfeiffer et al. (2008) found that 40% of ant species present on plantations were alien, and some of these were highly invasive.

In summary, all evidence shows that oil palm plantations do not support the biodiversity of native forests. Few of the species in native forests may survive in palm plantations, and the biological community becomes dominated by invasive and generalist species. Species that are highly specialized to live in the unique tropical forests of the region, and that require specific diets and habitat features, are the most vulnerable to expansion of plantations. Furthermore, measurements of biodiversity loss are likely underestimated given that (a) sampling efforts may be less accurate in dense, tropical forest (especially when many species reside high in tree canopies; Fitzherbert et al., 2008), and (b) there is a time lag between habitat loss and extinction, so the presence of a species does not indicate it is thriving or its ultimate survival (Sodhi et al., 2004).

CARBON BALANCE

Tropical forests store significant amounts of carbon (C), and their destruction poses a serious threat to climate stability. After the boreal ecosystem, tropical forests serve as the largest terrestrial carbon sink on Earth, storing approximately 428 Gt C evenly distributed between vegetation and soil (IPCC, 2000). In comparison, the Earth's atmosphere stores 589 Gt C (Ciais et al., 2013), so even relatively small changes to the tropical forest carbon stock could have serious consequences for atmospheric carbon. Indeed, land-use change in the tropics is the world's second largest source of greenhouse gas (GHG) emissions, accounting for 12-20% of total global emissions (IPPC, 2000; Don, Schumacher, and Freibauer, 2011).

The carbon footprint of the palm oil industry has two components: emissions from deforestation, and emissions from the processing of palm oil (Saxon and Roquemore, 2011). Deforestation reduces carbon stocks via biomass removal and also releases carbon from disturbed soils (Figure 3). In addition, it decreases future ecosystem carbon sequestration by reducing carbon inputs from vegetation and changing hydrologic cycles (Fargione et al., 2008). Palm oil processing requires the use of fossil fuel inputs for mechanized plantation equipment, chemical fertilizer, transportation of goods, and industrial processing (Saxon & Roquemore, 2011). Treatment of palm oil mill effluent releases substantial amounts of methane, a potent climate forcer. Chase and Hansen (2010) found deforestation and land conversion was the largest source of GHG emissions for palm oil production, while methane from mill effluent and nitrous oxide from fertilizers were the second largest contributors.

Indonesia is one of the world's top five GHG emitters and has set a goal to reduce its emissions by 26% below BAU by 2020 (PR 61/2011, Paltseva et al., 2016). However, Indonesia's GHG reduction goals cannot be met with BAU palm production, as more than 75% of the country's CO_2-equivalent emissions can be attributed to land-use change, including destruction of peatlands (Indonesian National Council on Climate Change, 2010). Indonesia's carbon reduction plans include a 23% renewable energy target by 2025 (GR 79/2014), and 30% biodiesel blending in road fuel by 2025 (MEMR 12/2015). However, much of the biodiesel mandate is expected to be met using palm oil. Without a new vision for biofuel production, there is great risk that this part of Indonesia's renewable energy policy will increase rather than reduce Indonesian emissions, undermining the commitment to emission reduction (Paltseva et al., 2016).

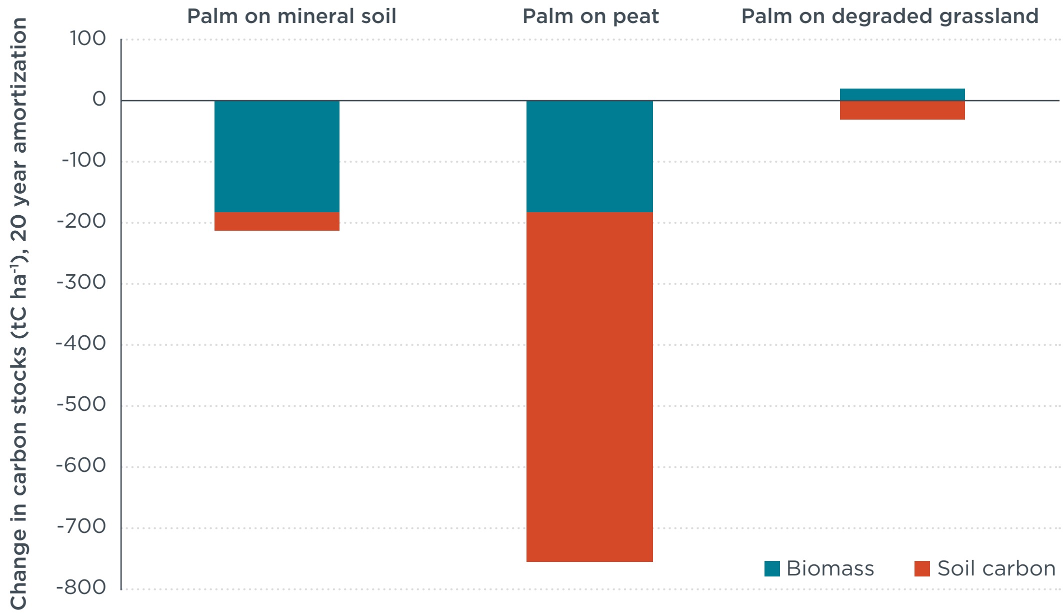

Figure 3. Changes in carbon (C) stocks over 20 years following forest conversion to palm plantations.

CARBON LOSS FROM VEGETATION

Researchers use various data sources to estimate carbon storage in forests, including remote sensing, forest inventory, and harvest data (Gibbs et al., 2007). Therefore, estimates of aboveground (standing vegetation) and belowground (root) biomass C storage vary widely, and these estimates also differ between peat forests and forests on mineral soils (Figure 3). Although specific estimates of carbon storage vary, Indonesian forests are consistently found to be a comparatively large and globally important carbon stock (i.e., Gibbs et al. 2007, Saatchi et al. 2011). In a study of tropical forests across three continents, Indonesia was found to have the third largest area of forest cover and carbon stocks (Saatchi et al., 2011). The same study, which used a robust combination of remote sensing and ground inventory data, estimated mean carbon storage in above- and belowground biomass across all forest types to be 158 Mg C ha^{-1} (Saatchi et al. 2011). Estimates of aboveground biomass specific to peat forests vary widely and range from 9.25 – 322 Mg C ha^{-1}, with a mean of 180 Mg C ha^{-1} (Murdiyarso et al., 2010).

When forests are converted to cropland, there is an initial loss of carbon through land-clearing fires and decomposition. In addition, the gradual decay of forest biomass post-conversion leads to carbon losses for decades (Fargione et al. 2008). Furthermore, biomass losses will not be fully replaced, as the aboveground biomass of palm plantations is only 20% of an intact tropical forest (Saxon and Roquemore, 2011). For example, Murdiyarso et al. (2010) estimated carbon stocks on oil palm plantations to be 24 Mg C ha^{-1}, compared to 180 Mg C ha^{-1} for natural peat swamp forest. Koh et al. (2011) measured similar differences between intact peat forests versus palm plantations, with carbon differences calculated as 155 Mg C ha^{-1}.

CARBON LOSS FROM MINERAL SOIL

Palm plantations are grown on a range of soils, from carbon-rich peatlands to highly-weathered soils, such as ultisols and oxisols, which have a comparably lower carbon concentration (Sung, 2016). However, significant amounts of carbon can be stored in mineral soils—typically 72-198 t C ha^{-1} in the top 30 cm (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). In general, review studies have found that 20-40% of soil carbon is lost when forests are converted to cropland (Don, Schumacher, and Freibauer, 2011; Luo, Wang, and Sun, 2010; Takahashi et al., 2010; Guo and Gifford, 2002; Murty et al., 2002; Davidson and Ackerman, 1993). For tropical forests in particular, conversion from primary forest to cropland causes a 25% decline in soil organic carbon (SOC), and conversion from secondary forest to cropland causes a 21% decline in SOC (Don, Schumacher, and Freibauer, 2011). Although palm plantations are not harvested annually, and therefore do not require as much soil disturbance as other crops, losses of soil carbon following forest conversion are consistent with annual crops. For example, Germer and Sauerborn (2008) found that initial conversion of forests to palm plantations resulted in a loss of 40 Mg C ha^{-1}, or about 30% of the mineral soil carbon stock.

CARBON LOSS FROM PEAT SOIL

Carbon emissions are higher when palm plantations are established on peat soils compared to mineral soils, discussed above. Peat is dead organic matter that is preserved in low-oxygen, flooded soils and accumulates over centuries to millennia; peat swamps in Indonesia store vast amounts of carbon in this material (Page et al., 2011). Cultivating peat swamps for oil palm requires both felling existing forest biomass and draining water from the top meter or so of the soil. Draining the soil exposes it to oxygen, which allows decomposition of the preserved organic matter and results in the release of high rates of CO_2. In a review, Page et al. (2011) estimated that peat drainage releases 29 Mg C ha^{-1} yr^{-1} (or 105 Mg CO_2 equivalent ha^{-1} yr^{-1}) when averaged over 20 years, or 573 Mg C ha^{-1} over 20 years combined. This is roughly three times greater than the amount of carbon lost from biomass with deforestation for oil palm. On a global scale, CO_2 emissions from peat drainage in Southeast Asia have been estimated to contribute the equivalent of around 2% of all fossil fuel CO_2 emissions (Hooijer et al., 2010).

The rate of conversion of peat to oil palm plantations has been accelerating steadily since 1990 (Miettinen et al., 2012; Pittman, 2013). Miettinen et al. (2012) projected that, even if the rate of peat conversion to palm remains linear in coming years, one-third of new oil palm plantations in Indonesia and Malaysia will be established on peat soils. Thus, palm oil expansion is strongly linked to very high carbon emissions from drained peatlands in Indonesia.

Drying of peat soils also makes these areas highly vulnerable to fires, which has an even more devastating effect on CO_2 emissions, as well as creating air pollution harmful to human health. GHG emissions from forest burning range from 207 Mg CO_2-equivalents ha^{-1} on mineral soils, to 1500 Mg CO_2 equivalents ha^{-1} on peatlands (Danielsen, 2009). Peat fires have been estimated to release 190 million tonnes of carbon per year globally (Page et al., 2002; van der Werf et al., 2008). Porter (2016) estimated that the GHG emissions from Indonesia's 2015 fires were roughly equivalent to the annual emissions of Brazil.

When CO_2 emissions from peat drainage are accounted for, analyses have found palm biodiesel to have a higher greenhouse gas impact than fossil petroleum on a lifecycle basis (Laborde, 2011; Valin et al., 2015; Malins, 2012). This means that policies supporting BAU palm biodiesel in Indonesia will have a detrimental effect on the country's GHG reduction goals, rather than comprising part of the solution.

POLLUTION

WILDFIRE HAZE

Wildfire smoke is a major source of air pollution that adversely affects human health and productivity in Southeast Asia (Pittman, 2013). Despite regulations against land-clearing fires, slash-and-burn agriculture is a common dry season occurrence. In Katapang, Indonesia, fire was the cause of 90% of deforestation between 1989 and 2008 (Pittman, 2013), and 20% of wildfires across Indonesia can be attributed directly to oil palm plantation practices (Goodman and Mulik, 2015). Confounded by hotter and drier conditions due to climate change (Tibbetts, 2015), the severity of forest fires is growing—2015 and 2016 have been the worst fire years on record (Porter, 2016).

Disturbance to humid tropical forests makes them more vulnerable to fire due to the drying effect of the opened canopy and greater amounts of dead woody debris (Turetsky, 2014). Drained peatlands are particularly vulnerable to fires (Turetsky, 2014); for example, 60-80% of the smoke and haze of a fire in 1997-1998 was traced to burning peatlands (Goodman and Mulik, 2015).

Wildfire smoke contains up to 10,000 substances (Tibbetts, 2015), some of which, such as CO and $NO_{x,}$ are already regulated due to their environmental and health impacts (Naeher et al., 2007). Although some assume that wood smoke, being a natural substance, is benign to humans, its effects are indistinguishable from urban particulate matter (Naeher, 2007), and the smoke contains harmful substances such as benzene (Johnston et al., 2012). The extent and severity of Indonesian wildfires can be so dramatic that pollutants reach levels greatly exceeding those considered to be safe. The Pollution Standard Index (PSI) reports of Indonesian wildfires have ranged from 400-2,000. A PSI of greater than 300 is considered hazardous.

Health impacts of wood smoke include eye and skin irritation, respiratory inflammation, cardiovascular issues, burns, psychological effects, heat-induced illness, and death (Finlay et al., 2012). More than 90% of the studies on wildfire smoke report incidents of respiratory morbidity (Liu et al., 2015). Johnston et al. (2012) estimated that 110,000 deaths each year in Southeast Asia could be attributed to wildfire haze.

In addition to devastating health effects, wildfires have adverse economic effects. Closed businesses, schools, and limited transportation can bring economies to a halt (Goodman and Mulik, 2015), and the effects of fires spread far beyond the geographic region where they originate. The Indonesian government estimated that a record-breaking fire in 2015 had cost the country US$30 billion after two months of burning (Lamb, 2015).

WATER POLLUTION

Pollutants from agrochemicals associated with biofuels (fertilizers, pesticides and rodenticides) have harmful impacts on terrestrial and aquatic ecosystems (Verdade et al., 2015). Palm oil mill effluent (POME), which is microbially digested in open ponds, often overflows into waterways during heavy rains. Heavy metal contamination of fish may be correlated with POME (Sheil, 2009), and abundant nitrogen fertilizer causes eutrophication of waterways.

In particular, the Middle Mahakam Wetlands, located in East Kalimantan, face serious threats from palm industry pollution. The wetlands serve as one of the most productive fisheries in Southeast Asia, in addition to providing fresh water and carbon storage in peat (De Jong et al., 2015). Lakes are also threatened by palm oil expansion, as decreased oxygen levels and increased nitrate loading (eutrophication) have been correlated with the burgeoning palm oil industry in the region (Gharibreza et al., 2013).

The use of the dangerous herbicides and pesticides also affects human health directly. The herbicide Paraquat, in particular, is lethal to humans in small doses and its use is illegal in several countries, including Austria, Denmark, Finland, Sweden, Hungary and Slovenia (RFA, 2010). Because women typically handle fertilizer and herbicide application, they have an increased risk of exposure to harmful chemicals (RFA, 2010). A lack of safety equipment and illiteracy also put workers at a disadvantage (RFA, 2010). Women commonly suffer from health conditions when working with these harmful chemicals, particularly if they are pregnant (Marti, 2008).

IMPACTS ON INDIGENOUS POPULATIONS

The palm oil industry creates significant economic benefits, but the largest payoffs are typically reserved for a small number of people (Sheil, 2009; Obidzinski et al., 2012). Some stakeholders experience significant gains from the burgeoning global palm oil trade (growers, investors, and employees), but other groups, such as traditional landowners, experience restrictions on land-use rights and land losses (Obidzinski et al., 2012). Native Customary Rights, which establish land ownership by active uses such as cultivation, burial, or rights of way (RFA, 2010), are often ignored when plantations are established (Marti, 2008). There are countless reports of indigenous peoples not being notified of or consulted about impending deforestation (Marti, 2008; Colchester et al., 2006; Colchester et al. 2007), which leads to conflict between indigenous peoples and palm oil companies. Grievances regarding the way companies acquire and hold land include, but are not limited to, the withholding of promised benefits, the withholding of compensation, serious human rights abuses, depletion of land and water resources, and encumbering smallholders with unjustifiable debt (Colchester et al., 2006; Sheil, 2009).

Although the development of palm plantations is often touted as an economic opportunity for indigenous Indonesians, former landowners and customary land users have been found to be the most negatively affected by land-use change (Obidzinski et al., 2012). They have to travel farther to gather limited forest resources, and in some cases change professions when resources (i.e., wood) are depleted (Obidzinski et al., 2012). Although the industry indirectly employs up to 7.5 million people, the quality of life resulting from such employment is minimal. The lack of land, clean water, and livelihood options for indigenous Indonesians, in addition to the destruction of culture and tradition, have been deemed unsustainable (FOE, 2005).

SOLUTIONS

All studies agree that enhanced regulation and stricter law enforcement are needed to protect biodiversity and limit deforestation and pollution. However, while laws may be put into place, but the indirect effects of those laws, whether intentional or not, may still have a negative impact on tropical forests. For example, the Malaysian government announced a ban on converting protected and reserve forests to palm plantations, but immediately thereafter revealed the acquisition of more than 150,000 hectares of forest in Indonesia, Papua New Guinea (Koh & Wilcove, 2008).

To address the climate impact of the palm oil industry, new development must be diverted from primary and secondary forests. Forests harvested for wood products should be left to regenerate, as 84% of forests species can be recovered within 30 years of deforestation (Koh & Wilcove, 2008). The High Conservation Value (HCV) approach could be used to help protect areas of exceptional biological importance (Yaap et al., 2010). The practice requires the assessment of management plans and the evaluation of proposed plantation land before a plantation can be erected. Azhar et al. (2015) point out that even with HCV areas protected, a heterogeneous landscape within any large plantation is critical for the success and connectivity of the HCV areas. Retaining a heterogeneous landscape by including native vegetation patches of different shapes and sizes can promote movement of organisms through a plantation (Azhar et al., 2015). Additionally, tolerating the growth of some native plant species within plantations, such as epiphytes, does not affect palm yield (Prescott, 2015).

New development of oil palm plantations may increase landscape carbon storage if it takes place on degraded or *Imperata* grassland. Estimates indicate that if tropical *Imperata* grassland is rehabilitated by oil palm plantations, carbon fixation in plantation biomass not only neutralizes emissions caused by grassland conversion, but also results in the net removal of about 135 Mg CO_2 ha^{-1} from the atmosphere (Germer and Sauerborn, 2008). Assuming aboveground biomass of 39 t C ha^{-1} (Murdiyarso et al., 2002), planting oil palm on degraded sites could lead to net increases in landscape carbon in only 10 years (Danielsen et al., 2009). Although development of plantations on degraded lands is promising, expectations of future production should be measured because the total extent of degraded lands in Indonesia is limited. An assessment by Indonesia's national team on biofuels, Timnas BBN, identified only 0.3 million hectares of degraded land as suitable for oil palm or other biofuel feedstock production (Caroko et al., 2011), far lower than the 8 million hectares of increased harvested area projected for oil palm in Indonesia from 2015 to 2025 (Figure 1). It is clear that BAU oil palm expansion must be slowed to avoid environmentally devastating levels of deforestation.

One alternative to support biofuel policies in Indonesia and elsewhere is the use of sustainably available cellulosic feedstocks. Paltseva et al. (2016) found that 15% of Indonesia's road fuel demand could potentially be displaced by biofuel made from palm residues without negatively impacting sustainable plantation practices. Biofuels from cellulosic residues have been generally found to deliver very high carbon savings compared to palm biodiesel or fossil fuels (Baral and Malins, 2014).

CONCLUSIONS

Palm oil plantations have serious consequences for biodiversity, climate change, and natural resources. All evidence points toward devastating losses of carbon from the landscape, threats to rare and endemic species, and pollution of air and water. The majority of indigenous Indonesians suffer from the palm oil industry instead of benefiting from it. The detriments to humans come in the form of serious health impacts from fires and chemical pollutants, in addition to the loss of land rights and depletion of natural resources that indigenous peoples depend on for survival.

Palm oil is expected to grow as a global commodity, and the environmental and social impacts of the industry must be addressed. Practices such as creating HVCs may help to protect some species, but the most effective solution to both species decline and carbon loss is to slow or stop tropical deforestation in Indonesia. As using palm oil in biofuels does not actually generate carbon savings, countries that plan on meeting their GHG emissions goals with palm oil-based fuels must reconsider their strategies.

Finally, the creation and enforcement of environmental standards is critical to the success of managing the sustainable development of the palm oil industry. Environmental impacts of new development must be carefully considered, and third party organizations should be involved in assessing the potential damage of new development.

REFERENCES

Abood, S.A., Lee, J.S.H., Burivalova, Z., Garcia-Ulloa, J., & Koh, L.P. (2015). Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest Loss in Indonesia. *Conservation Letters*, *8* (1), 58-67.

Agricultural Sector of Indonesia. (2016, June 2). *Indonesia-Investments.* Retrieved from http://www.indonesia-investments.com/culture/economy/general-economic-outline/agriculture/item378.

Aratrakorn, S., S. Thunhikorn, & P. F. Donald. (2006). Changes in bird communities following conversion of lowland forest to oil palm and rubber plantations in southern Thailand. *Bird Conservation International*, *16* (1), 71–82.

Azhar, B., Saadun N., Puanm C.L., Kamarudin, N., Aziz, N., Nurhidayu, S., & Fischer, J. (2015). Promoting landscape heterogeneity to improve the biodiversity benefits of certified palm oil production: Evidence from Peninsular Malaysia. *Global Ecology and Conservation*, *3*, 553-561.

Baral., A. & Malins, C. (2014). *Comprehensive carbon accounting for identification of sustainable biomass feedstocks*. Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_carbonaccounting-biomass_20140123.pdf.

Beck, J., Schulze, C.H., Linsenmair, K.E., & Fiedler, K. (2002). From forest to farmland: Diversity of geometrid moths along two habitat gradients on Borneo. *Journal of Tropical Ecology, 18*(1), 33-51.

Brühl, C.A., Eltz, T., & Linsenmair, K.E. (2003). Size does matter: Effects of tropical rainforest fragmentation on the leaf litter ant community in Sabah, Malaysia. *Biodiversity & Conservation, 12*(7), 1371-1389.

Caroko, W., Komarudin, H., Obidzinski, K. & Gunarso, P. (2011). *Policy and institutional frameworks for the development of palm oil–based biodiesel in Indonesia*. Bogor, Indonesia: CIFOR Working Paper 62. Retrieved from http://www.cifor.org/publications/pdf_files/WPapers/WP62Komarudin.pdf.

Chase, L.D.C. and Henson, I.E. (2010). A detailed greenhouse gas budget for palm oil production. *International Journal of Agricultural Sustainability*, *8*(3), 199-214.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R.B., Piao, S., and Thornton, P. (2013). Carbon and Other Biogeochemical Cycles. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Colchester, M., Jiwan, N., Andiko, Sirait, M.m Firdaus, A.Y., Surambo, A., & Pane, H. (2006). *Promised Land: Palm Oil and Land Acquisition in Indonesia—Implications for Local Communities and Indigenous Peoples.* Moreton-in-Marsh, United Kingdom: Forest Peoples Programme, and Java, Indonesia: Perkumpulan Sawit Watch. Retrieved from http://www.forestpeoples.org/sites/fpp/files/publication/2010/08/promisedlandeng.pdf.

Colchester, M., Pang, W.A., Chuo, W.M. & Jalong, T. (2007) *Land is life. Land Rights and Oil Palm Development in Sarawak*. Moreton-in-Marsh, United Kingdom: Forest Peoples Programme, and Java, Indonesia: Perkumpulan Sawit Watch. Retrieved from http://www.forestpeoples.org/sites/fpp/files/publication/2010/08/sarawaklandislifenov07eng.pdf.

Danielsen, F., Beukema, H., Burgess, N.D., Parish, Z., Bruhl, C.A., Donald, P.F., Murdiyarso, D., Phalan, B., Reijnders, L., Struebig, M., & Fitzherbert, E.B. (2009). Biofuel plantations on forested lands: Double jeopardy for biodiversity and climate. *Conservation Biology, 23*(2), 348-358.

Davidson, E. A., & I. L. Ackerman (1993). "Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils." *Biogeochemistry*, *20*(3), 161–93.

Davis, A.J., Holloway, J.D., Huijbregts, H., Krikken, J., Kirk-Spriggs, A.H., & Sutton, S.L. (2001). Dung beetles as indicators of change in the forests of northern Borneo. *Journal of Applied Ecology, 38*(3), 593-616.

De Jong, E.B.P., Ragas, A.M.J., Nooteboom, G., & Mursidi, M. (2015). Changing Water Quality in the Middle Mahakam Lakes: Water Quality Trends in a Context of Rapid Deforestation, Mining and Palm Oil Plantation Development in Indonesia's Middle Mahakam Wetlands. *Wetlands, 35*(4), 733-744.

Don, A., J. Schumacher, & A. Freibauer (2011). "Impact of Tropical Land-Use Change on Soil Organic Carbon Stocks—A Meta-Analysis." *Global Change Biology*, *17*(4),1658–70.

FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. *Harmonized World Soil Database (version 1.2)*. FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. *Science, 319*(5867), 1235-1238.

Finlay, S.E., Moffat, A., Gazzard, R., Baker, D., & Murray, V. (2012) Health Impacts of Wildfires. *PLOS Currents Disasters*, 1. Retrieved from http://currents.plos.org/disasters/article/health-impacts-of-wildfires/.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution, 23*(10), 538-545.

Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). (2016). *Crops; Indonesia; Oil, palm and Oil, palm fruit; Average production of commodity; 1990-2014.* Retrieved from http://faostat3.fao.org/browse/Q/QC/E.

Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT). (2015). *Crops processed; Indonesia and World total; Oil, palm; Production quantity; 2013.* Retrieved from http://faostat3.fao.org/download/Q/QD/E.

Friends of the Earth (FOE). (2005). *Greasy palms—palm oil, the environment and big business.* London: Friends of the Earth. Retrieved from https://www.foe.co.uk/sites/default/files/downloads/greasy_palms_summary.pdf.

Gathorne-Hardy, F.J., Jones, D.T., & Syaukani. (2002). A regional perspective on the effects of human disturbance on the termites of Sundaland. *Biodiversity & Conservation, 11*(11), 1991-2006.

Germer, J. & Sauerborn, J. (2008). Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. *Environmental Development and Sustainability*, 10, 697-716.

Gharibreza, M., Raj, K.J., Yusoff, I., Ashraf, M.A., Othman, Z., & Tahir, W.Z.W.M. (2013). Effects of agricultural projects on nutrient levels in Lake Bera (Tasek Bera), *Peninsular Malaysia. Agriculture, Ecosystems & Environment*, *165*, 19-27.

Ghazali, A., Asmah, S., Syafiq, M., Yahya, M., Aziz, N., Peng, T., Norhisham, A.R., Puan, C.L., Turner, E.C., & Azhar, B. (2016). Effects of monoculture and polyculture farming in oil palm smallholdings on terrestrial arthropod diversity. *Journal of Asia-Pacific Entomology*, *19*(2), 415-421.

Gibbs, H.K., Brown, S., Niles, J.O., & Foley, J.A. (2007). Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters*, *2*(4), Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/2/4/045023/meta;jsessionid=459ECC654103FD441A0AC11076BE1970.c5.iopscience.cld.iop.org.

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N., & Foley, J.A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences of the United States of America, 107*(38), 16732-16737.

Goodman, L.K., & Mulik, K. (2015). *Clearing the air: Palm Oil, Peat Destruction, and Air Pollution*. Cambridge, MA: Union of Concerned Scientists. Retrieved from http://www.ucsusa.org/sites/default/files/attach/2015/03/clearing-the-air-ucs-2015.pdf.

Gunarso, P., M. E. Hartoyo, F. Agus, & T. J. Killeen. (2013). *Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea*. Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO), Kuala Lumpur, Malaysia. Retrieved from http://www.tropenbos.org/publications/oil+palm+and+land+use+change+in+indonesia,+malaysia+and+papua+new+guinea.

Guo, L. B., & R. M. Gifford. (2002). Soil carbon stocks and land use change: A meta analysis. *Global Change Biology*, *8*(4), 345–60.

Heydon, M.J., & Bulloh, P. (1997). Mousedeer densities in a tropical rainforest: The impact of selective logging. *Journal of Applied Ecology, 34*(2), 484-496.

Hooijer, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H., & Jauhiainen, J. (2010). Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences*, *7*, 1505-1514.

Indonesian National Council on Climate Change. (2010). Indonesia's Greenhouse Gas Abatement Cost Curve. Kampung Bali, Indonesia. Retrieved from: http://www.mmechanisms.org/document/country/IDN/Indonesia_ghg_cost_curve_english.pdf

Johnston, F.H., Henderson, S.B., Chen, Y., Randerson, J.T., Marlier, M., Defrieds, R.S., Kinney, P., Bowman, D.M.J.S., & Brauer, M. (2012). Estimated Global Mortality Attributable to Smoke from Landscape Fires. *Environmental Health Perspectives*, *120*(5), 695-701.

Koh, L.P., Miettinen, J., Liew, S.C., & Ghazoul J. (2011). Remotely sensed evidence of tropical peatland conversion to oil palm. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(12), 5127-5132.

Koh, L.P., & Wilcove, D.S. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters, 1*(2), 60-64.

Laborde, D. (2011). *Assessing the Land Use Change Consequences of European Biofuel Policies*. Washington, DC: International Food Policy Institute. Retrieved from http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf.

Lamb, Kate. (2015, October 26) "Indonesia's fires labelled as 'crime against humanity' as 500,000 suffer." *The Guardian*.

Larsen T.H., Williams N.M., & Kremen C. (2005). Extinction order and altered community structure rapidly disrupt ecosystem functioning. *Ecology Letters*, *8*(5), 538–547.

Liow, L.H., Sodhi, N.S., & Elmqvist, T. (2001). Bee diversity along a disturbance gradient in tropical lowland forests of south-east Asia. *Journal of Applied Ecology, 38*(1), 180-192.

Liu, J.C., Pereira, G., Uhl, S.A., Bravo, M.A., & Bell, M.L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research*, *136*, 120-132.

Lucey J.M., Hill J.K. (2012) Spillover of insects from rain forest into adjacent oil palm plantations. *Biotropica*, 44, 368–377.

Luo, Z., E. Wang, & O. J. Sun (2010). Soil carbon change and its response to agricultural practices in Australian agro-ecosystems: A review and synthesis. *Geoderma*, *155,* 211–23.

Maddox, T.M., Gemita, E., Wijamukti, S., & Selampassy, A. (2007). *The conservation of tigers and other wildlife in oil palm plantations, Jambi Province, Sumatra, Indonesia*. Regents Park, London: Zoological Society of London. Retrieved from https://www.hcvnetwork.org/resources/folder.2006-09-29.6584228415/the-conservation-of-tigers-and-other-wildlife-in-oil-palm-plantations-zsl-no-7-b-409%20-1.pdf.

Malins, C. (2012). *Comments of the ICCT on EPA palm oil pathway NODA*. Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/ICCT_EPA-palm-NODA-comments_Apr2012.pdf.

Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F., & Hansen, M.C. (2014). Primary forest cover loss in Indonesia over 2000-2012. *Nature Climate Change, 4,* 730-735.

Marti, S. (2008). *Losing ground: the human rights impacts of oil palm plantation expansion in Indonesia.* LifeMosaic, Sawit Watch Indonesia and Friends of the Earth. Retrieved from http://www.foei.org/wp-content/uploads/2014/08/losingground.pdf

Meijaard, E., Buchori, D., Hadiprakarsa, Y., Utami-Atmoko, S.S., Nurcahyo, A., Tjiu, A., Prasetyo, D., Nardiyono, C.L., Ancrenaz, M., Abadi, F., Antoni, I.N.G., Armayadi, D., Dinato, A., Ella, G.P., Indrawan, T.P., Kussaritano, M.C., Priyono, C.W.P., Purwanto, Y., Puspitasari, D., Putra, M.S.W., Rahmat, A., Ramadani, H., Sammy, J., Siswanto, D., Syamsuri, M., Andayani, N., Wu, H., Wells, J.A., & Mengersen, K. (2011). Quantifying Killing of Orangutans and Human-Orangutan Conflict in Kalimantan, Indonesia. *PLoS One, 6*(11), 1-10.

Meijaard, E., & Nijman, V. (2001). The local extinction of the proboscis monkey *Nasalis larvatus* in Pulau Kaget Nature Reserve, Indonesia. *Oryx, 34*(1), 66-70.

Meijaard, E., & Wich, S. (2007). Putting orang-utan population trends into perspective. *Current Biology, 17*(14), R540.

Miettinen, J., Hooijer, A., Tollenaar, D., Page, S., Malins, C., Vermimmen, R., Shi, C., & Liew, S.C. (2012). *Historical Analysis and Projection of Oil Palm Plantation Expansion on Peatland in Southeast Asia.* Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/historical-analysis-andprojection-oil-palm-plantation-expansion-peatland-southeast-asia.

Murdiyarso, D., Hergoualc'h, K. & Verchot, L.V. (2010). Opportunities for reducing greenhouse gas emissions in tropical peatlands, *Proceedings of the National Academy of Sciences of the United States of America, 107*(46), 19655-19660.

Murdiyarso, D., van Noordwijk M., Wasrin, U.R., Tomich, T.P., & Gillison, A.N. (2002). Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra. *Journal of Vegetation Science*,13, 429–438.

Murty, D., Kirschbaum, M.U.F., McMurtrie, R.E. & McGilvray, H. (2002). Does Conversion of Forest to Agricultural Land Change Soil Carbon and Nitrogen? A Review of the Literature. *Global Change Biology*, *8*(2), 105–23.

Naeher, L.P., Brauer, M., Lipsett, M., Zelikoff, J.T., Simpson, C.D., Koenig, J.Q., Smith, K.R., (2007). Woodsmoke health effects: a review. *Inhalation Toxicology*, *19*(1), 67–106.

Nantha, H.S., & Tisdell, C. (2009). The orangutan-oil palm conflict: economic constraints and opportunities for conservation. *Biodiversity and Conservation, 18,* 487-502.

Ng, P.K.L., Tay, J.B., & Lim, K.K.P. (1994). Diversity and conservation of blackwater fishes in Peninsular Malaysia, particularly in the North Selangor peat swamp forest. *Hydrobiologia, 285,* 203-218.

Obidzinski, K., Andriana, R., Komarudin, H., & Andrianto, A. (2012). Environmental and Social Impacts of Oil Palm Plantations and their Implications for Biofuel Production in Indonesia. *Ecology and Society*, *17*(1), 25.

O'Brien, T.G., Kinnaird, M.F., & Wibisono, H.T. (2003). Crouching tigers, hidden prey: Sumatran tiger and prey populations in a tropical forest landscape. *Animal Conservation, 6*(2), 131-139.

Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.D.V., Jaya, A., & Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, *420*, 61-65.

Page, S.E., Morrison, R., Malins, C., Hooijer, A., Rieley, J.O., & Jauhiainen, J. (2011). *Review of peat surface greenhouse gas emissions from oil palm plantations in Southeast Asia*. Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/review-peat-surface-greenhouse-gas-emissions-oil-palmplantations-southeast-asia.

Paltseva, J., Searle, S., & Malins, C. (2016). *Potential for advanced biofuel production from palm residues in Indonesia.* Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/Indonesia%20Palm%20Oil%20White%20Paper_vFinal.pdf.

Peh, K.S.H., Sodhi, N.S., Jong, J.D., Sekercioglu, C.H., Yap, C.A.M., & Lim, S.L.H. (2006). Conservation value of degraded habitats for forest birds in southern Peninsular Malaysia. *Diversity and Distributions, 12*(5), 572-581.

Peraturan Menteri Energi dan Sumber Daya Mineral, Nomor 32 Tahun 2008, Tentang penyediaan, pemanfaatan dan tata niaga bahan bakar nabati (biofuel) sebagai bahan bakar lain. Signed by Purnomo Yusgiantoro on September 26, 2008.

Peraturan Menteri Energi dan Sumber Daya Mineral Republik Indonesia, Nomor 12 Tahun 2015, Tentang perubahan ketiga, atas peraturan Menteri Energy dan Sumber Daya Mineral, Nomor 32 Tahun 2008, Tentang penyediaan, pemanfaatan, dan tata niaga bahan bakar nabati (biofuel) sebagai bahan bakar lain. Signed by Sudirman Said on March 18, 2015.

Peraturan Presiden Republik Indonesia, Nomor 61 Tahun 2015, Tentang penghimpunan dan pengguanaan dana perkebunan kelapa sawit. Signed by Joko Widodo on May 18, 2015

Pfeiffer, M., Tuck, H.C., & Lay T.C.. (2008). Exploring arboreal ant community composition and co-occurrence patterns in plantations of oil palm Elais guineensis in Borneo and Peninsular Malaysia. *Ecography*, *31*(1), 21-32.

Pittman, A.M., Carlson, K.M., Curran, L.M., & Ponette-Gonzalez, A. (2013). NASA Satellite Data Used to Study the Impact of Oil Palm Expansion Across Indonesian Borneo. *The Earth Observer*, *25*(5), 12-16.

Porter, Sarah. (2016, March 14) Can Indonesia's forest fires be put out for good? *BBC News*. Retrieved from http://www.bbc.com/news/business-35770490.

Prescott , G.W., Edwards, D.P., & Foster, W.A. (2015) Retaining biodiversity in intensive farmland: epiphyte removal in oil palm plantations does not affect yield. *Ecology and Evolution*, *5*(10), 1944-1955.

Renewable Fuels Agency. (2010). Palm Oil Cultivation in Malaysia: A Case Study.

Robertson, J.M.Y., & Van Schaik, C.P. (2008). Causal factors underlying the dramatic decline of the Sumatran orang-utan. *Oryx, 35*(1), 26-38.

Saatchi, S.S., Harris, N.L., Brown, S. et al. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences of the United States of America, 108*(24), 9899-9904.

Saxon, E., & Roquemore, S. (2011). Ch. 6: Palm Oil. In Union of Concerned Scientists, *The Root of the Problem: What's Driving Tropical Deforestation Today?* (pp. 51-63). Cambridge, MA: Union of Concerned Scientists.

Senior, M.J.M., Hamer, K.C., Bottrell, S., Edwards, D.P., Fayle, T.M., Lucey, J.M., Mayhew, P.J., Newton, R., Peh, K.S.H., Sheldon, F.H., Stewart, C., Styring, A.R., Thom, M.D.F., Woodcock, P., & Hill, J.K. (2013). Trait-dependent declines of species following conversion of rain forest to oil palm plantations. *Biodiversity Conservation, 22,* 253-268.

Sheil, D., Casson, A., Meijaard, E., van Nordwijk, M. Gaskell, J., Sunderland-Groves, J., Wertz, K. & Kanninen, M. (2009). *The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?* Bogor, Indonesia: CIFOR, Occasional paper no. 51.

Sodhi, N.S. (2002). A comparison of bird communities of two fragmented and two continuous southeast Asian rainforests. *Biodiversity and Conservation, 11*(6), 1105-1119.

Sodhi, N.S., Koh, L.P., Brook, B.W., & Ng, P.K.L. (2004). Southeast Asian biodiversity: An impending disaster. *Trends in Ecology and Evolution, 19*(12), 654-660.

Sung, C.T.B. (2016). *Availability, use, and removal of oil palm biomass in Indonesia*. Washington, DC: The International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/Teh_palm%20residues_final.pdf.

Takahashi, M., S. Ishizuka, S. Ugawa, Y. Sakai, H. Sakai, K. Ono, S. Hashimoto, Y. Matsuura, & K. Morisada. (2010). Carbon Stock in Litter, Deadwood and Soil in Japan's Forest Sector and its Comparison with Carbon Stock in Agricultural Soils. *Soil Science and Plant Nutrition*, *56*(1), 19–30.

Tibbetts, J.H. (2015). Air Quality and Climate Change: A Delicate Balance*. Environmental Health Perspective*, *123*(6), 148-153.

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. P. Dobson, R. Howarth, D. Schindler, W. H. Schlesinger, D. Simberloff, & D. Swackhammer. (2001). Forecasting agriculturally driven global environmental change. *Science*, *292*(5515)**,** 281–284.

Turetsky, M.R., Benscoter, B., Page, S., Rein, G., van der Werf, G., & Watts, A. (2014). Global vulnerability of peatlands to fire and carbon loss. *Nature Geoscience*, *8*, 11-14.

Uryu, Y., Mott, C., Foead, N., Yulianto, K., Budiman, A., Setiabudi, Takakai, F., Nursamsu, Sunarto, Purastuti, E., Fadhli, N., Hutajulu, C.M.B., Jaenicke, J., Hatano, R., Siegert, F., & Stuwe, M. (2008). *Deforestation, forest degradation, biodiversity loss and* CO_2 *emissions in Riau, Sumatra, Indonesia*. Jakarta, Indonesia: World Wildlife Fund (WWF) Indonesia Technical Report.

Valin, H., Peters, D., van den Berg, M., Frank, S., Havlik, P., Forsell, N., & Hamelinck, C. (2015). *The land use change impact of biofuels consumed in the EU, Quantification of area and greenhouse gas impacts*. Utrecht, Netherlands: ECOFYS Netherlands B.V. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf.

Van der Werf, G. R., Dempewolf, J., Trigg, S. N., Randerson, J. T., Kasibhatia, P. S., Giglio, L., Murdiyarso, D., Peters, W., Morton, D. C., Collatz, G. J., Dolman, A. J., & DeFries, R. S. (2008). Climate regulations of fire emissions and deforestation in equatorial Asia. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 20350-20355.

Verdade, L.M., Pina, C.I., & Rosalino, L.M. (2015). Biofuels and biodiversity: Challenges and opportunities. *Environmental Development*, *15*, 64-78.

Wood, B.J., & Chung, G.F. (2003). A critical review of the development of rat control in Malaysian agriculture since the 1960s. *Crop Protection*, *22*, 445-461.

Write, T. & Rahmanulloh, A. (2015). *Indonesia Oilseeds and Products Annual Report*. USDA Foreign Agricultural Service, Global Agricultural Information Network. Retrieved from http://www.fas.usda.gov/data/indonesia-oilseeds-and-products-annual.

Yaap, B., Struebig, M.J., Paoli, G., & Koh, L.P. (2010). Mitigating the biodiversity impacts of oil palm development. CAB Reviews: *Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 5(19). Retrieved from http://laurancelab.org/publications/betsyyaap/Yaap_etal_2010_CABReviews_5.pdf.

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON