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The Relationship between Carbon Emissions, Land Use Change and the Oil Palm Industry within Southeast Asia

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This Master’s Project

The Relationship between Carbon Emissions, Land Use Change and the Oil Palm Industry within Southeast Asia

By:

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Abstract

Tropical forests store the largest amount of carbon globally by sequestering up to 2.7 Gt of carbon every year in soils and vegetation. Deforestation and the conversion of tropical peatland soil have contributed to global anthropogenic carbon dioxide emissions, as well as significantly hindering tropical ecosystems and the natural carbon sequestration potential that could potentially help mitigate atmospheric CO₂ levels. Deforestation has increased rapidly since the 1970’s across Southeast Asia with oil palm contributing to 61% of deforestation between 2010 and 2015 with emissions reaching 22.1 million tons CO₂-equivalent during that time. The conversions of tropical peatlands are a significant source of regional carbon emissions since the transformation of these soils both degrades carbon storage capacity, and increases emissions during the conversion process. Conversion processes for monoculture lead to long-term degradation and over the last four decades, emissions from tropical peatland modification has reached over 6 Gt CO₂-equivalent. Land use change by fire, although a method of deforestation, emits the highest levels of CO₂-equivalent during conversion. The conversion by fire also leads to an increased risk of wildfires within the area. As fire continues to be used as a method of land clearing, emissions and wildfires are expected to increase. There are two methods of oil palm extraction and production, wet and dry, and emissions from these processes average 3.03 and 1.69 tons CO₂-equivalent/ha respectively. The wastewater treatment system implemented for wet extraction could either aid in decreasing or result in increased production emissions. A transition in production processes could decrease emissions by up to 47%.

The evidence from the analysis was used to develop recommendations for carbon emission mitigation and land use change that results from the oil palm industry within Southeast Asia. These recommendations can be summarized into: discontinuing oil palm expansion on unsuitable land, promoting the movement towards sustainable oil palm production through sustainability certification processes as well as discontinuing fire related conversion processes, and already established plantations should transition from wet to dry extraction processes to reduce overall emissions; however, if this is not economically feasible, the implementation of a biogas capture system would aid in emission reduction.
1. Introduction:

Oil from tropical oil palm plantations is one of the most widely used agricultural products in the world (Carlson et al. 2012; Hamdan et al. 2016), and is only grown in tropical regions globally. There is consensus across literature that this agricultural product fuels large sectors of economies in countries where it is cultivated and is of vital import to the stability of these nations. While this crop provides much needed income, it is unfortunately causing considerable environmental damage in the tropical ecosystems where it is grown due to land use practices that are necessary to make areas suitable for this type of agricultural monoculture. Oil palm agriculture is responsible for the loss of some the most species rich areas of the globe, and continued unsustainable practices are threatening these sensitive and fragile ecosystems with potential collapse.

Tropical forests provide a variety of ecosystem services across biome scales, such as providing habitat for areas with high species diversity, supporting the nutrient cycling and formation of soil, and climate mitigation through carbon sequestration. Southeast Asia contains four of the 25 global biodiversity hotspots, and is home to approximately 4,295 species of mammals and birds, and 56,120 species of plants (Sodhi et al. 2004). The large forest structures and canopy levels provide habitats for species with specialized niches, such as the Proboscis Monkey (*Nasalis larvatus*) and the Rhinoceros Hornbill (*Buceros rhinoceros*)1. The trees also maintain soil structure in these highly precipitated areas through their extensive root structures. The organic material assists in cycling nutrients for the surrounding flora. Additionally, forests within tropical ecosystems hold the largest amount of carbon globally and store approximately 2.2 to 2.7 Gt of carbon per year (Goodman and Herold 2014). Tropical peatland forests specifically are estimated to store ten times more carbon than tropical forests on mineral soil (Page et al. 2011). The absorption of carbon by forests and tropical peatlands has the potential to mitigate and sequester atmospheric CO$_2$-eq concentrations.

Unfortunately, these ecosystem services are at risk due to increasing carbon emission levels. Tropical forests have been exploited at alarming rates, resulting in an unprecedented increase in CO$_2$-eq emissions that ultimately hinders the natural carbon cycle and contributing to global climate change. Deforestation across tropical ecosystems has been considered the second

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1 Personal observation based on research conducted for Dr. Gretchen Coffman's Tropical Restoration Ecology course on the island of Borneo, summer of 2016.
largest source of anthropogenic emissions globally, with the potential to create permanent climatic shifts (Cruz et al. 2007; Hamdan et al. 2016). When large scales of land are deforested or burned, there is an instant transition from carbon sink to carbon source and CO₂ is emitted into the atmosphere at a much more accelerated rate than what would occur naturally.

The oil palm industry has contributed significantly to these rising emission levels and deforestation rates, especially within Southeast Asia as 90% of global oil palm production is located within Indonesia and Malaysia, and 40% of these plantations replaced forests, some of which contain critical species, such as dipterocarp trees (Englund et al. 2015). Dipterocarps are the tallest tropical trees across the globe, and play a vital role in tropical ecosystems by providing canopy layers and promoting habitat biodiversity. However, in Indonesia, approximately 80% of lowland dipterocarp forests have been cleared and converted specifically for oil palm cultivation (Santilli et al. 2005). Coastal and low lying inland regions are ideal locations for oil palm cultivation and subsequent deforestation that ultimately degrades the island landscapes across Southeast Asia (Figure 1-1). Emission levels have increased with land use change within forests and tropical peatland, and have further increased with the use of fire to clear land for oil palm monoculture (Carlson et al. 2012; Warren et al. 2016). Tropical peatlands have been a major factor to these emission levels compared to other forest structures as they release larger quantities of CO₂-equivalent following draining, burning, and other conversion processes.

The precise recovery rate of tropical ecosystems following deforestation and degradation is uncertain within the scientific community, which aids in the seriousness of this issue and supporting the need for greater industrial sustainability practices. Literature suggests that tropical forests could either collapse completely or transition to an alternative stable state after a certain level of disturbance has been reached, permanently altering ecosystem services and biodiversity (Poorter et al. 2016). Given the increase in demand of oil palm and land for plantations, it can be expected that there will be an increase in deforestation, tropical peatland degradation and fire-related conversion, which will result in higher carbon emissions and continue to negatively impact tropical ecosystems unless mitigation procedures are implemented. Given the invasive nature of oil palm cultivation on tropical ecosystems, the goal of this paper is to evaluate how the oil palm industry has affected the ecosystem in regards to deforestation and tropical peatland degradation, and the increase in carbon emissions as a result. The primary research question for this analysis was:
What are the impacts on carbon emissions from oil palm related land conversion and production within Southeast Asia?

To further evaluate this question, the following sub-questions were developed for a more concise synthesis of data:

1. What are the carbon emissions from the processes of the deforestation and/or alteration of intact, logged, and agro-forests?
2. When analyzed as a separate entity, what are the carbon emissions from tropical peatland conversion, specifically within peatland soils?
3. Analyzed separately from deforestation, how have fire-related conversion processes contributed to increasing carbon emission levels?
4. What are the carbon emissions from the production processes of oil palm?
Figure 1-1: Current land use within Malaysian and Indonesian Borneo as of 2015. Considerable land use is dedicated to oil palm and timber harvesting at the expense of forests and tropical peatlands (Data from CIFOR, map document created by J. D. Heaster 2017).
2. **Background:**

2.1 *Elaeis guineensis*

Oil palm is one of the world’s most consumed vegetable oils, accounting for nearly 30% of the world’s vegetable oil demand (Corley 2009). It is grown and harvested in large quantities for the production of a low-cost vegetable oil that is used in a variety of food, cosmetic and household products. Oil palm is native to West Africa, although the production of it as a plantation crop originated in Southeast Asia. There are two main species of oil palm, *Elaeis guineensis* (African oil palm) and *Elaeis melanococca* (American oil palm) (Hai 2002). *Elaeis guineensis* is the main crop used for oil production as *Elaeis melanococca* has lower oil extraction rates. For the purposes of this paper, the analysis was focused around the planting and production of *Elaeis guineensis*.

The oil palm tree is monoecious and typically grows between 20 – 30 meters tall with a root system that reaches up to 1 meter deep (Pasiecznik 2013). *Elaeis guineensis* thrives in areas with high-precipitation, low elevation and an adequate amount of soil moisture. As the trees are a non-competitive species and are usually found in areas where other tree species do not grow well, or areas that are not dominated by dense forests, it is strictly found within tropical forest ecosystems within 10° north or south of the equator (Pasiecznik 2013). Oil palm plantations are typically established in low elevation areas because the crop cannot be planted on slopes greater than 25°, and elevation must be below 500 meters for best growth potential of fruitlets (Verheye 2010); these criteria make floodplains and tropical peatlands a target for oil palm production sites. However, most of these areas are prone to flooding and although oil palm is tolerant of fluctuating water tables and short periods of standing water it is a flood intolerant crop, resulting in high palm mortality (Pasiecznik 2013; Abram, et al 2014).

![Figure 2-1: Physical structure of oil palm fruit (Hai 2002).](image-url)
The fruit from the palm tree is condensed in bunches. Each palm bears 8 – 12 bunches with 1,000 to 1,300 fruitlets per bunch (Hai 2002; Verheyse 2010; Pasiecznik 2013). These fruitlets have a mesocarp layer and an endocarp layer (Figure 2-1; Hai 2002). The mesocarp is a fibrous layer of pulp, and the endocarp layer contains the oil palm kernel. Two types of oil are produced from the oil palm plant: oil from the mesocarp of the fruit and oil palm kernel. Due to the different oil produced from the plant parts, there is a preference on which subspecies of *E. guineensis* will be cultivated for harvesting. This preference is a constituent of the oil extraction rate (OER) of the oil palm mesocarp and kernel. There are three subspecies of *E. guineensis* that are cultivated for oil palm production: subsp. *dura*, *pisifera*, and *tenera* (Verheyse 2010). Each subspecies has a variance for extraction dependent on plant morphology. *Elaeis guineensis* subsp. *dura* possesses a larger kernel size (2 – 8 mm) and is therefore typically used via means of kernel extraction (Hai 2002). In contrast, *E. guineensis* subsp. *pisifera* possesses a greater percentage of mesocarp to kernel ratio (95%) and is therefore used via means of mesocarp extraction (Hai 2002). Compared to the other subspecies, *E. guineensis* subsp. *tenera* has the highest level of oil extraction with 60 – 95% of mesocarp content and thick kernels (05. – 3 mm) (Latiff 2000; Hai 2002).

The chemical characteristics of oil palm have contributed to the rise in consumer demand. Due to an increase in health trends to replace animal based products with alternatives, the demand for vegetable based oils with less trans-fat has been increasing more than 5% annually (Shibao 2015). The lower levels of saturated fatty acids make oil palm a more stable product, and therefore less likely to change chemical properties at high temperatures (Hai 2002). *Elaeis melanococca* is not typically cultivated for production due to the lower oil extraction rate compared to *E. guineensis*, as well as having higher levels of unsaturated fatty acids (Hai 2002). Oil from the palm kernel can also be produced in large quantities; however, it mainly contains saturated fatty acids, making it less desirable for the consumer market (Fitzerbert et al. 2008).

### 2.2 Global demand of oil palm

Inexpensive production and labor has also been a leading contributor to the rapid growth of the oil palm industry, especially within Southeast Asia. Oil palm is considered a production-efficient crop, yielding 11 times more oil per hectare (ha) than soybeans (Figure 2-2; Shibao 2015; Indonesian Investments 2016). In 2015, the global production of soybean oil was 47
million tons compared to the 52 million tons of oil palm produced in 2014 from Indonesia and Malaysia alone (Indonesian Investments 2016; Mylo Trade 2016). In response to the high demand of oil palm, approximately 9.97 Mha of cultivated cropland around the world was dominated by oil palm agriculture in 2000, and by 2012 it was over 17.1 Mha (Abram et al. 2014). Corley (2009) analyzed the predicted global population trends along with the current global demand for oil palm and hypothesized that the demand for oil palm will increase faster than the industry can supply. Based on the consumption of oil palm per capita and current global consumption rates, it is estimated that demand will increase by 240 Mt of oil palm by 2050, which is equivalent to double the current amount of production (Corley 2009). Global demand at that rate would require between 38.2 and 53 Mha of additional land for cultivation and production by 2050 based on per capita consumption (Corley 2009).

The rise in global demand has led to an increase in land use modification for oil palm monoculture, specifically deforestation, tropical peatland soil degradation, and fire-related conversion processes. Due to the specificity of oil palm habitat, monoculture is limited by geographic area. Most oil palm plantations are located in Southeast Asia, South America, and Africa because of the tropical climate required for maximum yielding potential of the crop. The rate of deforestation and tropical peatland degradation has continued to increase, which has significantly contributed to the rising carbon emission levels in these areas.
2.3 Oil palm industry expansion and deforestation in Indonesia

Oil palm is Indonesia’s third most valuable export, behind coal and petroleum gas and, as a result, experiences the world's highest deforestation rate (Abood et al. 2015). Indonesia has a longstanding history with the oil palm industry, much of which has been closely related to the country’s politics. The first oil palm plantation was established in 1911 and covered a total of 5,123 hectares of land in Aceh and Deli, North Sumatra (Shibao 2015). By 1923, production had become highly successful and the demand for crude oil palm in Europe was on the rise; that year Indonesia exported 850 tons of oil palm to various European countries (Shibao 2015). The global price of oil began to decline during the early 1980’s while the economic growth of Indonesia initially slowed. However, political instability caused a deregulation of foreign exchanges, which proved to be economically beneficial for the oil palm industry due to an increase in exports (Tsujino et al. 2016). Indonesia’s export of oil palm began to rise again and as expected, deforestation and degradation rates also increased. The estimated annual deforestation rate for Indonesia doubled from 0.3 Mha per year in the 1970’s to 0.6 Mha annually during the 1980’s (Table 2-1; Tsujino et al. 2016). By the 1990’s, the demand for oil palm was high enough that the expansion of oil palm plantations rapidly increased to approximately 2 Mha of land deforested annually in Indonesia, all while the country was still economically unstable (Tsujino 2016).

Deforestation as a result of oil palm expansion in Indonesia progressed at alarming rates from 1980 until 2000 (Figure 2-3). However, studies have shown that in more recent years, deforestation rates have not been as drastic. From 2000 to 2010, deforestation decreased to 0.82 Mha of loss per year, however, these losses still accounted for approximately 56% of total forest loss in Southeast Asia (Abood et al. 2015). The rate of deforestation continued to decrease in the following years. Data from the Ministry of Forestry reports that within a two-year span, from 2009 to 2011, Indonesia experienced a loss of 1.24 Mha of forest (Greenpeace 2013).

Records at the Civil Society Coalition for Fair and Sustainable Spatial Planning department show that 326 oil palm plantations currently own approximately 4.8 Mha of West Kalimantan, Indonesia, equivalent to the three times the size of the state of Texas (Shibao 2015). It is estimated that this number will increase to 13 Mha of oil palm monoculture by 2020 (Shibao 2015). Based on the leases already allocated for future oil palm plantations in Kalimantan,
Indonesia, Carlson et al. (2012) predicts another 9.3 Mha of forest will be cleared for cultivation, including an additional 41% of intact forest, 21% logged forest, and 27% agro-forest.

![Rate of Deforestation in Indonesia 1970-2010](image)

**Figure 2-3:** Trends of deforested land for oil palm cultivation across Indonesia, by year and measured in hectares. While data is usually measured in Mha, showing the deforestation in hectares, as above, gives a better understanding of the drastic increase in overall deforestation trends.

a. **Economically driven industry in Indonesia:**

Over the past six decades, Southeast Asia has experienced times of economic turmoil and has used oil palm monoculture to help counteract the decline in the economy. It is evident from the literature analysis that the rapid growth of the oil palm industry was largely economically driven, especially within Indonesia. During the 1960’s Indonesia was undergoing the fall of their president, their revenue from exporting goods was diminishing, and industrial plantations were operating at their lowest production rates. By 1966 Indonesia was within a major economic crisis with inflation levels reaching over 700% (Tsujino et al. 2016). At this time of heightened corruption, illegal logging and industrial practices occurred with little regulation enforced. Political officials and oil palm industry representatives financially benefitted from the
commercial exploitation and exportation of forest resources, including 1,000 ha of roundwood lumber to Japan, decreasing national forest cover from 162.3 Mha of land to 119.7 Mha by 1985 (Tsujino et al. 2016).

Indonesia underwent economic reform and deregulation in the 1980’s. Former laws that restricted foreign exchanges were changed to incorporate a freer flow of capital that resulted in national economic growth. In the late 1980’s the New Order Government started allocating reserved forest for industry representatives to further the “enterprise-driven deforestation” for their economic benefit (Abood et al. 2015, 58). The Indonesian economy grew at an annual rate of 8% GDP from 1989 until 1997, with forest logging concessions being the largest driver (Tsujino et al. 2016).

The expansion of job availability in the oil palm sector attracted immigrant families to relocate. This resulted in a dramatic increase in population densities, and in turn induced pressure on the clearing of forests for urban development and oil palm monoculture. Population census data estimates that from 1950 to 1979, there was an average of 6,570 families immigrating to Kalimantan, Indonesia; and that average rose to 73,200 families annually from 1980 to 1984 (Tsujino et al. 2016). Researchers conclude that the influx of immigrants is responsible for a large part of deforestation in Indonesia (Sunderlin and Resosudarmo 1996; Tsujino et al. 2016).

Political figures in Indonesia saw forests as a valuable but unnecessary resource. The conversion of forest to oil palm plantations was seen as an easy source of financial gain. There was little concern for the resulting carbon emissions or environmental degradation from the oil palm industry until recent years. Indonesia, in particular, has faced challenges to reduce their deforestation rates and carbon emissions. The Asian Financial Crisis of 1997 caused the Indonesian government to initiate reform and transition to a new administration. After the fall of the New Order Government in 2001, the local level authorities gained the power to allocate forested land for agricultural production (Tsujino et al. 2016). It was not until the Yudhyono government took office that there was a move away from an economically driven industry and a turn towards progressive movements to decrease deforestation and mitigate carbon emissions came into effect in Indonesia.
2.4 Oil palm industry expansion and deforestation in Malaysia

There is minimal data available on the expansion of the oil palm industry in Malaysia prior to 1960. The commercial production of crude oil palm did not begin in Malaysia until 1970 when the government transitioned their economic focus away from rubber. Hai (2002) reported that the geographical distribution of oil palm plantations increased 478% from 0.05 Mha in 1960 to 0.26 Mha in 1970, and continued to increase dramatically following the commercialization of the industry (Figure 2-4). By 2000, oil palm crops covered 3.37 Mha of land compared to 0.26 Mha in 1970 (Hai 2002), and by 2005 plantations covered 4.2 Mha (Fitzerbert et al. 2008). As seen in the data on Indonesia, deforestation in Malaysia decreased slightly during the turn of the century. According to the Malaysian Palm Oil Board, in 2013 Malaysia’s oil palm plantations 5.2 Mha of oil palm plantations that occupied 15.7% of total land area (Yamada et al. 2016). During this period of expansion, 55 – 59% of Malaysia’s oil palm industry had replaced old growth and secondary growth forests (Abram et al. 2014). The largest oil palm contributor in Malaysia is the state of Sabah, producing approximately 28.6% of the country’s total oil palm product (Abram et al. 2014). By 2011, 1.43 Mha of Sabah’s tropical ecosystems were dominated by oil palm plantations, with expansions projected to increase another 2.1 Mha by 2025 (Abram et al. 2014). Comparatively, Hamdan et al. (2016) estimated that oil palm plantations contributed to 61% of the deforestation that occurred between 2010 and 2015.

As a result of the rapid expansion of the industry, oil palm plantations have been cultivating floodplains with higher ground saturation for monoculture. Consequently, the crops cultivated on these floodplains experience palm mortality from root rotting and low oxygen from saline water. Using a Classification and Regression Tree (CART) analysis, Abram et al. (2014) examined oil palm dominated lands within the Lower Kinabatangan region of Sabah, Malaysian Borneo that are unsuitable for oil palm monoculture, but have still been converted for production. Abram et al. (2014) concluded that 51,466 hectares of oil palm dominated land is currently under-producing because of unsuitable soil conditions. The expansion of oil palm monoculture will prove to be difficult in Sabah as an estimated 66% of the 30,173 ha of undeveloped forest is unsuitable for oil palm production (Abram et al. 2014). However, 59% of these lands have already been reserved for oil palm conversion, and 11% were under land applications for future conversion (Abram et al. 2014). The research concluded that plantations are not abiding by the necessary requirements of the oil palm for maximum yield when planting.
Further expansion of the oil palm industry in these areas will depend on further research of land suitability.

Figure 2-4: Trends of deforested land for oil palm cultivation across Malaysia, by year and measured in hectares. While data is usually measured in Mha, showing the deforestation in hectares, as above, gives a better understanding of the drastic increase in overall deforestation trends.
Figure 2-5: An island-wide documentation of Borneo shows the impact of selective logging, fire, and conversion to palm oil plantations since the 1970s. (Data from CIFOR, map document created by J. D. Heaster 2017.)
2.5 Deforestation and degradation of tropical peatland

Tropical peatlands are coastal lowlands, usually less than 20 meters above sea level, covering 24 Mha of land in Southeast Asia and 44 Mha globally (Figure 2-4; Tonks et al. 2017). Their lowland nature makes them a prime location for oil palm plantations. The establishment and production of oil palm plantations on tropical peatlands require more modification than just deforestation due to the nutrient poor soils, high water tables and soil saturation. For example, deep drainage systems are dug between planted trees to help establish soil conditions and heavy machinery is driven over the soil for compaction to increase the stability of the palm trees during growth. The deforestation of tropical peatlands is considered the second largest contributor to the carbon emissions from peatland conversion next to drainage impacts of peatland soils (Page et al. 2011).

Across the island of Borneo, region of Sumatra and Malaysia, 5.1 Mha of tropical peatlands were cleared for the conversion to oil palm monoculture between 1990 and 2007 (Page et al. 2011). In Malaysia, oil palm plantations built on tropical peatlands is estimated to have increased to 0.53 Mha in 2010 from 0.38 Mha in 2000 (Page et al. 2011); and in Indonesia, oil palm plantations currently cover approximately 1.3 Mha of tropical peatlands, and an additional 1.2 Mha is estimated to be reserved for agricultural clearing by 2020 (Page et al. 2011).

Figure 2-4: Land cover in SE Asia of tropical peatlands in comparison to land cover of oil palm plantations (Koh et al. 2011).
A study conducted by Tonks et al. (2017) on the chemical and physical changes that result from the conversion of tropical peatland soil for oil palm monoculture found that the conversion process leads to long-term intense stages of degradation, and researchers question if it is possible to mediate these damages. After draining the peatland soil to acquire threshold moisture levels for planted oil palm, the water table is lowered and water-holding capacity is altered, this can result in the physical collapse of the soil structure and an increase in the risk of fire because of carbon levels in the soil (Tonks et al. 2017). Clearing the natural vegetation in the peatlands also removes organic matter needed for the physical stability of peatlands. Natural peatlands have an estimated 934 tons CO$_2$-eq/ha stored in biomass compared to oil palm plantations having 88.8 tons CO$_2$-eq/ha (Page et al. 2011). The combination of altered water tables, anthropogenic modifications during the conversion process, and the overall deforestation contributes significantly to the increase in carbon emissions. Tonks et al. (2017) outlined in their research the limitation on published data in relation to the deforestation of tropical peatlands and the negative effects of oil palm conversion processes. These research limitations are further discussed in 5.2.

2.6 Fire-related conversion

The conversion processes from forest and tropical peatland to oil palm monoculture include enacting fire-related techniques to clear vegetation and forest structure. Controlled burning has contributed significantly to carbon emissions related to the oil palm industry and the long-term degradation of tropical forests and peatlands. After the initial burning for clearing, the area is at an increased risk of burn cycles that will result in wildfires and the transition of forested land to degraded scrubland, such as the fire events following the El Niño droughts of 1983 (Gavaeu et al. 2016). Between 1997 and 2007, more than 72,000 fires were recorded in Raiu, Indonesia via satellite imagery, and 12% of areas had burned more than once (Uryu, et al. 2008). When fires occur that are not associated with land-use change or an agricultural conversion process, it is categorized as degradation (Pearson et al. 2017). The reoccurrence of fires interfere with natural regeneration and prevent tropical forests from recovering after fire events. Because of the increase of fire occurrences, carbon emission rates are expected to increase in the future as a result.
Fire clearing techniques have initiated other fire events, such as the Indonesian Haze Crisis. In June 2013, Indonesia experienced a fire event that resulted in a haze pollution spreading across Southeast Asia. The fires began on the island of Sumatra, and although the direct cause and nature of the fires is debated, The World Resources Institute (2013) reported that half of the fires occurred on timber and oil palm plantations. A satellite analysis on the Riau Province found that, out of 0.14 Mha of land that was burned, most of the fires were in areas of recently deforested tropical peatland, further suggesting the fires are a result of land clearing for new agriculture plantations (Greenpeace 2013). The haze from the fires caused an international crisis as airports in Indonesia had to temporarily close and the air quality in Singapore dropped to the worst levels ever recorded (Sizer et al. 2014). The following year in April, fires began again on Sumatra and at an increased rate compared to 2013. Data from the Global Forest Watch on tree cover change as a result of the fires reported that the clearing of forests for agriculture was the greatest primary influence of the fires (Sizer et al. 2014). Since then, Sumatra has had large-scale annual fire events affecting neighboring countries such as Malaysia and Singapore, while also spreading as far as Southern Thailand. The Global Fire Emissions Database estimated that the CO\textsubscript{2}-eq emissions from these fires exceed the daily average emitted by the United States (Schecter and Wright 2015).

2.7 Production:

In addition to land use modifications, and the resulting increase in carbon emissions, the production process of oil palm monoculture also contributes to increased carbon emissions through its complex system (Figure 2-5). The production cycle continues the deforestation and degradation of land, as one set of oil palm crop only lasts 25 years. After 25 years, the palm tree becomes too tall for harvesting and the plantation clears their crop and begins another cycle (Hai 2002; Page et al. 2011). Harvesting begins 24 – 30 months after planting and lasts until the plantations initiate the next production cycle (Hai 2002). Different extraction processes of oil from fresh fruit bunches (FFB) have been found to emit different levels of CO\textsubscript{2}-eq. There are two processes of extracting oil palm from the FFB, wet and dry extraction (Poku 2002; Klaarenbeeksingel 2009; Kaewmai et al. 2012; Bunchai et al 2016). More studies have been conducted on the wet extraction process, as it results in larger carbon emissions and more negative effects than the dry extraction process due to wastewater treatment. Prior to Bunchai et
al. (2016) there were no studies published that analyzed the emissions from the dry extraction process although it is considered to be more efficient than wet extraction. Most studies do not analyze the emissions from packaging and distribution, but rather, emissions from cradle-to-gate. Cradle-to-gate is defined as emissions from the time of extraction to when the oil is ready for transportation. Wet and dry extractions have different emission factors involved, as they are implemented differently. However, between both extraction processes, the common emission factors are the utilities used during the extraction process, the transportation of products to specific mills, and the processing of the oil palm plant (Kaewmai et al. 2012; Kusin et al 2016).

There is a preference for the dry extraction process of oil palm production because it can process more FFB than wet extraction and has less environmental impacts (Poku 2002). The purpose of the dry extraction process is to mechanically press the oil from the fruit bunches. Most large-scale oil palm plantations adopt the ‘dry’ method of oil extraction because of the larger volume of oil that can be extracted (Poku 2002). In the primary production stage the fresh fruit bunches (FFB) are harvested from the palm trees and the palm fruit is transported to the oil palm mill. The palm fruit is processed in a series of chambers for cleaning and drying. The drying chamber is heated to 100° C with firewood (Poku 2002). After the fruit has been cleaned and dried, it is taken through the dry extraction mill and processed through a screw press where the oil is extracted (Poku 2002). The screw press is a common tool used for the extraction of food material processing and oil extraction (Poku 2002; Azizi et al. 2015). Screw presses are able to break open fruit cells and release more oil than wet extraction from the pressure exerted on the fruit bunches. Although, it is expected to extract the maximum amount of oil palm from the fruit bunches, the screw press is prone to malfunction frequently making it a less sustainable tool for processing oil palm (Azizi et al. 2015). The products of the dry extraction process are mixed oil palm (MOP) and palm kernel cake (PKC). Mixed oil palm is the main product, and is the oil that is most widely used in household merchandise and biodiesel. After extraction, MOP undergoes a filtration process that separates crude oil palm (CPO) and the kernel oil so the MOP can be collected and distributed to the oil palm refineries. PKC is typically used as animal feed for cattle, however, other PKC extraction procedures are possible to create oil from the byproduct (Hosseini and Wahid 2013). The analysis of the extraction and production of CPO is more common since it is the more widely exported oil than PKC. Therefore, for the purposes of this paper, the emissions based on the production of CPO will be analyzed rather than PKC.
The term “wet extraction” comes from the use of hot water to leach the oil from the FFB (Poku 2002). The production process of wet extraction can be summarized into the sterilizing, stripping, separating the FFB, digestion and pressing, oil extraction and purification of the oil (Hosseini and Wahid 2015). During wet extraction, FFB are processed whole in large amounts of water to extract the oil, however, the fruit and mesocarp are processed separately. The water allows the heavy materials from the fruit bunch to separate from the oil. The “stripped” empty fruit bunches are taken to another mill to be processed for mulch, while the fruit are transported to be pressed for oil (Fitzerbert et al. 2008). The high temperature of water and steam weakens the fruit bunches and allows the fruit to be removed more easily.

Figure 2-5: The overall oil palm extraction and production processes, including wet and dry extraction (Kaewmai et al. 2012).

The process of extracting the oil is the largest contributor to wastewater. The wastewater produced during the production process is typically referred to as palm oil mill effluent (POME). Emissions from palm oil mill effluent can contribute to more than 90% of overall emissions during this process (Hosseini and Wahid 2015). Approximately 0.5 - 0.75 tons of POME are produced for every ton of FFB that is processed (Reijnders and Huijbregts 2008). Following oil
extraction the wastewater is transferred into a ponding system for treatment. Oil palm plantations typically use stabilization ponds or open tank systems to treat the wastewater that results from the production process. Ponding systems are the most common methods of wastewater treatment because of the low cost due to minimal utilities needed. The ponding system used, and whether it is a closed system or not, greatly affects the amount of emissions. Following treatment, the wastewater is usually discharged back into the oil palm fields to water to crops.

3. Methods

My methodology for deriving an answer to my primary research question was a literature review and synthesis with some minor support for my evidence utilizing ArcGIS® technology. For the purposes of this study, the research focused on carbon emissions resulting from the conversion and production of oil palm monoculture within Southeast Asia. The goal of the research was to analyze the carbon emissions that result from oil palm cultivation, land conversion, extraction processes (both wet and dry), and the impacts these processes have had on tropical ecosystem carbon emissions. Carbon emissions and CO₂-equivalent data were analyzed from a variety of literature sources, and it is noteworthy that there is a lack of consensus on emissions data, especially within conversion factors.

To properly examine the relationship between the variables of land use change, oil production and transport, land conversion, and regional carbon emissions, I used a comparative analysis to elucidate how these different factors increase CO₂ outputs related to this industry. Additionally, the comparative analysis that I used assists in informing policy practices within the industry, and my professional recommendations to increase the sustainability of this industry. To further quantify and clarify how land use changes or practice affect regional carbon emissions I looked at the industry practices within Southeast Asia, specifically Malaysia and Indonesia. Literature regarding land clearing, land use changes, and production methodologies provided supporting data to strengthen my analysis of the primary region of study in Malaysia and Indonesia, and particularly, the island of Borneo.

Literature review is the primary source of data that was used to provide evidentiary answers for these questions. Through extensive research I was able to accumulate enough peer-reviewed documentation to provide answers to my sub-questions. To further support my
conclusions, minor use of geospatial technology was included to provide spatial reference for factors such as fire, logging, and plantation conversion. Government literature is available to support my findings; however, this literature should be considered somewhat suspect due to rampant government corruption and overt influence that economic interests wield on government reporting to the international community.

For studying carbon emissions resulting from oil palm monoculture, two major categories were analyzed: land use change and oil palm production. For the scope of land use, there were three subcategories: conversion of forest (defined as intact, logged, and agro-forests), conversion of tropical peatlands, and land use modification by method of fire (commonly referred to as “slash and burn”). Tropical peatlands were investigated separately to display the significant contribution to CO₂-eq emissions rates unique to these ecosystems from soil composition. Land use change by fire was also analyzed separately due to its significant contribution to overall emissions. Although fire is a method of deforestation, there is discrepancy amongst data and literature on how fire related emissions should be categorized; therefore the emissions strictly from fire were analyzed as a separate parameter. When considered separately, these categories aid in provided a more accurate estimation of potential carbon emissions from the processes within the region, and further providing information to support the need for changes in industry practices to favor increased sustainability.

Emissions from these parameters were measured in carbon dioxide equivalent (CO₂-eq), CO₂-eq per hectare and CO₂-eq per ton of oil produced. As means of accurate comparison, the conversion of carbon (C) to CO₂-equivalent was calculated. The unit of “carbon dioxide equivalent emissions per ton of oil produced” was used to analyze production emissions while the unit “carbon dioxide equivalent emissions per hectare” was used to analyze emissions related to land use change, and the changes in carbon stocks (Klaarenbeeksingel 2009). It is important to understand the distinction between these two methods as the quantity listed on a per hectare basis implies a spatial attribute, while the carbon emissions per ton of oil produced is strictly a unit of production emissions with no direct spatial component. This is critical because emissions from land clearing and cultivation are somewhat more difficult to mitigate, while emissions from the production process of the actual oil can be more readily addressed through process and engineering control modifications.
Within the category of production, there were two extraction processes that were analyzed: the wet and dry extraction processes. Data was gathered via peer-reviewed and academic literature for comparative analysis to analyze the carbon emissions resulting from both processes. This analysis focused on the emissions from cradle to gate (emissions from the time of extraction to when the oil is ready for distribution). Other sources of emissions have been documented, such as packaging and distribution, however, they reside outside the scope of this study and were not incorporated in the analysis due to lack of pertinence. Although other greenhouse gas emissions, such as N₂O and CH₄, play an important role in understanding the extent of impacts created by the oil palm industry in tropical ecosystems, this paper focuses strictly on carbon equivalent emissions. Evidence supporting my conclusions regarding land use changes influence on regional carbon emissions are delineated in the following Section 4: Evidence.

4. Evidence

4.1 Emissions as a result of conversion processes

a. Conversion of forest

Deforestation within tropical ecosystems is the second largest source of anthropogenic greenhouse gas emissions (Hamdan et al. 2016). There is a consensus among the literature that the conversion of forest to oil palm monoculture has had larger effects on carbon emissions than other agriculture industries due to the loss of biomass that is associated with industry expansion, and therefore deforestation should be analyzed separately from tropical peatland degradation. The rate of CO₂-eq emissions varies based on the type of forest that is converted for oil palm. The three forest types discussed among researchers were intact, logged (also called secondary growth forests), and agro-forests. Intact forests are defined as pristine old-growth forest with little or no signs of anthropogenic influence (Koh et al. 2011). Logged forests are old-growth forest that have lost their original structure, and have gone through a previous industrial-related conversion but have recovered (either naturally or through restoration efforts) much of their original biodiversity and structural integrity (Carlson et al. 2013). Agro-forests are forests built around croplands to promote biodiversity and maintain some or most ecosystem services associated with this region (Gaveau et al. 2016).
Distinguishing the types of forest is imperative to understand the extent of how
deforestation contributes to CO$_2$-eq emissions as each forest type provides different services in
terms of habitat or carbon sequestration capabilities. The process of converting intact forests to
oil palm monoculture is the most detrimental to overall carbon emissions, as these forests (when
converted) are responsible for the greatest quantities of CO$_2$-eq emissions. Between the years of
1990 – 2010 in Kalimantan, Indonesia, forests converted for oil palm monoculture consisted of
intact (47%), logged (22%), and agro-forests (21%), and more than 560 Mt (75%) of the nations
CO$_2$-eq emissions are a result of the conversion of these forests (Carlson et al. 2012). If all
current allocated leases of intact, logged, and agro-forests for oil palm production are converted,
Carlson et al. (2012) predicts Kalimantan’s emissions will increase 284% and contribute to 34% of
Indonesia’s national land-based emissions.

In their analysis of deforestation rates across tropical countries that have growing
agriculture industries, Pearson et al. (2017) found that emissions from the conversion of non-
peatland forest ranges from 2,300 to 4,200 Mt CO$_2$-eq per year. The reason for the large range in
emissions varies on the study conducted and whether or not the researchers focused on net or
gross emissions (considering carbon stock loss) and the study area in question (Pearson et al.
2017). Throughout the literature analysis, some studies include the sequestration of carbon from
oil palm monoculture into their analysis while others focused strictly on net carbon emissions
from conversion. This exclusion of biomass and carbon stock in CO$_2$-eq analyses is further
discussed in Section 5.2.

Within the province of Riau, Indonesia, the deforestation of non-peatland forest
contributed 52.4 Mt of CO$_2$-eq/year between 1982 and 2007, equivalent to 63% of the regions
total estimated emissions (Uryu et al. 2008). With the inclusion of forest degradation through
conversion, total CO$_2$-eq emissions were estimated to be 366 Mt CO$_2$-eq/year from 1997 to 2007
(Uryu et al. 2008). Following the early 2000’s deforestation emission rates decreased (Table 4-1).
It can be assumed that this was due to the transition from deforesting large areas of intact
forest to converting already logged and agro-forested areas, resulting in lower emissions.

Forests in oil palm dominated areas also go through ongoing conversion after the
production of oil plantations begin due to crop rotation. Oil palm trees cannot be harvested after
the tree grows past a specific height, therefore plantations conduct “crop rotation” by cutting
down the trees that are too tall and replant new crops. Forest conversion of oil palm crops per
rotation period of 25 years also contributes to deforestation rates and is estimated to emit a total of 795 – 1099 tons CO$_2$-eq/ha during each cycle (Hergoualc’h and Verchot 2013). This variance cannot be measured on an annual scale as each plantation rotates their crops at different time periods based on initial planting and the size of the plantation. It is highly likely that the spike in emissions from 2010 – 2015 is associated with crop rotation. Because of the lack of uniformity in crop rotation schedules, CO2-eq/ha is the more accurate measure of emissions from crop rotation processes.

<table>
<thead>
<tr>
<th>Source of conversion emissions</th>
<th>Emission rates (Mt/CO$_2$-eq)</th>
<th>Note</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforestation</td>
<td>26</td>
<td>Annual emissions from deforestation during 1990's and 2000's in Indonesia</td>
<td>Ramdani and Hino 2013</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Annual emissions from deforestation during 2000's to 2012 in Indonesia</td>
<td>Ramdani and Hino 2013</td>
</tr>
<tr>
<td></td>
<td>6.33</td>
<td>Average annual emissions from deforestation between 2005 – 2010 across tropical ecosystems</td>
<td>Pearson et al. 2017</td>
</tr>
<tr>
<td></td>
<td>52.4</td>
<td>Annual emissions from deforestation between 1982 and 2007 in Indonesia</td>
<td>Uryu et al. 2008</td>
</tr>
</tbody>
</table>

*Table 4-1: Summary of emission rates of non-peatland forest converted within Southeast Asia, measured in Mt of CO$_2$-eq.*

The conversion of forests for oil palm cultivation was estimated by Singh et al. (2015) to release approximately 650 tons CO$_2$-eq/ha. Comparatively, Bunchai et al. (2016) found that undisturbed intact forests that underwent conversion emitted 322.4 – 404.2 tons CO$_2$-eq/ha, showing that intact forest result in higher emissions than other forests. When these forests are degraded, one of the primary mechanisms for removing excess atmospheric CO$_2$ is lost or severely limited, with damaging effects to neighboring ecosystems. Because the conversion process of forest to oil palm monoculture releases up to 420 times more CO$_2$-eq than annual reductions from natural sequestration this results in a “carbon debt” (Singh 2015). One significant counter finding during the literature analysis is that the conversion from logged
forests, cleared specifically for rubber plantations, to oil palm plantation could result in lower CO$_2$-eq emissions due to an increase in carbon stocks. Kusin et al. (2016) found that the conversion of intact tropical forest to oil palm plantations results in four times higher emissions and 50% carbon stock reduction when compared to the conversion of logged forests, however, the conversion from previously logged forest for rubber plantations to oil palm increased carbon stocks by 20%. This indicates that this process creates a carbon sink in newly established oil palm plantations from logged forests. This is due to the amount of CO$_2$-eq from aboveground and belowground biomass that is lost during the conversion of intact forest systems, while logged over forests gain sequestration potential from the planting of oil palm trees.

b. Conversion of tropical peatlands

Tropical peatlands are one of the Earth’s most efficient reserves for terrestrial organic carbon and are at considerable risk for industrial conversion into oil palm plantations (Page et al. 2011; Tonks et al. 2017). As of 2010, 46% of tropical peatlands in Southeast Asia had been burned and cleared for agriculture, of which 20% of those lands were converted to oil palm plantations (Hergoualc’h and Verchot 2014). As tropical peatlands are a major carbon repository and store ten times more carbon than forests on mineral soil, they should be analyzed separately when looking at deforestation rates because of the extensive conversion procedures for peatland soils (Sodhi et al. 2004). For the purpose of this analysis, the conversion of peatlands is defined as the clearing and drainage for oil palm cultivation.

All processes in the conversion of tropical peatland soil to oil palm plantations affect the natural characteristics of tropical ecosystems while expediting decomposition rates, and result in an increase of CO$_2$ emissions. During the conversion process, carbon resources are depleted and tropical peatland soils transition from a carbon sink to a carbon source. This is due to the high concentrations of available organic carbon that is stored within the strata of peatland soils; this carbon is then combusted during conversion processes. The more destructive or invasive the conversion process, the more tropical peatlands will become a significant carbon source within the region. The rate of decomposition of tropical peatland soil depends on the forest vegetation, hydrology, nutrient levels and any other disturbances, including natural and anthropogenic effects (Page et al. 2011). The most recent publication on tropical peatland conversion, Tonks et al. (2017), analyzed the ways that the chemical and physical properties of tropical peatlands are altered during land conversion to oil palm and the predicted rate of carbon emissions as the oil
The palm industry continues to grow in Central Kalimantan, Indonesia. The researchers concluded that the conversion of peatlands outweighs natural sequestration and results in a rapid loss of carbon, emitting approximately 39.6 – 52.4 t CO₂-eq/ha per year while taking carbon stocks into account. Their modeling studies on the rate of carbon emissions from peat degradation and carbon stock assessments predict an increase of 5,138 tons CO₂-eq/ha over a period of 100 years and the majority of carbon loss in these areas will be at the expense of conversion from tropical peatland to oil palm plantation (Tonks et al. 2017). Naturally occurring climatic fluctuations are also being altered or intensified by the increased anthropogenic landscape alterations. For example, temperatures are warming as a result of increased atmospheric CO₂ levels and are likely to increase decomposition rates of tropical peatlands as a result.

During the transition for oil palm monoculture, there are fertilizers used to prepare the soil for planting. The fertilizer causes an increase in nutrient levels, resulting in peat decomposition and an increase in CO₂-eq emissions. Although these fertilizers emit more nitrogen-based emissions than carbon equivalents, it is acknowledged that this factor contributes to greenhouse gas emissions from the oil palm industry; however, for the purposes of this paper the rate and impact of these emissions were not further analyzed.

Along with the loss of biomass from conversion, tropical peatlands become carbon sources when they lose sequestration potential. Tropical peatlands have shallow water tables that must be lowered and altered through pumping or aquifer diversion for successful conversion. This process of drainage to make land suitable for oil palm agriculture also contributes to the increase in conversion-related carbon emissions. The conversion of tropical peatlands for oil palm monoculture requires the drainage of water to 60 – 80 cm below the soil surface, which also results in a higher rate of peat decomposition (Klaarenbeeksingel 2009; Koh et al. 2011; Page et al. 2011; Carlson et al. 2012; Ramdani and Hino 2013; Tonks et al. 2017). Emissions during peat conversion are highest during the initial processes of drainage since the level of emissions increases with drainage depth (Page et al. 2011; Tonks et al. 2017). The Roundtable of Sustainable Palm Oil (RSPO) estimated that there are 9 tons of CO₂-eq emissions for every 10 cm of peatland drained during conversion and emit 18 – 73 tons CO₂-eq/ha annually (Klaarenbeeksingel 2009). This estimation increased in following years, as Page et al. (2011) concluded that emissions range from below 30 tons CO₂-eq/ha to above 100 tons CO₂-eq/ha annually depending on the depth and scale of land undergoing conversion (Figure 4-1).
Following their research, Ramdani and Hino (2013) estimated that the conversion of peatlands accounted for 41% of annual CO$_2$-eq emissions (0.54 Mt CO$_2$-eq/year) during the 1990’s and 2000’s (Table 4-2). Recent publications concluded that the emissions from the conversion to oil palm monoculture were the largest contributor to the degradation of tropical peatlands from 2009 to 2011 (Greenpeace 2013). Although emissions up until 2012 decreased (0.24 Mt CO$_2$-eq/year), approximately 69.94% of total emissions after the 2000’s until 2012 could be contributed to peatland drainage (Table 4-2). Hergoualc’h and Verchot (2014) predicted that if conversion for oil palm continues at the current rate, tropical peatlands might be nonexistent in Southeast Asia by 2030.

### Table 4-2: Summary of emission rates from various literature sources of peatland drainage and conversion within Southeast Asia, measured in tons of CO$_2$-eq.

<table>
<thead>
<tr>
<th>Peatland conversion emission statistics</th>
<th>Emission (t/CO$_2$-eq)</th>
<th>Note</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual estimations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual emissions during the 1990's and 2000's from peatland drainage in Indonesia</td>
<td>538,000</td>
<td>Annual emissions during the 1990's and 2000's from peatland drainage in Indonesia</td>
<td>Ramdani and Hino 2013</td>
</tr>
<tr>
<td>Estimated annual emissions until the early 2000’s across Southeast Asia</td>
<td>4.6 million</td>
<td>Estimated annual emissions until the early 2000’s across Southeast Asia</td>
<td>Koh et al. 2011</td>
</tr>
<tr>
<td><strong>Overall estimations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total peatland drainage emissions across Southeast Asia</td>
<td>0.6 trillion</td>
<td>Total peatland drainage emissions across Southeast Asia</td>
<td>Tan et al. 2009</td>
</tr>
<tr>
<td>Total emissions from peatland drainage during 2000's to 2012 in Indonesia</td>
<td>246,000</td>
<td>Total emissions from peatland drainage during 2000's to 2012 in Indonesia</td>
<td>Ramdani and Hino 2013</td>
</tr>
<tr>
<td><strong>Emissions per hectare (ha)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions from peatland drainage</td>
<td>18 – 73</td>
<td>Emissions from peatland drainage</td>
<td>Klaarenbeeksingel 2009</td>
</tr>
<tr>
<td>Emissions from peatland drainage</td>
<td>30 – 100</td>
<td>Emissions from peatland drainage</td>
<td>Page et al. 2011</td>
</tr>
</tbody>
</table>

#### c. Land use change by fire-related clearing

Land use change through controlled burning is one of the most significant contributors to carbon emissions, affecting both the physical and chemical composition of soils. It is evident that...
fire-related clearing techniques result in increased in larger carbon emissions in comparison to deforestation and degradation emissions (Figure 4-1). Although fire is plays a major role in land conversion emissions, many published articles have a variety of data regarding how they are categorized. Within tropical ecosystems, fire emissions from deforestation and degradation are categorized separately based on the length of time that each fire burns (Pearson et al. 2017). Although it is a method of deforestation, due to the effects that fire-related conversion has on increasing emissions, it is imperative to analyze this process separately when measuring the effects of oil palm monoculture on tropical ecosystems. Researchers have highlighted that the distinction between deforestation and degradation is essential to accurately measure carbon emissions, especially in relation to fire conversion processes, and avoid the misrepresentation of emissions associated with deforestation with emissions from fire degradation. Deforestation is a direct human caused landscape alteration and is defined throughout literature as the clearing of trees with no subsequent regeneration or replanting, such as the clearing for oil palm monoculture or other land uses. Forest degradation is the deliberate and direct, human-induced decrease in the overall quality of tropical forest ecosystems, including soil and biodiversity. However, degradation addresses a multifaceted change to landscapes that affect not only above ground ecosystems, but their sub surface components as well. Recent publications estimated that the total carbon emissions from forest degradation were 2.1 Gt CO$_2$-eq annually across 74 tropical countries as a result of oil palm plantations (Pearson et al. 2017). In terms of relativity, fire-related degradation emissions measure to be about one-third of deforestation emissions (Pearson et al. 2017).

Fire-related clearing, also called “slash-and-burn systems,” is used to convert large scales of land for oil palm monoculture due to the inexpensive cost and how quick land can be converted afterwards. Initially, the vegetation in the area is cut down and the remainder is set on fire. Hamdan et al. (2016) estimated that the overall net CO$_2$-eq emissions from deforestation including fire-related conversion processes in Malaysia were 110 teratonnes (Tt) CO$_2$-eq from 2010 to 2015, which is equivalent to 22 Tt CO$_2$-eq/year. The oil palm industry contributed to 61% of these emissions during this time period, which is estimated to be approximately 67 Tt CO$_2$-eq (Hamdan et al. 2016). A study conducted by Carlson et al. (2012) concluded that fire was the primary cause of 93% of the deforestation in Indonesia from 1989 to 2008. This estimation included the fire-related conversion of land to oil palm monoculture, which
contributed to 69% of total carbon emissions; logging was the second largest contributor at 27% of emissions (Carlson et al. 2012). Hergoualc’h and Verchot (2013) estimated that emissions from a single fire-related land clearing are 493.0 – 649.0 t CO$_2$-eq/ha.

Clearing techniques for the establishment of plantations have numerous contributing factors to carbon emissions, including the direct carbon loss from cutting down vegetation, the emissions from forest-burning techniques, and the carbon loss from the aboveground biomass (approximately 40%, [Klaarenbeekingsel 2009]). The conversion via fire has caused significant damage to tropical ecosystems, such as the rapid decline in the fertility of the land from fire induced biogeochemical changes to the soil. Natural decomposition of debris also allows for the return of vital nutrients to the soils via organic pathways, increasing soil fertility and allowing nutrient transport to undisturbed areas via natural mechanisms. When fire is not used as a clearing technique for tropical forests and peatlands, the vegetation debris is left to decompose, which oxidizes and releases CO$_2$ emissions, but at a much slower and reduced rate. If one hectare of land was to be cleared without the use of fire-related clearing techniques, it would take approximately three years for the biomass to biodegrade before the land would be clear to build oil palm plantations which some producers deem to be an unacceptable delay (BBC 2013).

Climatic fluctuations will also have an effect on fire emissions from the conversion of tropical peatlands, as they are expected to emit more than twice the amount of carbon emissions from fire than drainage processes (Tan et al. 2009). Like forests, tropical peatlands will experience higher flammability indexes during drier seasons and will therefore experience more intense burnings during the conversion to oil palm monoculture. Warren et al. (2016) predicts that using fire to clear tropical peatlands would increase emissions significantly on the hectare scale to approximately 1,101 t CO$_2$-eq/ha during the wet season, and 1,174.4 – 1,211.1 t CO$_2$-eq/ha during the dry season (Warren et al. 2016). Based on these estimations, the emissions from just tropical peatlands are equivalent to about 15% of Indonesia’s total loss from deforestation (Warren et al. 2016).

Warren et al. (2016) describes the risk of sporadic wildfires as a result of deforestation and tropical peatland drainage processes for plantation establishment and concludes that the risk of fires during drier seasons is even higher for areas of drained peatlands under oil palm monoculture due to the altered water table. Unaltered areas near oil palm plantations are also exposed to the risk of wildfires because of the migration of groundwater away from the unaltered
areas to the locations where the water table has been modified for conversion. This process of hydrologic migration can be compared to osmosis due to water migrating from an area of high concentration to low concentration within the water table, i.e. areas altered for oil palm monoculture. As the water table levels balance, the risk of fire increases and as a result fires burn much larger areas with increased frequency. Carlson et al. (2012) concluded that 8% of the wildfires in Indonesia in 1997 resulted from oil palm production, as these fires occurred within 5 km from operating oil palm plantations (Figure 4-2).

Many of these fire emission estimations also depend on future climate patterns as longer periods between wet seasons, or an increase in mean temperatures, can increase the spatial extent and quantity of areas prone to burning, i.e. areas of dense vegetation susceptible to uncharacteristic drying. Forest loss from fire in Indonesia reached 9% per year during the 1997 – 1998 El Nino Southern Oscillation due to an increase in wildfires (Carlson et al. 2012). The fires that resulted from the event contributed to the highest annual net carbon flux in Indonesia and carbon emissions were estimated to account for 19% of the annual 45.1 t CO2-eq emitted per year (Carlson et al. 2012). Warren et al. (2016) looked at simulated models of the carbon emissions over a 100-year period in regards to forest clearing and crop rotations as a result of the oil palm industry. Their conclusions were based on current trends of oil palm expansion and climate in Southeast Asia; however, the authors noted that the predictions will change based on global climate change, especially if drier conditions occur. For example, drier conditions and increased fire frequency could result in total emissions from conversion and cultivation reaching over 30.7 Gt CO2-eq over a 100-year period, compared to the current estimate of 8.7 Gt CO2-eq (Warren et al. 2016).

Although these clearing techniques are illegal in most countries, such as Indonesia, they are still widely used with little to no repercussions to plantation stakeholders. South American countries, such as Brazil, have implemented stricter policies about deforestation and land degradation using fires to clear land for oil palm monoculture (Vijay et al. 2016). The policies in these countries have severe consequences for stakeholders and employees in the agriculture industry if found to be using fire for clearing. However, fire techniques are still used in other countries mainly because of how soon the plantation owners can begin production following conversion, compared to waiting for the biodegradation of biomass after cutting down vegetation.
(BBC 2013). The World Wildlife Fund reported that more than 2 Mha of land are burned every year globally for the cultivation of oil palm (2016).

Fire is perhaps the single largest contributor of regional carbon emissions and is in need of stringent monitoring to quantify, inform, and support reduction recommendations to both private and governmental entities if these emissions are to be decreased in the future. To better quantify the extent of fire-related emissions from land use change for oil palm monoculture in future studies, emissions should be categorized as a form of deforestation emissions rather than degradation because it is a land use change to fully transform forest (Pearson et al. 2017). The Global Fire Emissions Database could be a useful resource for future studies, as it estimates emissions from forest fires while providing a monthly update of data. Due to the higher resolution imagery needed to identify degradation, beyond the canopy cover, the accurate monitoring and measuring of tropical forest degradation has proven to be challenging (Pearson et al. 2017). Given the ease of the “slash and burn” method of land clearing, it is reasonable to conclude that carbon emissions from fire related conversion in Southeast Asia will continue to increase unless direct and stringent measures are enacted to cease this practice; and that requires increased enforcement by governmental regulators.

![Figure 4-1: Comparison of emissions resulting from deforestation, peatland drainage and fire related conversion processes measured in CO₂-eq per hectare.](image-url)
Fires Near Oil Palm Plantations & Timber Harvesting Regions, Borneo

Map Author: James D Heaster
Data Source: www.ESRionline.com, CIFOR

Figure 4-2: Locations of fires in Malaysian and Indonesian Borneo compiled from NOAA data on tropical Fires (Data from CIFOR, map document created by J. D. Heaster 2017).
4.2 Emission as a result of oil palm production

There is no one methodology to calculate CO$_2$-eq emissions that include all contributing variables in the production of oil palm (Kaewmai et al. 2012). The range of emission factors analyzed varies on the study conducted, as some researchers include carbon stock assessments and others omit this parameter. Across literature, emissions from oil palm production are categorized as the daily operations of plantations (including transportation during production and utilities to power the plantation), fresh fruit bunch acquisition and processing, wastewater treatment (if applicable at that location), and the changes in carbon stocks in either soils or above ground biomass. Due to the various emission factors, studies analyze overall emissions using either the unit of “CO$_2$-eq per ton of CPO produced” or “CO$_2$-eq per hectare.” The units of CO$_2$-eq/ton CPO is used to describe emissions directly related to the extraction and production of oil palm, while CO$_2$-eq/ha is used for emissions related to changes in carbon stock and production emissions (Klaarenbeek singel 2009). During the literature analysis, both units were quoted, and neither of the units includes emissions from the clearing or conversion processes of land.

As discussed in Section 2.7, there are two production processes of oil palm, wet and dry. The emissions as a result of these processes vary due to the use of water for wet extraction and increased firewood usage for dry extraction. Due to the inclusion of water during wet extraction, there is an additional emission factor from wastewater treatment processes; these wastewater treatment emissions will also vary based on whether the plantation has biogas capture systems for treatment (Figure 4-2). Within the wastewater treatment stage, there are also various ponding mechanisms used, which will also affect emission levels. Data across literature have wide estimations on the extent of CO$_2$-eq emissions as a result of different extraction processes and wastewater treatment involved. Most literature analyses focus on the wet extraction process as it is more widely used across oil palm production; however, a study conducted by Bunchai et al. (2016) focused strictly on the dry extraction process, and therefore I was able to provide a more accurate comparison of emissions from both processes by analyzing the difference in emission levels between processes. For this project and to facilitate ease of comparison, the emissions from wet and dry extraction are investigated on a CO$_2$-eq/ton CPO basis.

Reijnders and Huijbregts (2008) and Kusin et al. (2016) analyzed the overall emissions of oil palm plantations on a CO$_2$-eq per hectare basis, as they included estimated changes in carbon stock to their analyses. It was concluded that production related CO$_2$-eq emissions vary based on
the age of the plantation, as well as the extraction process used (Figure 4-3). There is an average daily emission value of 1.76 tons CO₂-eq per hectare for mature plantations and 3.0 tons CO₂-eq per hectare for new plantations (Reijnders and Huijbregts 2008). Although the literature does not clearly define why there are large differences between carbon emissions between old and new oil palm plantations, it can be assumed that this increase is a result of numerous emission factors; these factors include the expansion of plantation sizes of newly established cultivation sites, the growth of production and thus an increase in transportation and electricity usage.

![Emissions based on age of oil palm plantation](image)

**Figure 4-3: Average emissions per hectare based on plantation age, measured in tons of CO₂-eq per hectare.**

There is a general consensus across data that the highest levels of emissions come from the energy use of daily operations and FFB acquisition processes (Reijnders and Huijbregts 2008; Kusin et al. 2016). Reports are also produced by the RSPO on the emissions from oil palm production and the emission factors involved. The RSPO analyzes their emissions based on how much CPO is produced as well as the CO₂-eq per hectare. They estimate that for every 3.2 to 4 tons of CPO produced, emissions would measure to 4.5 - 22.8 t CO₂-eq (Klaarenbeeksingel 2009). Based on the extraction process used, utilities are estimated to contribute 150 – 236 kg CO₂-eq/ton of oil palm produced (Klaarenbeeksingel 2009). Electricity to power oil palm plantations is either derived from the national grid or diesel fueled steam turbines (Hosseini and Wahid 2015).
Gas to fuel machinery in the production process was measured to release 6 kg CO$_2$-eq/t of oil produced (Klaarenbeeksingel 2009). The transportation sector of the production process uses high-emitting fossil fuels, such as diesel, to power the machinery needed to harvest, collect, transport, and mill the fruit bunches. Carbon emissions from diesel use were quoted to be 3.21 kg CO$_2$-eq per ton of diesel used, resulting in 225 kg CO$_2$-eq/ha per year (Klaarenbeeksingel 2009). Klaarenbeeksingel (2009) estimated that annual emissions from transportation contribute to 45 – 125 kg CO$_2$-eq/t CPO.

Table 4-4: Summary of estimated production emissions including the wet and dry extraction processes of oil palm monoculture, measured in tons CO$_2$-eq.

<table>
<thead>
<tr>
<th>Source</th>
<th>Emissions (t/CO$_2$-eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall emissions per ton of CPO produced including wet extraction</td>
<td>1.3</td>
</tr>
<tr>
<td>Overall emissions per ton of CPO produced including wet extraction</td>
<td>1.21</td>
</tr>
<tr>
<td>Overall emissions per ton of CPO produced in 2009 including dry extraction</td>
<td>1.14</td>
</tr>
</tbody>
</table>

a. Extraction processes:

Wet extraction:

Carbon emissions of the wet extraction process of oil palm production result from the numerous inputs associated, such as: the acquisition of raw fruit bunches, chemical input for wastewater treatment, disposal of chemical waste, energy and utilities, and wastewater treatment after production (Poku 2002; Klaarenbeeksingel 2009; Kaewmai et al. 2012; Carlson et al 2012; Bunchai et al 2016). Wet extraction emits higher levels of carbon emissions than dry extraction because it requires large amounts of water and energy to convert FFB to CPO (Figure 4-4), and therefore involves a wastewater treatment procedure and chemical inputs (Kaewmai et al. 2012). The average rate of emissions from oil palm mills in Thailand using the wet extraction processes were 1,039 kg CO$_2$-eq/t CPO in 2009 (Bunchai et al 2016). Wastewater treatment accounts for approximately 58% of CO$_2$-eq emissions in the wet extraction process (Bunchai et al 2016).
There are three ponding systems used to treat wastewater, anaerobic, aerobic and detention ponds (Reijnders and Huijbregts 2008; Kaewmai et al. 2012; Hosseini and Wahid 2015). Each of the three ponds provides different stages of treatment through separate processes, and whether or not the ponding systems are covered affects carbon emissions. For example, the aerobic ponds decrease the amount of organic material in wastewater and are estimated to emit 225 kg CO₂-eq/Mt CPO; however, if the ponding system were to be covered, emissions could decrease to 25 kg CO₂-eq/Mt CPO (Hosseini and Wahid 2015). These pond systems are the most common wastewater treatment method because of the low cost. Emissions from the electricity demand of ponding systems generate about 0.50 kg CO₂-eq/t CPO (Hosseini and Wahid 2015). Following treatment, wastewater is discharged into the oil palm fields or held in the detention ponds.

Numerous techniques have been applied to the oil palm industry to improve wastewater treatment while also reducing emissions, such as a biogas capture system. These capture systems are used to generate electricity using the biogas that results from the oil palm effluent during plantation operations. The electricity generated is used to power the mills for the production of oil palm. In 2010, only 10% of Malaysian palm oil plantations had installed the biogas capture infrastructure (Hosseini and Wahid 2015). There is a general consensus that biogas capture systems have not been seriously considered among more oil palm plantations due to the national grid being easily accessible, the low cost of electricity, a lack of information or interest, and the lack of regulations on plantations (Hosseini and Wahid 2015). However, the conversion of biogas to electricity also causes the conversion of CH₄ to CO₂, which can also result in an increase of emissions if it is not implemented properly (Klaarenbeeksingel 2009).

Based on a study by Hosseini and Wahid (2015), oil palm plantations in Malaysia that did not have a biogas capture system emitted approximately 1,102 kg CO₂-eq/t CPO, while plantations that implemented the system emitted 192.5 kg CO₂-eq/t CPO (Figure 4-4). The researchers found that the implementation of biogas capturing technology decreased overall emission levels by 80% (Hosseini and Wahid 2015). A significant counter finding to these emissions is that the extent of emission mitigation varies based on the location of oil palm plantations across Southeast Asia, and what wastewater treatment ponding system is used. Kaewmai et al. (2012) assessed the emissions of 14 oil palm plantations in Thailand with and without biogas capture and different ponding systems. Their studies found that the average

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emissions of oil palm production were approximately 1,198 kg CO₂-eq/t CPO produced. Within those emissions, the plantations that have implemented biogas capture systems emitted 1,039 kg CO₂-eq/t of CPO, while those without biogas systems emitted 1,484 kg CO₂-eq/t CPO (Figure 4-4; Kaewmai et al. 2012). Kaewmai et al. (2012) predicted that biogas systems could reduce carbon emissions in Thailand palm oil plantations by 30%. Thailand is believed to have relatively higher emissions than other Southeast Asian countries producing oil palm because of the wastewater treatment (Kusin et al. 2016).

Dry extraction:

During the dry extraction process there is no wastewater treatment involved, which results in relatively lower GHG emissions. However, due to the lack of wastewater treatment and chemical input, compared to the wet extraction process, the utilities used during the dry extraction process are measured to emit higher levels of carbon emissions than other contributors (Kaewmai et al. 2012; Bunchai et al 2016). The process of harvesting of the palm fruit was the
largest contributor of emissions during the dry extraction process, measuring to approximately 448 kg CO$_2$-eq per ton of oil, which is approximately 83.4% of total emissions (Figure 4-5; Bunchai et al 2016). Firewood, diesel and electricity are the remaining contributors emissions, as firewood is used to dry the palm fruit, measuring to about 5% of emissions; the diesel is used in the transportation of the fruit to the mills for processing, approximately 1.82% of emissions; and the electricity that are used to power the plantations, typically through generators on smaller scale operations, contributing to 9.78% of emissions (Figure 4-5; Bunchai et al 2016). It is assumed that these emissions result from the electricity and fuel use during the harvesting process, rather than production emissions. The removal of the palm fruit from the FFB is usually done by the employees of the oil palm plantation, therefore most studies did not incorporate this process in their analyses. Without incorporating carbon emissions of firewood and burning, the average total emissions of the dry extraction process are 537 kg CO$_2$-eq/t CPO (Figure 4-4; Bunchai et al 2016). The burning of firewood increased these emissions significantly to 871 kg CO$_2$-eq per ton of oil that was extracted (Bunchai et al 2016).

Figure 4-5: Emission factors involved with the dry extraction process and the percentage of how much each factor contributes to overall emissions. The harvesting of the oil palm fruit contributes the largest amount of emissions during the process, as the remaining factors have lower emission levels and a wastewater treatment facility is not needed.
The study conducted by Bunchai et al. (2016) analyzed the emissions from both the wet and dry extraction processes and concluded that if oil palm plantations converted to using strictly dry processes, it could decrease overall emissions 5.08 t CO$_2$-eq/ha/year. Dry extraction also results in a more efficient oil extraction rate (OER) during production than wet processes. This is caused by just palm fruit being used during dry extraction (called raw material), while the palm fruit, FFB and EFB are used in wet extraction; and when moisture is lost in the process it effects the overall extraction of oil (Bunchai et al 2016). The OER of wet extraction is estimated to range from 14 to 19% (Kaewmai et al. 2012; Hosseini and Wahid 2015), compared to a 22.3% OER for dry extraction (Bunchai et al 2016). A conversion from wet to dry extraction could prove significantly beneficial for all countries that are producing large amounts of oil palm as the conversion of extraction processes will also effect the direct and indirect land use changes. It is estimated that this conversion of extraction processes in Thailand could result in a 3% saving of emissions from land use of up to 274,774 t CO$_2$-eq/year (Bunchai et al 2016). Across all parameters, the conversion of extraction processes (from wet to dry), or implementation of biogas capture technology, will result in a reduction of CO$_2$-eq emissions and also increase oil palm production levels.

5. Discussion:

Due to the lack of consensus on one methodology to measure emissions, CO$_2$-eq is measured on annually or per hectare basis throughout literature. Emissions vary across the type of forest converted, i.e. intact, logged, and agro-forests. The deforestation and conversion of intact forests also emit the highest levels of CO$_2$-eq across all forest-related parameters measured. Plantations replace intact forests more frequently, followed by logged forests, then agro-forests. It is evident that the continuous harvest rotation aids in a spike of emission levels when crops are replaced every 25 years.

The degradation of tropical peatland soils is an important factor that is often underestimated, or not included, when analyzing CO$_2$-eq emissions as a result of oil palm conversion. For the purposes of this analysis, tropical peatlands were analyzed separately from forests (intact, logged, and agro-forest) to outline the significance of how the conversion process results in the transition from natural carbon sinks to carbon emitters; and it was evident that tropical peatland soils, although having lower CO$_2$-eq emission rates, lose large quantities of
carbon stock during conversion process. Draining and conversion processes expedite degradation rates, the risk of wildfires and the water table collapsing. The draining of peatlands has the most significant impact on the carbon balance in these soils as CO$_2$-eq emissions increases with depth. The necessary modifications for oil palm monoculture on tropical peatland composition also hinder carbon balance and sequestration potential through the alteration of the water table.

Land use change via fire related clearing events was also analyzed separately due to more significant emissions rates. The conversion of tropical peatlands by fire related tactics emit twice as much CO$_2$-eq than strictly draining. Fires not only emit more CO$_2$-eq but also significantly affect the overall ecosystem, i.e. the combustion of carbon stored in aboveground biomass. Future climatic patterns will have an effect on these emissions and drier seasons will also put Southeast Asia at greater risk for wildfires. Although the amount of land cleared by fire for oil palm cultivation has decreased in recent years, fire-related conversion tactics should be of concern for future studies.

The process used for extraction determines emissions from the production of oil palm. There are numerous emission factors that contribute to overall emission measurement, however, as previously mentioned, this analysis focuses on emissions strictly from cradle to gate. Emissions are typically measured by how many tons of oil palm is produced per hectare. It was evident that wet extraction emits more CO$_2$-eq than dry extraction processes; however, the counter finding showed that the implementation of a biogas capture system could lower wet extraction emission levels past those from dry extraction. Emissions from plantations using wet extraction with a biogas capture system are considerably lower than those without, by approximately 30-80% depending on the wastewater treatment facilities installed on the plantation site. It can be concluded that the implementation of this system, if economically feasible, could prove to be beneficial in decreasing overall production emissions. This conversion is further discussed in Section 6.

It is important to clarify that this paper is not claiming the oil palm industry is the only cause of deforestation and degradation in tropical ecosystems, but rather the most influential factor. Other agricultural industries have contributed to the rates of deforestation, i.e. pulpwood and soybeans; however, these crops are not as economically feasible as the cultivation of oil palm and therefore the industries have not expanded or contributed as much to the dramatic increase of deforestation rates the last five decades. For example, from 1973 to 2015 industrial
plantations expanded by 9.1 Mha of land on the island of Borneo, 1.3 Mha were cultivated for pulpwood production and the remaining 7.8 Mha were oil palm plantations (Gaveau et al. 2016). The emissions as a result of the oil palm industry has had greater impacts on the environment than just aiding to the percentage of global anthropogenic carbon emissions. Carbon emissions have effects that range from small-scale to large-scale. It is evident across literature that the conversion of forests, degradation of tropical peatland soils and fire-related clearings have broader effects on tropical ecosystems and ecosystem services. Biodiversity of flora and fauna are ultimately altered, as are the soil characteristics within the areas cultivated for oil palm production.

There were many emission related data gaps found during the literature analysis which researchers concluded result in statistical errors and do not represent a thoroughly accurate assessment of the amount of CO₂-eq that is released from the conversion and production of oil palm. These data gaps and limitations result in more assumptions than concrete based conclusions across research. However, countries within Southeast Asia have committed to mitigation programs to lower their national CO₂-eq emissions that result from large-scale agriculture industries. For example, Indonesia has put a moratorium in place that has seized future cultivation for oil palm while protecting an additional 43 Mha of land, and Malaysia has committed to the program of Reducing Emissions from Deforestation and Degradation, and Forest Conservation (REDD+). The broader impacts on tropical landscapes as a result of oil palm cultivation and the data limitations are discussed in the following section.

5.1 Broader impacts resulting from an increase in deforestation, degradation and carbon emissions

a. Impacts of deforestation and forest degradation on surface characteristics:

Most deforestation and degradation results from the establishment of new plantations for large-scale cultivation. Many plantation owners prefer to clear intact forests so they are able to benefit from the sale of the timber after clearing, rather than planting on already cleared land or abandoned plantations (Tan et al. 2009). The impacts of deforestation have a significant effect on the carbon cycle and biophysical processes in tropical ecosystems. The clearing of land, removal of canopy structures, and conversion to oil palm plantation also change the surface
characteristics of the area, such as an increase in albedo (the reflective capacity of surface soils) and surface temperatures. Different vegetation compositions have different absorbency and reflective rates, and therefore different radiative forcing profiles. It is estimated that the loss of 60% of tropical forests by 2100 would contribute to the warming climate, equivalent to an additional 44,000 Mt of CO$_2$-eq in the atmosphere (Parrotta et al. 2012). A study conducted by Saswattecha et al. (2016) found that the impacts of converting land to oil palm monoculture between 2009 – 2012 were significantly higher than 2000-2009. It can be expected that any future land conversion will continue to have increased rates of negative effects on tropical ecosystem surface characteristics and their ecosystem services. The long-term success of these services is of scientific and environmental management concern.

b. Impacts of carbon emissions on flora biodiversity:

Although this paper does not examine the full extent of the effects that the oil palm industry has on biodiversity, it is important to address how drastic these impacts have also been on tropical ecosystems. Metrics of flora biodiversity are typically divided into structural (growth potential) and compositional (species richness) parameters (Parrotta et al. 2012). It has been disputed within literature whether or not increased levels of CO$_2$ emissions have a negative effect on plant biology and biodiversity. One argument is that increased CO$_2$ emissions are beneficial for plants, as they need CO$_2$ for growth (Shwartz 2002). However, recent publications have proven these claims irrelevant and the negative effects to be accurate. Carbon emissions have consequences on photosynthesis, as it depends on the equilibrium of metabolic processes. When there is a greater abundance of one chemical, it has an overall effect to the photosynthetic process. An increase in CO$_2$ has been found to affect a plant’s water balance and nutrient cycling, such as stomatal closure within plant leaves (Feng 2015). The closing of the stomata restricts the consumption of water and a decrease in transpiration.

Comparatively, as the emissions and atmospheric levels of CO$_2$ increase the nitrogen concentration in plants will decrease; this results in a decline of plant protein levels and affects ultimate growing potential (Feng 2015). Studies have confirmed that nitrogen concentration in terrestrial plants decrease by 10% when there is an increase in CO$_2$ (Feng 2015). A loss of nitrogen in already nutrient-poor soils, such as tropical peatlands, will impede greatly on plant biodiversity. At Stanford University, a study examining the effect CO$_2$ in combination with atmospheric temperature, water, and nitrogen levels was administered under controlled
circumstances (Shwartz 2002). Across all scenarios of the 36 plots in the experiment, Shwartz (2002) found that the addition of increased CO₂ levels hindered plant growth, regardless of any changes made to the other controlled parameters. Other analyses suggest that the loss of plant diversity can result in the decline of key functional species within the area (Parrotta et al. 2012), such as the estimated 11% of endemic flora species that reside in tropical peatlands (Evers et al. 2017). This loss of key species can ultimately affect trophic levels by decreasing primary production. It can be concluded that plant growth and biodiversity within tropical ecosystems will be significantly affected due to rising CO₂ levels emitted from the continuation of oil palm related emissions.

**c. Impacts of deforestation and degradation on species biodiversity:**

The fragmentation of forests from deforestation and its effect on species biodiversity is a growing concern amongst researchers (Abdullah and Nakagoshi 2007). Tropical forests in Borneo are home to approximately 129 species of mammals, 314 species of birds, 101 species of reptiles, and 33 species of amphibians (Abram et al. 2014). Comparatively, the IUCN estimated 259 endemic mammals, 382 endemic birds, and 172 endemic amphibians within Indonesia (Profauna 2012). Out of these estimates, 507 species are currently threatened (184 mammals, 119 birds, 32 reptiles, 32 amphibians, and 140 fish) (Profauna 2012). Since the expansion of the oil palm industry, and the resulting increase of deforestation and degradation, there have been significant declines in species richness. For example, bird species experienced a 77% decline in richness and butterfly species declined 83% just within Malaysia in response to deforestation rates (Butler and Laurance 2009). The various levels of deforestation and degradation of tropical forests and peatlands for oil palm monoculture is fragmenting natural habitats and converting them to “biological deserts” (Butler and Laurance 2009), causing substantial changes in trophic structure and food chains (Parrotta et al. 2012). Among the species that are greatly affected by the oil palm related habitat destruction are Asian elephant species and the Sumatran tiger.

Sumatran elephant (*Elephas maximus ssp. sumatranus*) population numbers in Riau, Indonesia declined 84% over a 23-year period, from approximately 1,342 in 1984 to 210 in 2007 (Uryu et al. 2008). By 2007, elephant populations in Rokan Hilir, Kerumutan, Koto Panjang, Bukit Rimbang Baling, Tanjung Pauh and Bukit Suligi had gone extinct, and as a result, the number of elephant herds declined from 15 in 2003 to nine (Uryu et al. 2008). The Borneo elephant (*Elephas maximus borneensis*) has suffered similar fates to those of Sumatran
elephants. Recent studies estimate there are approximately 1,500 individuals left on the entire island (Asian Elephant Support, n.d.). This decline in population numbers can be correlated to the forest loss. Uryu et al. (2008) estimated that during the same time that elephant populations were rapidly decreasing, 65% of forests were lost. It is evident that the number of elephant herds decline as deforestation increases and forests became more fragmented. When deforestation and forest fragmentation occurs, elephants become separated from their herds and are more vulnerable to poachers due to lack of habitat cover.

Elephants have been known to damage the oil palm crops and eat the fruit bunches off of the trees. As a result, many plantation owners and employees install illegal snares (a trapping mechanism typically made of wire, usually with an attached noose) to trap elephants, as well as other small game animals. There has also been evidence in recent years of elephants being poisoned on or near oil palm dominated land across Southeast Asia. In Indonesia, four mass poisonings of elephant herds have been reported between 2002 and 2006; however, it is concluded literature suggests that other poisonings have eliminated entire herds at one time but have gone unnoticed. In 2015, 14 pygmy elephants in Borneo were poisoned over a four-week span all within government owned wood and oil palm plantations (Asian Elephant Support, n.d.). Comparatively, the capturing of elephants by government teams from nearby oil palm plantations has also caused a decline in population numbers. Uryu et al. (2008) reported there were at least 224 captures in Indonesia, and it is suspected that most of the elephants died during the capture or within holding facilities. These captures often claim the lives of young elephants, ultimately creating a threat to the future populations. Due to the sensitivity of these species, it can be assumed that many of these captures have gone undocumented.

The Sumatran tiger (*Panthera tigris sumatrae*) has also faced a similar fate to the Asian elephant species; it is the only living species of Indonesian tigers left, as the rest have gone extinct (Uryu et al. 2008). Tiger populations require a forest cover for a variety of reasons, including prey availability, protection from anthropogenic influence and habitat for propagation. Numerous studies have been conducted on the population of tigers in Riau, Sumatra and all have concluded the decline in population is a result of habitat loss from deforestation (Uryu et al. 2008; Wibisono and Pusparini 2010; Sunarto et al. 2013). Research conducted by Sunarto et al. (2013) found that tiger densities in Sumatra are roughly 50% lower than expected. Uryu et al. (2008) estimated, based on previous studies, that there was at least one tiger per 10,000 hectares
and the populations of tigers were declining faster than forests. In 1982, Riau had 6.4 Mha of suitable habitat for tigers, and it was estimated that there were 640 individuals living in the area (Uryu et al. 2008). In 2007, habitat availability declined so rapidly that tiger population numbers decreased 70% to 192 individuals and tigers were separated into nine isolated population patches (Uryu et al. 2008). The loss of habitat at this rate hindered the overall prey availability for tigers, also affecting population viability. Contrary to prior research, as of 2013, there was approximately <1 tiger per 10,000 hectares (Sunarto et al. 2013).

The fragmentation of forests has destroyed wildlife corridors and isolated viable habitat into small patches, some of which could not hold more than 50 individuals at a time, according to Uryu et al. (2008). For the survival of tiger species, conservation biologists have determined there needs to be a minimum of 100 individuals to create new subpopulations (Uryu et al. 2008). These corridors are essential for the movement of species within habitat patches in metapopulations. All species within Southeast Asia, especially Asian elephants and Sumatran tigers, have experienced isolation due to increasing deforestation rates. Isolation of individuals can lead to inbreeding within smaller populations and the degradation of existing population genetics. When there is a decline of diversity in the phenotypes of a particular gene pool, a reduction in the fitness of subsequent generations occur because of a lack of heterogeneity in the genetic matrix. Long-term viability of these species require the connectivity of functioning corridors so species are able to access habitat, food sources and breeding populations.

The critical status of these species, and others that have been affected by the oil palm industry, has brought attention to Southeast Asia. Many non-governmental organizations have begun campaigns to bring awareness to the issues, such as Asian Elephant Research and Conservation (AERC) and the Global Tiger Initiative. Researchers believe that there is hope for the array of threatened species in agriculture-dominated areas, as long as government-supported implementation plans are put into place. Sunarto et al. (2013) explains how controlling the illegal activity, i.e. illegal methods of deforestation and fire-related clearing, could facilitate the recovery of natural habitats, and thus the recovery of species populations. A successful habitat protection program will require the cooperation of stakeholders within the oil palm industry and forest reserve services.

Tropical forests are home to some of the highest levels of biodiversity, as well as providing many other ecosystem services, and the expansion of the oil palm industry has
significantly hindered these imperative ecosystems. It is evident from the literature analysis that the oil palm industry will continue to accelerate tropical deforestation and the destruction of natural habitats. The long-term effects of this destruction are not within just the forest structure, but also the degradation of species. The conservation of tropical forests is essential for the success of maintaining species diversity and preservation of those already in danger of extinction.

5.2 Research Limitations:

There are gaps in data pertaining to the relationships between carbon emissions, deforestation, and the effects on biodiversity and ecosystem services. Conclusions within data based on the literature evaluation have highlighted data gaps on carbon emissions from the oil palm industry practices within Indonesia and Malaysia. While the data is sufficient for a broad analysis overall, there are significant limitations. These limitations require assumptions on certain facets rather than solid conclusions. The following data gaps were found within the literature analysis:

- Discrepancy in government based analysis compared to academic literature in regards to deforestation rates and actual industry-related emissions
- Ambiguity in definitions of forests and the overlapping concessions in satellite imagery analysis
- Under-estimations of emissions due to methodologies used, such as closed chamber flux measurements
- The exclusion of aboveground biomass and carbon sequestration potential within literature

The data used in this analysis supports the conclusions and assumptions discussed below.

a. Government based analyses:

A significant limitation in further research of the effect the oil palm industry has on carbon emissions and the environment is the inconsistency amongst data between academic literature and government documentation. A study conducted by Gavaeu, et al. (2016) analyzed the expansion of the oil palm industry and the deforestation as a result between 1973 and 2015 in Borneo. Using satellite imagery, researchers concluded that the estimated total of forest area loss to plantation expansion was 18.7 Mha (Gavaeu et al. 2016). However, the actual estimate of how
extensive deforestation as a result of industrial plantations in Southeast Asia is ambiguous. Official government registered documents for the construction of plantations claimed that 1.6 Mha to 1.9 Mha of forest was cleared between 2000 and 2010 (Gavaeu et al. 2016). However, LANDSAT satellite imagery shows Indonesia lost approximately 14.7 Mha of forest between 2000 and 2010, and oil palm plantation monoculture contributed to 90% of that deforestation (Gavaeu et al. 2016; Abood et al. 2015).

The Land Development Minister of Sarawak, Malaysia and the Malaysian Palm Oil Council chief executive officer claimed that oil palm plantations do not cause deforestation, but instead make “reasonable use” of current deforested and degraded lands (Gavaeu et al. 2016). Santilli et al. (2005) estimated that annual deforestation in Indonesia from 1987 to 1997 was approximately 1.7 Mha, and increased to 2.1 Mha by 2003. However, data from the Food and Agriculture Organization (FAO) claimed that deforestation rates were only 1.7 Mha over a 15 year period, 1990 and 2005 (Gavaeu et al. 2016). Koh and Wilcove (2008) addressed that one of the shortcomings of their research was FAO reported data due to the lack of validation; they discuss how the self-reporting data puts actual deforestation rates at risk for bias rather than an accurate measurement.

Country-level estimates on carbon emissions that are reported by government agencies have been based on forest inventory data from the FAO. Gibbs et al. (2007) concluded these estimates to be inaccurate as they are subject to inadequate sampling procedures across a national scale and inconsistent monitoring methods; and as a result, national carbon emission estimates are relying on “best guesses” (Gibbs et al. 2007). The accurate measurement of deforestation is necessary to measure CO$_2$-eq emissions, and the lack of reliable data has caused a difficulty for researchers to quantify the extent to which oil palm monoculture has affected these parameters.

b. Definition ambiguity

Abood et al. (2015) addressed two major limitations in accurately understanding deforestation data as a result of large-scale industrial agriculture. First, the overlapping of data in different concessions causes ambiguity. For example, a majority of oil palm dominated forest has been categorized as mixed concessions (where other agricultural cultivation included in dataset). Mixed concessions cover approximately 2.2 Mha of land in Kalimantan, and the overlap of data may result in researchers under-reporting the extent of forest within oil palm concessions (Abood et al. 2015). Prior to 1984, satellite imagery was not as widely used to measure deforestation and
degradation; however, attempting to measure these parameters via satellites, such as LANDSAT, has also proven to be a difficult process and has aided in the overlap of data. Due to the spectral colors of logged forests resembling intact forests on satellite imagery after forest regrowth, it is assumed that recent studies have categorized logged forests as intact forest (Gaveau et al. 2016).

The second limitation is the definition of forests within literature. Abood et al. (2015) outlines how the definition of forest varies across data. Carlson et al. (2013) includes plantations and regrowth in the forest definition while Abood et al. (2015) analyzes forest and agro-forest separately. It is imperative to understand the definition within literature to accurately analyze the extent of deforestation and degradation from oil palm monoculture. For example, Gaveau et al. (2016) found in their literature analyses that forest was defined as old growth and logged forest in some articles, but the definition included agro-forest in others. In the study that defined forest as old growth and logged forest, the researchers estimated that 43% of oil palm plantations resulted in deforestation, while the other study that included agro-forest in their definition estimated 90% of plantations were established at the expense of forests (Gaveau et al. 2016).

Government based organizations also have a differentiating definition of forest in their published reports. The Food and Agriculture Organization defines forest as “naturally regenerated forests of native tree species, in which there are no clearly visible indications of human activity and ecological processes are not significantly disturbed” (Murdiyarso et al. 2011). It was found in a study by Murdiyarso et al. (2011) that this definition signifies old growth forests that have experienced little to no anthropogenic influences with high species richness.

This limitation also has affected the policy reform within progressive movements in Southeast Asia. In regards to the moratorium in Indonesia, there were mixed interpretations on the terminology used in the Letter of Intent and Inpres No. 10/2011. The moratorium applied to “primary natural forests” and peatlands; however the LoI called for the protection of “natural forests” (Murdiyarso et al. 2011; Austin et al. 2014; Kissinger 2016). The ambiguity on these definitions affected the scope of what was protected under the moratorium. As a result, the areas of forest protected were limited to those without any licensing application or logging roads. The new term, (primary natural forest), excludes disturbed and secondary forests. Any secondary, logged, or agro-forests within the moratorium boundaries will not be protected based on the definition of “primary natural forests.” Secondary forests contribute to more than half of
Indonesia’s forested areas (41.4 Mha), other disturbed forested areas contribute 5.3 Mha, and both hold higher carbon stocks than oil palm plantations (Murdiyarso et al. 2011). By not including these areas in the moratorium, Indonesia is at a loss of at least 46.7 Mha of carbon, and biodiversity rich forests (Murdiyarso et al. 2011). The differentiating definitions in these documents could lead to discrepancies within future government based climate change mitigation plans.

c. Emission ambiguity:

For the purpose of this literature analysis, emissions were distinguished between the deforestation of various forest types, the degradation of peatlands, and fire-related conversion. The emissions as a result of conversion via fire techniques were analyzed as a separate entity to highlight the distinct impact these fires have had on tropical ecosystems dominated by oil palm monoculture. Many authors generalize their analysis of carbon emissions and disregard the emissions from different forest ecosystems. As presented in the evidence, intact forests, logged forests, agro-forests and tropical peatlands emit different levels of CO$_2$-eq during deforestation and land conversion processes; by considering these various forest types as a single stratum it makes data analysis less transparent. Many publications have outlined their use of LANDSAT, synthetic aperture radar (SAR), or Palsar/Palsar-2 satellite programs in an attempt to gain the best estimate for emissions data, as these programs have been recognized to have more accurate sensors. However, as a result of these uncertainties, researchers and recent publications have relied on the data presented in long-term studies and literature surveys (Hamdan et al. 2016). Accurate, detailed data on these emissions have not been readily available.

There are numerous sources of error when analyzing CO$_2$-eq emissions, which has caused discrepancy in data amongst researchers, such as the underestimation or exclusion of emissions from the conversion and degradation of tropical peatlands for oil palm cultivation. One example of this ambiguity was discussed in Page et al. (2011); the researchers describe how emissions from oil palm plantations were calculated to be approximately one-quarter (18.4 Mt CO$_2$-eq/ha/year) of the value outlined by the IPCC in 2006; however, this approximation is expected to be underestimated because CO$_2$-eq emissions from the conversion and drainage of peatlands were not included based on the assumption that oil palm monoculture required less soil disturbance at the time the study was conducted (Page et al. 2011).
Many analyses use closed-chamber methods to measure CO₂-eq emissions from the degradation of tropical peatlands and agricultural cultivation, however there are limitations in the results based on the analytical methodology (Kutzbach et al. 2007; Fargione et al. 2008; Page et al. 2011; Koh et al. 2011). Closed-chamber methods analyze atmospheric concentrations within a free-flowing, non-steady state. The air sample is injected into a chamber and the CO₂-eq flux is estimated based on the change during circulation (Riederer et al. 2014). The rate of CO₂-eq accumulation or depletion is quantified based on a set time parameter. Closed-chamber methods are typically used due to their low cost and short-term analytical run time (Kutzbach et al. 2007; Page et al. 2011; Riederer et al. 2014); however, these could also be disadvantageous as they can result in errors. The short-term analysis minimizes the accuracy of emissions due to the changing CO₂-eq fluxes between the time period that is sampled as well as soil, vegetation and atmospheric composition (Kutzbach et al. 2007; Riederer et al. 2014). Due to the sensitivity of atmospheric conditions, closed-chamber fluxes vary on sampling time that the analysis is conducted. Researchers have found that fluxes are greater in the late afternoon during surface cooling or times of high wind velocity, while the evenings have higher variability but more stable data (Riederer et al. 2014).

Literature on the emissions of tropical peatlands as a result of the palm oil industry conversion process usually report either direct measurements of fluxes within closed-chamber analyses or an estimation of carbon loss. Studies that have based their results on just closed-chamber methods have been considered insufficient due to the constant change in flux values and the exclusion of CO₂-eq emissions strictly from tropical peatland degradation (Page et al. 2011; Riederer et al. 2014). The underestimation of emissions from tropical peatland conversion within previous assessments has consequences for future models of land use impacts from the oil palm industry and the policies that would be associated with decreasing these emissions (Kutzbach et al. 2007; Page et al. 2011). To improve these analyses, long-term studies (over a period of years) need to be conducted and the accurate measurement of peatland density and actual carbon concentration should be involved.

d. **Exclusion of aboveground biomass and carbon sequestration potential within literature:**

The impact on carbon stocks from land use change for oil palm monoculture has been disputed because the establishment of plantations removes the present aboveground carbon
stocks; however, plantations also promote the storage of carbon through crop cultivation. Carbon stocks in tropical ecosystems usually consist of the aboveground living biomass (AGB), belowground living biomass, detritus, and soil organic matter (Gibbs et al. 2007; Hamdan et al. 2016). There is a consensus across the literature that aboveground biomass is the largest carbon stock that is directly affected by deforestation and degradation. It is estimated that the transition from forest to oil palm cultivation results in a reduction of the carbon stock of the area converted by more than 50%, and AGB contributes to 89% of this carbon loss (Morel et al. 2011; Kusin et al. 2016). A recent study, conducted by Kusin et al. (2016), estimated through a soil carbon content analysis that carbon stocks in areas converted for oil palm monoculture and logged forests are approximately -99 t CO$_2$-eq/ha and 473 t CO$_2$-eq/ha respectively, resulting in a carbon debt within oil palm plantations. Intact forests are expected to have the highest levels of AGB, although logged forests have been found to have similar levels depending on when it was logged and the intensity of the degradation (Morel et al. 2011). The regrowth after forest degradation, specifically secondary forests, also contribute to carbon stock estimates, however, they are usually analyzed among other forest types.

The inclusions of diameter at breast height (DBH) and tree height estimations are also important measurements for AGB calculations (Gibbs 2007; Morel et al. 2011; Abram et al. 2016). Oil palm plantations, and other large-scale agriculture, remove the largest trees from the region (i.e. trees from the Dipterocarpaceae family). Morel et al. (2011) found that there is a positive correlation between height measurements and biomass estimations since the DBH can be used to explain 95% of variation in AGB and carbon stocks in tropical ecosystems. The researchers concluded that AGB equations that included DBH and overall tree height result in a more accurate analysis than those conducted without this variable.

Many carbon stock estimations are made based on previous academic studies or the generalization of data from country-level estimates such as the FAO (Gibbs et al. 2007). These estimations may cause gaps in data as different studies use different methods for estimating carbon stocks and levels of AGB, or rely on anecdotal data. However, studies found during the literature analysis that investigate these parameters use allometric functions to estimate aboveground biomass. Due to the protracted and costly nature of developing species-specific allometric relationships, as tropical ecosystems hold over 300 species of trees, using generalized
allometric functions by grouping forest types has been considered highly effective in estimating AGB (Gibbs 2007; Hamdan et al. 2011). As seen with measuring the extent of deforestation, challenges in mapping AGB and other carbon stocks are a result of the complexity of canopy structures causing uncertainties in satellite imagery (Morel et al. 2011; Gibbs et al. 2007; Hamdan et al. 2016). Although there is no exact methodology to measure carbon stocks on forests, the use of SAR and LiDAR assist researchers in better estimations for AGB, as they are more sensitive to complex forest structures especially when analyzing tropical peatlands (Gibbs et al. 2007; Morel et al. 2011; Hamdan et al. 2016). Many studies do not address these parameters when looking at the carbon emissions from the conversion and production processes of the oil palm industry due to their uncertainties; however, recent publications outline that these parameters are critical to consider, especially within tropical peatlands where soils are a massive carbon sink and source of emissions following deforestation (Gibbs 2007; Morel et al. 2011). The analysis of AGB and other carbon stocks would give future studies a more accurate representation of carbon emissions that result from the oil palm industry.

5.3 Efforts to reduce emissions:

Both Malaysia and Indonesia have committed to United Nations Framework Convention on Climate Change (UNFCCC) and programs within it, such as Reducing Emissions from Deforestation and Degradation, and Forest Conservation (REDD+). There is a wide range of intergovernmental cooperation with regards to mitigating greenhouse gas emissions and reducing deforestation that are outside the scope of this analysis. For the purpose of this paper, the REDD+ program and association with the UNFCCC were the main focus. The REDD+ program was adopted at the 13th Session of the Conference of Parties in 2007 (Murdiyarso et al. 2011). This program aims to mitigate increasing greenhouse gas emissions through reducing deforestation while providing incentives. Countries that display a reduction in emissions and the conversion of land are financially rewarded based on the extent of the remedial actions taken and the resulting reductions.

REDD+ is an extension of the originally proposed REDD program, and was finalized in 2010 at the Cancun Agreements (REDD Desk 2016). Initially REDD was focused on just reducing emissions from deforestation and degradation, however REDD+ incorporated the
conservation and enrichment of forest carbon stocks and the sustainable management of forests (Parker et al. 2009). The reason for expanding the original program to REDD+ was to provide benefits to countries that already exhibit low emission and deforestation rates and promote conservation within these areas (Campbell 2009). Originally, programs that put a hold on further deforestation were excluded from the first commitment period of the Kyoto Protocol because government representatives were concerned with the procedures to measure emissions and reduction, and the effect on national economies (Gibbs et al. 2007). However, within Malaysia and Indonesia specifically, the REDD+ program has the ability to supply incentives to government representatives, oil palm stakeholders and landowners that would promote the conservation of forests and the ecosystem services they provide (Abram et al. 2016).

There have been disputes as to whether or not the REDD+ program is feasible for the oil palm industry, based on the price of carbon credits compared to the profits made per ton of oil palm produced. Recent studies have concluded that REDD+ incentives are a feasible option for conservation, especially for tropical peatlands (Abood et al. 2015). Tsujino et al. (2016) found that the carbon-rich nature of peatlands outcompete current carbon credit prices and costs of industrial land use, therefore REDD+ would be a practicable program for countries with high CO2-eq emissions and significant amounts of peatland landscape. The implementation of this program could also assist local communities by enforcing land tenure rights to local landowners (Abram et al. 2016). On the other hand, there are challenges with the framework of REDD+. For example, the definition of policies and management are imperative for the successful implementation of this program as it includes stakeholders at national, sub-national, district, local, government and private levels (Abram et al. 2016). These parameters must be determined for the overall benefit of the countries involved. Overall, the REDD+ program has the potential to contribute significantly to the success of climate change mitigation through providing countries with a financially beneficial opportunity to reduce their greenhouse gas emissions while conserving the biodiversity of their nations.

a. Malaysia:

Malaysia became a ratified party of the UNFCCC in 1994 and then ratified the Kyoto Protocol in 2002 (UNFCCC Malaysia 2011). The Malaysian government has committed to reducing national carbon emissions levels by 45% by 2030, compared to 2005 levels (Abram et al. 2016; Gill et al. 2017). Although Malaysia has not committed to a moratorium to halt future
deforestation and land conversion for oil palm monoculture, the government has moved towards mitigating these issues in other ways. In Malaysia’s Second National Communication to the UNFCCC, the government agreed to practice Reduced Impact Logging and Sustainable Forest Management to decrease deforestation while maintaining 50% of land area as forest in an attempt to reduce carbon emissions (UNFCCC Malaysia 2011; REDD Desk 2016). It is estimated that a 1% and 5% reduction in the current deforestation rate can reduce approximately 3.34 Mt and 16.68 Mt of CO₂-eq annually until 2030 (UNFCCC Malaysia 2011).

The sequestration of forests in Malaysia also plays a role in these decreased emission rates as Malaysia has had a history of sequestration positively benefiting their overall emissions. Although carbon emissions were approximately 223 Mt CO₂-eq in 2000, sequestration removal was estimated to be 249.7 Mt of CO₂-eq, concluding that Malaysia was a net carbon sink during that time (UNFCCC Malaysia 2011); following that period, they transitioned into a net emitter. This change was a result of increases in emissions from the energy and agriculture sectors (UNFCCC Malaysia 2011).

The Malaysian government has made progress towards their goal through the implementation of the REDD+ program; however, the state of Sabah has had more success in developing REDD+ than the state of Sarawak. Sabah is a recipient of sub-national and state funded REDD+ projects (Abram et al. 2016). The Sabah Forestry Department has been working alongside World Wildlife Fund in carbon emission assessment methodologies as well as the appropriate legal and policy structure for financing the progression of REDD+ (REDD Desk 2016). Sabah has received support through other international organizations, such as the United Nations Development Programme and Forest Stewardship Council. Sabah has also received funding from the European Union on their ‘Tackling Climate Change through Sustainable Forest Management and Community Development’ program (REDD Desk 2016). Malaysia has faced many challenges in the progression of emission mitigation programs, such as gender discrimination when discussing native peoples rights to land, although they have worked towards alleviating this issues in their continuing program drafts. Malaysia’s third draft of the National Communications to the UNFCCC promotes gender equality for the adaption of climate change and mitigation (REDD Desk 2016). Through the resolution and enactment of mitigation programs, such as REDD+, and their commitment to decreased deforestation rates, Malaysia has the potential to make significant changes in their emissions prior to 2030.
b. Indonesia:

In Indonesia, the Yudhyono government developed national and provincial climate change mitigation plans to reduce carbon emissions beginning in the early 2000’s (Murdiyarso et al. 2011; UNFCCC Indonesia 2011; Michaelowa and Michaelowa 2015). These progressive movements within the Indonesian government led to long-term commitments to reduce emissions and deforestation across the country. During their initial agreement with the UNFCCC in 2009, Indonesia committed to reduce greenhouse gas emissions 26% by 2020, and up to 41% if other countries provided support (Murdiyarso et al. 2011; UNFCCC Indonesia 2011; Austin et al. 2014). This international assistance includes an official Letter of Intent (LoI) with the Kingdom of Norway, signed on May 26, 2010, and US $1 billion to Indonesia in support of their actions (Murdiyarso et al. 2011). In this LoI, Indonesia agreed to: the development of a national REDD+ strategy, the establishment of an agency to implement emission reduction strategies, develop policy enforcements - which included a two-year suspension of all new plantation development and the conversion of forests and tropical peatlands (Murdiyarso et al. 2011; UNFCCC 2011). In their agreement, the Indonesian government outlined that their goal would be achieved through:

• Sustainable tropical peatland management;
• A reduction in the rate of deforestation and land degradation;
• The development of carbon sequestration projects in forestry and agriculture;
• The promotion of energy efficiency;
• The development of alternative and renewable energy sources;
• A reduction in solid and liquid waste;
• Shifting to low-emission modes of transport.

President Yudhoyono also committed to making sure all actions taken would have proper monitoring systems and accurate reports that assisting countries would need to verify funding.

In May 2011, the Indonesian government released a document, known as Inpres No. 10/2011, which announced a forest moratorium that would be implemented to meet the requirements of the LoI (Murdiyarso et al. 2011; Austin et al. 2014). Inpres No. 10/2011 not only implemented a moratorium to reduce deforestation and degradation of forests and peatlands; it suspended new concession licenses for agriculture, including oil palm, and promoted the scientific analysis of the areas to allow the development of better management practices. Any
concession licenses, or land grants, that had been approved prior to the Inpres being formally announced are exempt from the moratorium.

The coverage of this moratorium has been questioned as different stakeholders had given different estimates when it was first announced. An advisor from the President’s council told the public that the land protected by the moratorium would be as much as 96 Mha, however, the Secretary-General of the Ministry of Forestry publically stated at a different time that only 72 Mha of land would be protected, 55 Mha of primary forest and 17 Mha of tropical peatlands (Murdiyarso et al. 2011). Later, a digital analysis constructed the Indicative Moratorium Map (IMM) and the actual coverage of the moratorium was approximately 46 Mha; however, recent analysis suggests that the extent of forests and peatlands protected by the moratorium is closer to 66 Mha (Murdiyarso et al. 2011). Currently, there are approximately 28.4 Mha of primary forest and 14.9 Mha of tropical peatlands within the IMM (Austin et al. 2014). Although there were discrepancies on the definition of forest between the LoI and Inpres No. 10/2011, the Inpres No. 10/2011 implied that the moratorium will cover all peatlands regardless of their type, depth, location, jurisdiction or level of disturbance within the IMM; previously regulations from the Ministry of Agriculture only protected tropical peatlands that were deeper than 3 m (Murdiyarso et al. 2011).

Peatlands in Southeast Asia are believed to be one of the largest storage locations of terrestrial carbon, with an estimated 42,000 Mt of carbon across 12% of the region (Tonks et al. 2017). The level of degradation as a result of oil palm industry expansion thus far has had long-term effects on tropical peatlands, such as the continuation of the emission of greenhouse gases after a halt on conversion processes. By allowing the moratorium to cover all peatlands within the IMM, the Indonesian government is making a progressive move to reduce emissions and prevent further environmental degradation, to the physical nature of peatlands and the carbon storage potential. The moratorium was renewed in 2013 and then again in 2015, concluding there are positive developments within the government towards the reduction of emissions and deforestation.

6. *Recommendations*
It is evident there is an increase in CO\textsubscript{2}-eq emissions as a result of the expanding oil palm industry in tropical regions, specifically Southeast Asia. Current environmental policies are progressing in terms of reducing these emissions and reducing the deforestation and degradation of forests and tropical peatlands. However, it can be concluded that due to the rising demand for oil palm there will be a continuing increase in emissions. Based upon the evidence from the literature analysis in Section 4, I recommend the following measures:

1. Discontinue oil palm expansion on unsuitable land
   a. Transition away from tropical peatlands
   b. Establishment of plantations on already deforested or degraded land
   c. Unsuitable lands could hinder overall oil palm profits

As discussed previously, the rapid expansion of the oil palm industry has resulted in cultivation on lands that are unsuitable for production, especially within floodplain regions and over tropical peatlands. By discontinuing this expansion on land that is unable to support oil palm monoculture, CO\textsubscript{2}-eq emissions and overall degradation of land could decrease. Tropical peatlands should be of major conservation concern since they can assist in the mitigation of oil palm related and atmospheric CO\textsubscript{2}-eq levels. As seen in the evidence, the conversion and cultivation of tropical peatlands contributes significantly to overall carbon emissions; therefore, land suitability is imperative to analyze for the future of oil palm plantations and the reduction of emissions. Recent studies suggest that if the conversion of peatlands to oil palm plantations seize, over a 100-year period, 4,600 Mt CO\textsubscript{2}-eq/ha could be avoided, based on moderate climate patterns (Warren et al. 2016). Comparatively, Reijnders and Huijbregts (2008) found that if oil palm plantations were to expand on non-peatland soils, emissions during production could result in a decrease of 1.6 - 7 tons of CO\textsubscript{2}-eq per ton of CPO produced, based on the size of the plantation and productivity rates.

The use of already degraded land, or previously abandoned plantations, could also aid in the reduction of emissions. It was concluded from the literature analysis that the conversion of former rubber plantations may prove beneficial to emission factors and increase carbon stocks by approximately 20%, compared to the carbon loss of 50% from the conversion of forest to oil palm monoculture (Kusin et al. 2016). By expanding plantations on already degraded land, intact
forests, logged forests, agro-forests and tropical peatlands have the ability to retain carbon storage and regain ecosystem services that may have been lost in previous conversion processes.

An analysis of land suitability could be beneficial for not only the ecosystem, but also the economy within Southeast Asia. For example, within Sabah, Malaysian Borneo, 54-68% of the 251,000 ha of land cultivated for oil palm is unsuitable for production, primarily due to flooding (Abram et al. 2014; Abram et al. 2016). Abram et al. (2014) estimated 66% of the remaining uncultivated land in the area is unsuitable for oil palm production based on CART analysis. However, more than 64% of those lands are already alienated for oil palm and 11% were in the process of conversion as of 2014 (Abram et al. 2014; Abram et al. 2016). The continuation of converting these lands could become more costly than profitable for the oil palm industry due to financial losses from underproduction and palm mortality. It is estimated that 51,466 ha of overall oil palm plantations are under-producing, and 15,810 hectares experience palm mortality annually (Abram et al. 2014). As a result of these losses, plantations experience up to $299 per hectare per year, totaling annual losses to be approximately $4.7 million (Abram et al. 2014; Vogel 2016). Rather than continuing cultivation on unsuitable soil every year, oil palm stakeholders should seize replanting within these areas and the financial losses could be used to integrate more sustainable production methods or restore unsuitable areas. It costs approximately $3,100 to restore one hectare of land through replanting and other regeneration methods (Vogel 2016). The financial losses in this area could restore approximately 1,351 hectares of land every year, which would assist in the country’s goal to combat the increase in carbon emissions (Vogel 2016).

2. Movement towards sustainable production
   a. Stricter regulations on fire-related conversion processes
   b. Certification process from RSPO

The production of oil palm has gone through scrutiny over the use of sustainable practices, leading to the development of the RSPO. The Roundtable of Sustainable Palm Oil is an association comprised of palm oil industry representatives, manufacturers, and other stakeholders to promote the sustainable production of oil palm. As of 2012, only 15% of oil palm plantations in Indonesia were RSPO certified (Greenpeace 2013). A movement towards becoming sustainably certified is recommended for the remaining oil palm industries within
Southeast Asia. This transition could assist with increasing production levels to meet the global demand of oil palm. As discussed in section 2.2, the high demand of oil palm will result in further expansion and establishment of the oil palm industry within Southeast Asia; therefore developing sustainable practices for the new plantations will prove beneficial to meet these demands. To successfully implement these strategies, stakeholders involved with the oil palm industry will need to collaborate and create new management strategies, and there will have to be cooperation among all parties involved.

While developing new management strategies, it is imperative that the oil palm industry takes conservation into account. The rate of deforestation and degradation within forests and tropical peatlands have had significant effects on the ecosystem services and biodiversity within the area and these factors need to be of more concern. By involving themselves with programs, such as REDD+ and the Indonesian moratorium, Southeast Asian countries will be able to combat some of the long-term effects, while progressively moving towards preventing future damage. Within the certification process, the RSPO has criteria that plantations must meet that would benefit future conservation efforts of biodiversity and ecosystem services; for example, the negative impacts on from the plantation in question to the surrounding environment, such as habitat and species richness, are assessed. I recommend that all future oil palm plantations, and those in the process of establishment, undergo an environmental assessment and sustainability certification process.

I also recommend discontinuing all fire-related conversion techniques. Land clearing by fire puts the area at risk for wildfires and severe degradation, seen in the tropical peatland degradation that results and Indonesia’s fire crisis discussed in section 2.6. By discontinuing fire-related clearing, there is a greater probability that the natural resources and biodiversity can regenerate while mitigating the increasing carbon emissions. For example, eliminating the use of fires could reduce emissions by 52% over a 100-year period, equivalent to 2,000 Mt CO₂-eq per hectare (Warren et al. 2016). Also, since fire-related clearing increases the risk of wildfires, especially from the conversion of tropical peatland soils, a transition to more sustainable conversion processes will decrease this risk. Comparatively, this decrease in the wildfire risk is beneficial for the neighboring communities whose homes and land have been affected by the wildfires in recent years. The RSPO bans the use of fire for land clearing, so affiliating oil palm
plantations with the sustainability certification process will improve future land clearing by promoting less damaging conversion tactics.

3. For already established plantations, a conversion from wet to dry extraction processes
   a. A conversion of processes could increase oil extraction rates (OER)
   b. Overall decrease in CO₂-eq emissions

   As discussed in section 4.2, the transition from wet to dry extraction could prove beneficial for high CO₂-eq emitting oil palm plantations. Due to the emission factors involved in wet processes, such as wastewater treatment, emissions are higher and oil extraction rates are lower than the dry process. Refer to section 4.2 for the statistics as to why I made this recommendation. The literature does not define the financial cost for oil palm plantations to move towards dry extraction. Therefore, further economic feasibility studies should be conducted to determine the possibility for oil palm plantations to make this transition.

   Comparatively, dry extraction can assist in increasing oil palm production through higher oil extraction rates. Since dry processes have a more efficient OER (by 3.3 - 8.3% respectively), it can be concluded that oil palm plantations that undergo conversion will increase production and generate more revenue than those with lower efficiency production rates from lower extraction. As I outlined in section 2.3 and 5.2, the oil palm industry has a strong correlation to government representatives. This increase in production and revenue could prove beneficial for not only oil palm stakeholders, but also the national economy through increased exports. If this recommendation is implemented, it can be assumed that the decrease in emissions would assist in climate change mitigation programs within oil palm dominated landscapes, such as REDD+, and contribute to national goals of reducing overall emission levels.

7. Conclusions

   The oil palm industry has been growing at alarming rates within tropical regions globally, but especially in Malaysia and Indonesia. During this expansion, plantations have been established at the expense of intact forests, logged forests, agro-forests and tropical peatlands. The rising deforestation and degradation rates that have resulted from this expansion have significantly hindered these valuable and essential ecosystems and their services. Comparatively to deforestation and tropical peatland degradation, fire-related conversion has also had increasing
negative effects on tropical ecosystems. Burning large scales of land as a quick solution for clearing areas for oil palm cultivation has proved to be extremely harmful with little or no benefit, as it emits at least twice the amount of CO$_2$-eq than natural draining or clearing and increases the risk of wildfires. Additionally, this practice alters soil hydrology, nutrient loading, and overall quality to the detriment of entire regions that were previously pristine tropical rainforests. This method increases exposes large swaths of unprotected soil, increasing erosion rates and exasperating the problem of nutrient loading in already low-nutrient soils. Using these “slash and burn” clearing methods ultimately makes recovery and restoration efforts extremely expensive and difficult, given the degradation of the soils throughout the study area.

In addition, the rising carbon emissions because of the conversion and production of land for oil palm monoculture have contributed an increase to overall global climate emissions. However, these carbon emissions not only affect atmospheric carbon levels, but also the biodiversity of the region. Flora and fauna across Southeast Asia face challenges from the increase in CO$_2$-eq because of saturation of this gas that can overwhelm plant respiratory metabolic processes. The increased atmospheric CO$_2$ levels that lead to warming also affect plant communities due to the interference with temperature dependent lifecycles, or other phenological considerations. Many government and non-profit organizations have worked progressively towards mitigating these emissions, providing incentives for oil palm stakeholders; however, there is still much to be accomplished by way of implementation of these programs, or enforcement of rules (and subsequent sanctions for violations). By continuing with these programs, and providing economic incentives, the oil palm industry across Southeast Asia has the potential to assist their national governments in reaching their carbon emission goals, discussed in section 5.3.

It can be concluded that further studies must be conducted to provide accurate data on parameters of deforestation, increased CO$_2$ effects, and the feasibility of oil palm restoration in highly altered areas. As discussed in section 5, there are various data gaps that cause ambiguity within this area of research, largely due to governmental malfeasance. Further investigations into tropical peatlands, specifically their soils, and fire related conversion processes, as separate entities would provide scientists and oil palm stakeholders with clear data to use in developing carbon emission mitigation strategies. In addition, the inclusion of aboveground biomass and carbon stocks within study regions would be beneficial for future studies.
Although it is questionable whether the current damage can be remediated, there is hope within the scientific community that these tropical regions have not passed a critical “point of no return” where total ecosystem collapse is inevitable, and ecosystem services, species richness, and biodiversity are irreversibly altered. By reducing deforestation and ecosystem degradation within tropical ecosystems, putting an end to fire-related clearing techniques, and discontinuing building oil palm plantations on unsuitable lands, oil palm industry stakeholders are giving the region an opportunity to naturally regenerate. This demonstrates to stakeholders, and ultimately end use consumers, that this industry can be responsible environmental stewards. Tropical ecosystems hold the highest levels of biodiversity and ecosystem services globally while serving as a natural climate regulator, and therefore it should be of upmost concern to protect them.
References:


