BIODIVERSITY LOSS ASSOCIATED WITH OIL PALM PLANTATIONS IN MALAYSIA: SERVING THE NEED VERSUS SAVING THE NATURE

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Abstract — Oil palm is considered as one of the most important crops for the future in serving the global food and biodiesel needs. Oil palm also serves as the important source for rural employment and plays a major role in poverty alleviation in Malaysia. The increasing need for palm oil has resulted in the rapid expansion of oil palm plantations in the last few decades, which has become the biggest cause for deforestation in Malaysia. The google deforestation map for the year 2000-2012 shows that Malaysia has the highest deforestation rate of all the countries in the world. Malaysian forests are the home for numerous endemic species, which are threatened. Some oil palm promoting corporations have claimed that oil palm plantations support a healthy biodiversity. This research assessed the biodiversity value of oil palm in comparison with primary forests and secondary forests. The biodiversity value of secondary forests are overly underestimated and are readily converted into plantations. Using species richness data of vertebrates and invertebrates from previous publications, this research argues that conversion of either primary or secondary forest to oil palm plantation would adversely affect biodiversity. The oil palm plantations are filled with non-native invasive species or generalist species of low conservation interest. The review results compiling numerous species richness surveys in Malaysia show that there is a 34.9% reduction in species richness in oil palm compared to forest habitats, and 79.6% of the species found in forest habitats were not found in oil palm habitats. The primary causes for the reduction of species richness is found to be poor ground vegetation, lack of structural complexity and poor microclimate in oil palm plantations. In order to sustain the biodiversity in Malaysia, it is recommended that future expansion of plantations in primary or secondary forests should be strictly prohibited. It is also recommended that the oil palm management regime should focus on improving the structural complexity and ground vegetation of oil palm plantations.

Keywords — Palm oil plantation, species richness, primary forest, secondary forest, Malaysia, biodiversity loss, biodiesel.

Word count — 9,454
INTRODUCTION

The expansion of agricultural land area is the single biggest threat to world’s remaining biodiversity (Fitzherbert et al., 2008; Green et al., 2005; Donald, 2004; Bateman et al., 2010), especially in tropical countries (Indrarto et al., 2012; Danielsen et al., 2009; Koh and Wilcove, 2008; Edwards et al., 2013). The agricultural expansion in tropics is fuelled by the increased need for renewable energy and sustainable global food supply since the escalating price of non-renewable energy source and increasing global population respectively (Tan et al., 2009; Danielsen et al., 2009). Palm oil is considered as a crop that can serve both these needs (Tan et al., 2009; Corley, 2009; Bruhl and Eltz, 2010; Lam et al., 2008). Other than that palm oil production and export plays a significant role in poverty alleviation and rural development in the tropics (Corley, 2009). But still Palm oil expansion remains as the greatest cause for deforestation in Southeast Asia (Indrarto et al., 2012).

Global need for palm oil

Oils and fats play an essential role in the human diet (Lam et al., 2009). World Health Organization (WHO) suggests that for a healthy human, 30% of energy should be obtained from oils and fats. Palm oil is considered as a replacement for trans fatty acids in many food products, and it is used as marketing strategy for many processed and packed food products to have 0% trans fats on the label. The palm oil contains high amount of saturated fatty acids, which are equally detrimental to replace trans fatty acids. The high amount of saturated fats in palm oil changes the microbiota in the gut and shifts lipopolysaccharides from gut to blood leading to obesity, heart disorders, insulin resistance and many other disorders. Palm oil in fresh form is found to be healthy by numerous researches, while the processed, oxidized form is considered to be very detrimental (Ebong et al., 1999). Ong et al. (2002) and Gutherie et al. (1997) consider palm oil as one of the healthiest oils with beneficial health properties such as antioxidant, anticancer and cholesterol-lowering effects. The countries like Malaysia, Indonesia, Papua New Guinea and Nigeria, which use palm oil as their staple oil were found to have relatively lower rate of diabetes, heart disease and cancer (Lam et al., 2009). However, the oxidized palm oil, which is a common constituent in processed and packed food in western markets are found to have adverse effects on human health. Research by Laugerette et al.

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1 Accessed from http://www.mpoc.org.my/ on 25.05.2014


(2012) on four different kinds of fats including milk fat, rapeseed oil, sunflower oil and palm oil, found that palm oil has the most active transfer of lipopolysaccharides, resulting in the greatest inflammatory outcome of all the different fat sources researched. Though there is a mixed view on the nutritional value of palm oil, the global demand for biodiesel, the interchangeability of palm oil with other vegetable oils, relatively lower cost of production and higher productivity make palm oil important oil for the future in catering the food and oil needs of growing world population.

Figure 1. Yield of selected vegetable oils (oil per hectare per year during the production years). Source: Tan et al., 2009.

Fossil fuels have been the main source of power supply for the world (Tan et al., 2009). However, the resource for non-renewable energy is depleting, making the world turn to alternative energy source for development (Tan et al., 2009). As the resources get fewer, the prices of non-renewable energy have increased over the years, which have hastened the search for alternative energy. Biodiesel is one of the most widely researched alternative energy source (Tan et al., 2009). Currently, most of the biodiesel production comes from rapeseed oil (Tan et al., 2009). However, palm oil remains as a very attractive candidate for biodiesel because of its high productivity (see Figure 1) and lower costs (see Figure 2) compared to other vegetable oils. If the goals set by European Union on promoting biodiesel production are to be met, biofuel demand is expected to exceed edible use of vegetable oils in the future (Corley, 2009; Fitzherbert et al., 2008). The increased demand would increase prices of vegetable oils (Fitzherbert et al., 2008). Given the interchangeability of most vegetable oils for biodiesel production and edible use, the increased price for vegetable oils would lead to further expansion of palm oil agriculture (Corley, 2009). Apart from this, palm oil is used in the production of
other products ranging from cosmetics to engine lubricants\(^4\). These vast applications of palm oil made it an important agriculture crop in the tropics (Tan et al., 2009).

![Price projections of selected vegetable oils (US Dollars per ton)](image)

**Figure 2.** Price projections of selected vegetable oil (US Dollars per ton).

Source: FAPRI (Food and Agriculture Policy Research Institute)

Although palm oil has got the potential to become the leading vegetable oil in terms of food, biodiesel and other products (Tan et al., 2009), there are lots of other issues surrounding palm oil production. The expansion of palm oil plantations is primarily based on the tropical forests. Tropical forests are considered as the most productive forests in the world\(^3\) (Montagnini and Jordan, 2005). The tropical forests are found only in three regions of the world- tropical South America, Central Africa and Southeast Asia\(^3\) (See Figure 3). The major issues related to palm oil expansion are deforestation, species extinction, peat land degradation and forest fires (Tan et al., 2009). This study focuses on the biodiversity loss associated with Palm oil plantations in Malaysia. Malaysia is a developing country which depends on palm oil products for the economic development (See Table 1 and 2) (Rashid et al., 2013). Basiron and Weng (2004) suggest that oil palm can be used as a vehicle for rural poverty eradication in Malaysia. The palm oil also plays a major role in tackling rural unemployment problems. In 2010, there were more than 6 million people employed in the Malaysian palm oil industries\(^5\).

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Figure 3. Tropical areas suitable for palm oil plantation.

Table 1. Palm oil as a source of higher income levels and poverty eradication. Source: Palmoilworld.org

FELDA: Federal Land Development Authority
RM: Malaysian Ringgit

<table>
<thead>
<tr>
<th>Year</th>
<th>FELDA settler</th>
<th>Independent small holder</th>
<th>National poverty line</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>RM 1,338</td>
<td>RM 476</td>
<td>RM 526</td>
</tr>
<tr>
<td>2007</td>
<td>RM 2,221</td>
<td>RM 1,209</td>
<td>RM 740</td>
</tr>
<tr>
<td>2008</td>
<td>RM 3,278</td>
<td>RM 1,094</td>
<td>RM 691</td>
</tr>
<tr>
<td>2009</td>
<td>RM 2,457</td>
<td>RM 944</td>
<td>RM 666</td>
</tr>
<tr>
<td>2010</td>
<td>RM 3,000</td>
<td>RM 1,259</td>
<td>RM 720</td>
</tr>
</tbody>
</table>
Table 2. The significance of palm oil industry in Malaysia’s export earnings. Source: Palmoilworld.org

<table>
<thead>
<tr>
<th>Year</th>
<th>Palm oil export value (RM billion)</th>
<th>Export value of all commodities (RM billion)</th>
<th>Percentage of palm contribution in the overall export value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>2.89</td>
<td>48.80</td>
<td>6.1%</td>
</tr>
<tr>
<td>1990</td>
<td>5.50</td>
<td>20.70</td>
<td>26.6%</td>
</tr>
<tr>
<td>2000</td>
<td>14.94</td>
<td>42.72</td>
<td>35.0%</td>
</tr>
<tr>
<td>2007</td>
<td>44.71</td>
<td>88.70</td>
<td>50.4%</td>
</tr>
<tr>
<td>2008</td>
<td>65.22</td>
<td>112.43</td>
<td>58.0%</td>
</tr>
<tr>
<td>2009</td>
<td>49.59</td>
<td>91.2</td>
<td>54.0%</td>
</tr>
<tr>
<td>2010</td>
<td>59.79</td>
<td>113.3</td>
<td>52.8%</td>
</tr>
<tr>
<td>2011</td>
<td>80.30</td>
<td>130.0</td>
<td>61.8%</td>
</tr>
</tbody>
</table>

The importance of Malaysian forest

The Southeast Asian rainforests are considered the oldest, consistent rainforest on the earth. The rainforests in Malaysia and Indonesia dates back to the Pleistocene epoch, 70 million years ago. Once forests covered the total land area of Malaysia, still forest covers 59.5% (See Table 3) of Malaysia Land area (Rashid et al., 2013; WWF, 2014). These forests are rich in biodiversity with many distinct endemic species (Sunderlin et al., 2000) and are among the most bio diverse and threatened forests in the world (Bateman et al., 2010). The forest lands in Malaysia are diverse with different variety of kerangas (Sundaland heath), lowland, montane, swamp, riverine and mangrove forests (Rashid et al., 2014). Malaysia is one of the 12 mega biodiversity countries of the world (Basiron and Weng, 2004). The rainforests in Malaysia are rich in biodiversity and carbon storage (Dinerstein and Wikramanayake, 1993; Fargione et al., 2008). So, the destruction of these forests would affect global climate change and habitats of many endemic species.

Table 3. Land and forest areas in Malaysia (Million hectare). Source: Palmoilworld.org

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Palm oil and deforestation in Malaysia

The oil palm (Elaeis guineensis) is native to West Africa (Danielsen et al., 2009; Tan et al., 2009). It was first introduced to Malaysia as an Ornamental plant (Abdullah et al., 2009). The first industrial plantation in Malaysia was established on 1917 by Henry Fauconnier at Selangor (Abdullah et al., 2009). Malaysia was once known for the high production of cocoa, rubber and coconuts (Basiron, 2007). Due to the fall in price of rubber in 1960s, plantation industrialists and agriculturists preferred oil palm plantations over the other crops, which lead to the rapid expansion of palm oil plantations in the last few decades, replacing other commercial crops (see Figure 4) (Basiron, 2007). Now, Malaysia and Indonesia together accounts for more than 80% of global palm oil production (Bateman et al., 2010). In 1985, 1.5 million hectares in Malaysia were planted with palm tree, and it has increased to 4.3 million hectares in 2007 (Rashid et al., 2013). In 2011, the total planted area in Malaysia was 4.917 million hectares and it reached 5.230 million hectares in 2013 (Rashid et al., 2013). These figures show the success of palm oil industry and the contribution of palm oil as a world food source. As the definition of forest differs with different institutions, it is not clear whether secondary forest area is included in the data. However, the study by Sodhi et al. (2010) shows that large areas of secondary forests were converted to palm oil plantations. Many other studies have shown that secondary forests are overly under estimated of their biodiversity value (Cusack, 2011) and are readily converted into palm oil plantations (Fitzherbert et al., 2008). Though a part of the expansion occurred in the previous plantations of other crops (See Figure 4), the reports by United Nations Food and Agriculture Organisation suggests that during the period of 1990-2005, at least 55% - 59% of oil palm expansion was in the expense of forest (Koh and Wilcove, 2008). The rate of deforestation in Southeast Asian tropical forests is comparatively higher than tropical deforestation rate in any other region (Achard et al., 2002). Google forest map reveals that (see Figure 5 & 6), Malaysia has the highest deforestation rate of all the

<table>
<thead>
<tr>
<th>Region</th>
<th>Land area (Million Hectares)</th>
<th>Natural Forest(Million Hectares)</th>
<th>Plantation forest (Million Hectares)</th>
<th>Total forested land (Million Hectares)</th>
<th>% Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dry inland</td>
<td>Swamp forest</td>
<td>Mangrove forest</td>
<td></td>
</tr>
<tr>
<td>Peninsular Malaysia</td>
<td>13.16</td>
<td>5.40</td>
<td>0.30</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Sabah</td>
<td>7.37</td>
<td>3.83</td>
<td>0.12</td>
<td>0.34</td>
<td>0.11</td>
</tr>
<tr>
<td>Sarawak</td>
<td>12.30</td>
<td>7.92</td>
<td>1.12</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>32.83</td>
<td>17.15</td>
<td>1.54</td>
<td>0.58</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Palm oil and deforestation in Malaysia

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countries in the world\textsuperscript{7}. With high deforestation rate, it is not surprising to see the results of Sodhi et al. (2010) stating that Southeast Asia has the highest mean proportion of endemic plants, reptiles, birds and mammals species that are threatened, compared to the forests in the rest of the world. Southeast Asian forest also ranks second in the mean proportion of threatened endemic amphibians in the world, next only to Meso-America.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Change in the plantation area of selected crops in Malaysia. Source: MPOB (Malaysian Palm Oil Board) and MRB (Malaysian Rubber Board)}
\end{figure}

\textsuperscript{7} Butler, A (2013) Malaysia has the world’s highest deforestation rate, reveals google forest map. Accessed from \url{http://news.mongabay.com/2013/1115-worlds-highest-deforestation-rate.html} on 25.05.2014
Figure 5. Deforestation map of Sabah and Sarawak (2000-2012), Malaysia. Source: Mongabay.com

Figure 6. Deforestation map of peninsular Malaysia (2000-2012). Source: Mongabay.com
Need for sustainable palm oil

The high yield and low cost of palm oil compared to other vegetable oils (See Figures 1 & 2) made it the most suitable candidate for biodiesel production (Tan et al., 2007). Given, the global demand for palm oil and powerful economic and social forces involved in palm oil expansion (Koh and Wilcove, 2008), the palm oil plantations are likely to increase in Southeast Asia. As the Southeast Asian countries depend on palm oil plantations for the economic development, it gets more complicated. The plantations also play a major role in rural poverty alleviation in Malaysia by providing employment to rural people (see Table 4). Hence, there is a need for sustainable production of palm oil, catering the global needs and local development, without affecting the environment and the biodiversity of rainforests.

Table 4. Palm oil plantations in Malaysia as a source of employment. Source: Palmoilworld.org

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (ha)</th>
<th>People employed (Person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1,203,306</td>
<td>92,352</td>
</tr>
<tr>
<td>1990</td>
<td>2,029,464</td>
<td>115,285</td>
</tr>
<tr>
<td>2000</td>
<td>3,376,664</td>
<td>251,039</td>
</tr>
<tr>
<td>2007</td>
<td>4,304,913</td>
<td>426,000</td>
</tr>
<tr>
<td>2008</td>
<td>4,487,957</td>
<td>438,000</td>
</tr>
<tr>
<td>2009</td>
<td>4,691,160</td>
<td>451,000</td>
</tr>
<tr>
<td>2010</td>
<td>4,853,766</td>
<td>603,786</td>
</tr>
</tbody>
</table>

The organisations like Malaysian Palm Oil Board (MPOB), Malaysian Palm Oil Council (MPOC) and the Roundtable on Sustainable Palm Oil (RSPO) works on the sustainable management of palm oil production in Malaysia. MPOB is a government agency established in the year 2000, by merging the functions of Palm Oil Research Institute of Malaysia (PORM) and the Palm Oil Registration and Licensing Authority (PORLA), to serve palm oil industry in Malaysia. Both the merged organizations were involved in the palm oil industry for more than 20 years (MPOB, 2014). The primary objective of MPOC and MPOB is to increase the market and production for Malaysian palm oil industry by enhancing the image of Malaysian Palm oil through environmentally sustainable production. These organisations are criticized as industry-advocacy groups (Laurence et al., 2010), for promoting expansion of oil palm plantations. The RSPO is a non-profit organisation
established in 2004 to promote the growth and the use of sustainable palm oil through co-operation within the supply chain and stake holders (Tan et al., 2009). RSPO tries to remain distinct from other palm oil promoting institutes by having 4 of the 16 executive members from conservation or social-development organisations (Laurance et al., 2010). RSPO defines sustainable palm oil production as a legal, economically viable, environmentally appropriate and socially beneficial management and operations (RSPO P&C, 2013). According to RSPO (2014), countries like Germany, United Kingdom, Belgium, France and Netherlands use 100% certified palm oil and the nations like U.S.A., India, China, Italy and Australia are showing positive momentum towards the sustainable palm oil8. The environmental organisations like Greenpeace (2008) criticize certified palm oil as the terms of laundering illegal palm oil through RSPO (Maitar, 2009). Greenpeace (2008) also notes that RSPO-certified palm oil was rarely segregated from conventional palm oil9. Worse, RSPO members have been caught buying palm fruit from developers who have illegally cleared rainforests for plantations4. Even if RSPO certification is followed, the environmental sustainability of palm oil remains doubtful in Malaysia (Koh and Wilcove, 2010), as government itself acts as potential producer, regulator and enforcer, creating potential conflicts of interest (Lopez and Laan, 2008).

Objectives

Given the global need for palm oil and the dependence of Malaysian economy on palm oil industries, the plantation area is expected to increase in Malaysia, which would lead to further deforestation. Deforestation eventually results in habitat depletion and biodiversity loss. The secondary forests in Southeast Asia were not given enough protection against the conversion to oil palm plantations (Fitzherbert et al., 2008; Sodhi et al., 2010). This study is conducted to find the effects of conversion of both primary and secondary forests to palm oil plantations on different species in Malaysia. The research focuses on answering the following three questions,

1. Do Malaysian palm oil plantations support as much biodiversity as forest habitats?
2. What are the observed causes for the reduction of species richness in oil palm habitats in Malaysia?
3. Are the Malaysian secondary forests significant for the conservation of forest species?

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4. Are the results of the present review on biodiversity of palm plantations in Malaysia including new recent studies in agreement with the results of previous reviews on oil palm biodiversity?

**METHODS**

To address these questions, the results from previous studies were compiled. The literature search was conducted between April and August 2014 for biodiversity data from forests and plantations in Malaysia. The land use change data was also collected to check the effect of palm oil expansion on primary forest cover. The search included internet search engines, academic literature and data from specialist organizations. The previously published reviews were used for additional data. The bibliographies of past reviews and publications were also checked for references. The full list of search sources used is given below.

**Internet search engines**
- Google: www.google.co.uk
- Google scholar: www.scholar.google.co.uk
- Yahoo: www.uk.yahoo.com
- Bing: www.bing.com

**Literature databases**
- Wiley online library
- Springer
- Cambridge university press
- ScienceDirect journals and books
- Lancaster University library Onesearch
- Environmental evidence journals

**Specialist organizations**
- Stability of Altered Forest Ecosystems (SAFE)
- Center for International Forestry Research (CIFOR)
- Food and Agriculture Organization of the United Nations (FAO)
- Malaysian Palm Oil Board (MPOB)
- Malaysian Palm Oil Council (MPOC)
- Roundtable on Sustainable Palm Oil (RSPO)
- Food and Agriculture Policy Research Institute (FAPRI)
- Malaysian Rubber Board (MRB)
- Forest Research Institute Malaysia (FRIM)
- Forest department of Peninsular Malaysia
- Sabah forestry department
- Forest department of Sarawak

**Study selection**

*Species richness*

The literature search on species richness returned several thousand results. Then the search was narrowed down to species richness in particular location – Malaysia. The literature containing species richness data for Palm oil plantations, primary forests or secondary forests in Malaysia were used. Where possible, the number of species present in both the forest and palm plantations, i.e., shared species also collected. The quantitative studies were given primary importance while qualitative and descriptive studies and reports were also included for the research.

*Land use change*

The palm plantation area data were got from Malaysian Palm Oil Board. The other data related to Malaysian palm oil industry were collected from Malaysian Palm Oil Council (MPOC) annual reports. The data for Malaysian forest cover were collected from Forestry department of Malaysia, Food and Agriculture organization of United Nations (FAO) and other sources.

**Comparing faunal biodiversity**

The species richness of vertebrates and invertebrates were compared among oil palm plantations, primary forests and secondary forests. The species richness data from palm oil plantations and secondary forests were standardized to the species richness value of primary forest.

Some studies needed special treatment to be included. The study conducted by Pfeiffer et al. (2008) on arboreal ants on oil palm plantations did not have data on primary forest. So it was standardized against the primary forest data on arboreal ants obtained by Bruhl et al. (1998). The standardized species richness of different animal species in palm oil plantations and secondary forests were compared to the primary
forest species richness. The species richness of Palm oil plantation was also compared with the secondary forest species richness. While comparing species richness of palm oil plantation and secondary forests, the species richness of oil palm was standardized to the species richness of secondary forest.

The review results for species richness between palm oil plantations and primary forest in Malaysia was compared with the previous reviews published by Danielsen et al. (2009) and Savilaakso et al. (2014) including palm plantations from different countries. To have a standardized comparison, a simple method following Savilaakso et al. (2014) was used to calculate the mean change in the number of species present in oil palm compared to the number of species in primary forest and also shared species between oil palm and forest habitats, standardized by the total number of species present in the primary forest.

RESULTS

Study selection

There were 40 studies found from 28 different publications containing species richness data for primary forests and oil palm plantations. 29 studies provided data on shared species. There were 11 studies comparing the species richness of secondary forest and primary forest. Eight studies were found, which have species richness for both oil palm plantations and secondary forest. All the studies conducted by Stability of Altered Forest Ecosystems (SAFE) contained data from different disturbance gradients including primary forest, secondary or logged forest and palm oil plantations.

![Figure 7. Number of articles published in different years comparing species richness of forest and oil palm habitats in Malaysia included in the review (including Juliani et al., 2012)](image-url)
The search could not find any quantitative studies before 1997. The numbers of studies were increasing in the later years (see Figure 7), with the establishment of many specialist organizations to research on agricultural systems in Southeast Asia such as Stability of Altered Forest Ecosystems (SAFE), Center for International Forestry Research (CIFOR) and Crops for the Future Research Centre (CFFRC). The publications are expected to increase in the coming years as there are many ongoing quantitative biodiversity surveys conducted by these specialist organizations. This increased number of researches shows the increasing global awareness about rapid expansion of oil palm plantation and deforestation in Southeast Asia.

![Bar chart showing taxonomic groups studied till date](image1.png)

**Figure 8.** Taxonomic groups studied in the 40 studies from 29 publications (including Juliani et al., 2012) on biodiversity included in the review, comparing forest and oil palm habitat.

Figure 8 shows different taxonomic group studied till date. Most studies were conducted on invertebrates, especially ants. This might be due to relatively easier survey techniques. Very few studies covered vertebrates like Birds, Bats, Amphibians and small mammals. There were no studies found on large forest mammals like Orang-utans and Tigers.

**Species richness**

*Palm oil versus primary forest*

The results from the species richness and community similarity studies included in the review clearly illustrate the lower species richness in oil palm habitats compared to the forest habitats. Though few studies showed higher species richness in palm oil habitats (Cusack, 2011; Faruk et al., 2013; Chey, 2006; Liow et al., 2001;
Hashim et al., 2010; Bruhl, 2001), many of the species present in palm oil were non-forest generalist species of low conservation interest (Bruhl and Eltz, 2010). It is evident from the fact that all the studies in the review which depicted higher species richness in oil palm, also showed lower proportion of species shared with the forest (see Figure 9). Some studies show that there is no shared species between forest and oil palm habitats (Hassall et al., 2006; Bernard et al., 2009). This depicts the complete extinction of forest species in oil palm habitats. Only one study conducted by Chang et al. (1997) on mosquitoes showed the presence of all forest species with lower abundances in palm oil plantations, but more recent study on mosquitoes by Brant (2011) showed lesser mosquito species richness in oil palm habitats with only one species shared with the forest habitats. Overall, there is a high reduction of forest species richness in oil palm plantations.
Primary forest versus secondary forest

The results show the persistence of many species in secondary forests, even after numerous disturbances. The secondary forests are found to support almost as much vertebrate species as primary forests (see Figure 10). Cusack (2011) found more small mammals species in secondary forest than in the primary forest. Edwards et al. (2013) recorded all the bird species in secondary forests, which were found in primary forest. Styring and Hussain (2004) recorded 24 bat species in primary forest and found 18 of them in secondary forests fragmented by oil palm plantations. The results of species richness of invertebrate species were varied with different studies. The study by Bishop (2012) on ants showed higher species richness in secondary forests and the study by Woodcock et al. (2011) showed same number of ant species in both primary and secondary forests, while Floren (2005) found very less proportion of ant species in secondary forests compared to the primary forests. The survey conducted by March (2013) on termites found very less number of termite species in secondary forests, compared to the primary forests.

Figure 9. Comparison of species richness and forest species richness in oil palm plantation relative to primary forests.

Figure 10. Comparison of species richness in secondary forest relative to primary forest.
**Palm oil versus secondary forest**

The comparison of species richness values between oil palm plantations and secondary forest showed less proportion of species in oil palm in almost all the surveys. The study by Brant (2011) on mosquitoes is the only survey which found more number of species in oil palm than in secondary forest. However, the number of mosquito species in oil palm habitat was much lesser than the number of mosquito species in primary forest and most of the species recorded in oil palm were not found in forest habitats (See Figure 9). The survey by Juliani et al. (2012) found 7 species of bats in oil palm plantations, among which 4 species were new, which were not found in forest habitats. The two studies (Brant, 2011; Juliani et al., 2011) which showed relatively higher proportion of species richness, compared to other studies, were also found to have high number of non-native species. All the other studies showed that Oil palm had only about half the species richness as secondary forest (see Figure 11).

![Figure 11](image)

**Figure 11.** Comparison of species richness in oil palm relative to secondary forest.

**Reduction of species richness in oil palm**

All the surveys involving various census methods and different species, included in the review showed a marked loss of forest species (See Table 5). Irrespective of the species, the most repeated reasons stated in the studies for the decrease of species richness in oil palm plantations were lack of structural complexity and poor ground vegetation affecting the microclimate in oil palm monocultures (Chey, 2006; Fayle et al., 2010; Vaessan et al., 2011; Azhar et al., 2011; Cusack, 2011; Sheldon et al., 2010; Edwards et al., 2013; Faruk et al., 2013;
Chung et al., 2000; Edwards et al., 2014; Azhar et al., 2013; Bruhl and Eltz, 2010). Combining all the studies including in the review, mean percentage of reduction in species richness was found to be 34.9%. Totally, 79.6% of forest species recorded in forests were not found in palm oil plantations. In all the studies which showed higher species richness in oil palm than forest habitat, it is found that most species in oil palm were generalists or invasive tramp species. The only study, which showed 0% reduction on species richness in oil palm, also showed a reduction in abundance (Chang et al., 1997).

**Table 5.** Summary of information on the studies included in the review comprising the causes for species reduction, percentage of forest species lost, percentage reduction in species richness and other observations.

<table>
<thead>
<tr>
<th>Study</th>
<th>Taxa</th>
<th>Census Method</th>
<th>% reduction of total species richness in oil palm</th>
<th>% of forest species lost</th>
<th>Observations and Causes for reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chang et al., 1997</td>
<td>Mosquitoes</td>
<td>Human bait</td>
<td>0.00%</td>
<td>0.00%</td>
<td>No species loss but reduced abundance in oil palm</td>
</tr>
<tr>
<td>Bruhl, 2001</td>
<td>Ants (site 1)</td>
<td>Tuna bait</td>
<td>45.00%</td>
<td>70.00%</td>
<td>Most species in oil palm were invasive tramps</td>
</tr>
<tr>
<td></td>
<td>Ants (site 2)</td>
<td>Tuna bait</td>
<td>-87.50%</td>
<td>25.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ants (site 3)</td>
<td>Tuna bait</td>
<td>-100.00%</td>
<td>75.00%</td>
<td></td>
</tr>
<tr>
<td>Hassall et al., 2006</td>
<td>Terrestrial isopods</td>
<td>Quadrats</td>
<td>66.67%</td>
<td>100.00%</td>
<td>NA</td>
</tr>
<tr>
<td>Chey, 2006</td>
<td>Moths (site 1)</td>
<td>Light traps</td>
<td>-13.33%</td>
<td>62.67%</td>
<td>Low floristic diversity</td>
</tr>
<tr>
<td></td>
<td>Moths (site 2)</td>
<td>Light traps</td>
<td>45.11%</td>
<td>78.95%</td>
<td>Open habitat</td>
</tr>
<tr>
<td></td>
<td>Moths (site 3)</td>
<td>Light traps</td>
<td>-15.38%</td>
<td>85.90%</td>
<td>Noctuid and arctiid favoured open habitat</td>
</tr>
<tr>
<td>Koh and Wilcove, 2008</td>
<td>Butterflies</td>
<td>Banana bait traps</td>
<td>78.26%</td>
<td>82.61%</td>
<td>NA</td>
</tr>
<tr>
<td>Fayle et al., 2010</td>
<td>Ants (canopy)</td>
<td>Fogging</td>
<td>54.69%</td>
<td>86.72%</td>
<td>Temperature, Simplification of canopy structure</td>
</tr>
<tr>
<td></td>
<td>Ants (fern)</td>
<td>Entire fern sampling</td>
<td>2.78%</td>
<td>94.44%</td>
<td>Competitive interactions</td>
</tr>
<tr>
<td></td>
<td>Ants (leaf-litter)</td>
<td>Litter samples</td>
<td>74.07%</td>
<td>86.57%</td>
<td>Hotter and drier environment, Competition</td>
</tr>
<tr>
<td>Study</td>
<td>Species/Group</td>
<td>Method</td>
<td>Change in Number</td>
<td>Change in Percentage</td>
<td>Notes</td>
</tr>
<tr>
<td>-------------------------------</td>
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<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Hashim et al., 2010</td>
<td>Ants</td>
<td>Hand-collecting and pitfall traps</td>
<td>-40.00%</td>
<td>40.00%</td>
<td>NA</td>
</tr>
<tr>
<td>Vaessen et al., 2011</td>
<td>Termites</td>
<td>Transects</td>
<td>45.45%</td>
<td>81.82%</td>
<td>Decrease in dead wood</td>
</tr>
<tr>
<td>Azhar et al., 2011</td>
<td>Birds</td>
<td>Transect counts</td>
<td>71.65%</td>
<td>74.74%</td>
<td>Absence of ground layer vegetation</td>
</tr>
<tr>
<td>Cusack, 2011</td>
<td>Small mammals</td>
<td>Traps</td>
<td>-14.29%</td>
<td>85.71%</td>
<td>Poor quality of micro-habitat</td>
</tr>
<tr>
<td>Fukuda et al., 2009</td>
<td>Bats</td>
<td>Mist nets and hard traps</td>
<td>73.68%</td>
<td>78.95%</td>
<td>The frugivorous species rarely use agricultural land for feeding</td>
</tr>
<tr>
<td>Gillespie et al., 2012</td>
<td>Amphibians</td>
<td>Transects</td>
<td>42.86%</td>
<td>52.38%</td>
<td>High temperature flux between day and night. Increased evaporation and lower humidity, Pesticide use, Periodical clearing (disturbance)</td>
</tr>
<tr>
<td>Juliani et al., 2011</td>
<td>Bats</td>
<td>Mist nets</td>
<td>22.22%</td>
<td>66.67%</td>
<td>NA</td>
</tr>
<tr>
<td>Sheldon et al., 2010</td>
<td>Birds</td>
<td>Point counts</td>
<td>74.79%</td>
<td>84.87%</td>
<td>Simple botanical structure</td>
</tr>
<tr>
<td>Peh et al., 2006</td>
<td>Birds</td>
<td>Point counts</td>
<td>74.84%</td>
<td>77.36%</td>
<td>Simplification of vegetation structure</td>
</tr>
<tr>
<td>Brant, 2011</td>
<td>Mosquito eggs, larvae and adults</td>
<td>Aquatic nets or dippers and ovitraps</td>
<td>42.86%</td>
<td>85.71%</td>
<td>NA</td>
</tr>
<tr>
<td>Lucey and Hill, 2012</td>
<td>Ground dwelling ants</td>
<td>Pitfall traps</td>
<td>31.11%</td>
<td>59.26%</td>
<td>Proximity to forest would increase diversity in plantations</td>
</tr>
<tr>
<td></td>
<td>Butterflies</td>
<td>Fruit-baited traps</td>
<td>14.29%</td>
<td>45.71%</td>
<td>Air and soil temperature</td>
</tr>
<tr>
<td>Edwards et al., 2013</td>
<td>Dung beetles</td>
<td>Baited pitfall traps</td>
<td>51.92%</td>
<td>71.15%</td>
<td>Altered microclimate and increased soil temperature affecting roller larvae in shallow depth of the soil</td>
</tr>
<tr>
<td>Benedick et al., 2006</td>
<td>Butterflies</td>
<td>Banana bait traps</td>
<td>53.85%</td>
<td>96.15%</td>
<td>NA</td>
</tr>
<tr>
<td>Study</td>
<td>Method</td>
<td>Species</td>
<td>Plantation Type</td>
<td>Percentage</td>
<td>Summary</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Faruk et al., 2013</td>
<td>Plots</td>
<td>Anurans</td>
<td>Plantation</td>
<td>-25.00%</td>
<td>Banks are more straight sided in plantations</td>
</tr>
<tr>
<td></td>
<td>Plots</td>
<td>Anurans</td>
<td>Riparian</td>
<td>-18.18%</td>
<td>The species in plantations are common species not of conservation concern</td>
</tr>
<tr>
<td></td>
<td>Plots</td>
<td>Anurans</td>
<td>Terrestrial</td>
<td>14.29%</td>
<td>High temperature, reduced leaf litter, homogenized forest structure</td>
</tr>
<tr>
<td>Bernard et al., 2009</td>
<td>Live cage traps with baits</td>
<td>Small mammals</td>
<td>Plots</td>
<td>83.33%</td>
<td>NA</td>
</tr>
<tr>
<td>Chung et al., 2000</td>
<td>Winkler sampling</td>
<td>Subterranean beetles</td>
<td>Plots</td>
<td>79.08%</td>
<td>Lower plant species richness</td>
</tr>
<tr>
<td></td>
<td>Mist blowing</td>
<td>Arboreal beetles</td>
<td>Plots</td>
<td>77.01%</td>
<td>Reduced amount of litter</td>
</tr>
<tr>
<td></td>
<td>Flight interception</td>
<td>Ground beetles</td>
<td>Plots</td>
<td>86.54%</td>
<td>Tree and sapling densities</td>
</tr>
<tr>
<td>Edwards et al., 2013</td>
<td>Transects</td>
<td>Birds</td>
<td>Plots</td>
<td>76.98%</td>
<td>Lower canopy, understorey density and increased temperature</td>
</tr>
<tr>
<td>Bishop, 2012</td>
<td>Quadrat and soil pits</td>
<td>Ants (Formicidae)</td>
<td>Plots</td>
<td>46.99%</td>
<td>Under dispersed in oil palm because of lack of hypogaeic predators</td>
</tr>
<tr>
<td>Liow et al., 2001</td>
<td>Baited transects</td>
<td>Bees</td>
<td>Plots</td>
<td>-112.50%</td>
<td>NA</td>
</tr>
<tr>
<td>March, 2013</td>
<td>Quadrat and soil pits</td>
<td>Termité</td>
<td>Plots</td>
<td>81.82%</td>
<td>High temperature and disturbance in oil palm</td>
</tr>
<tr>
<td>Gray et al., 2014</td>
<td>Transects</td>
<td>Dung beetles</td>
<td>Plots</td>
<td>76.19%</td>
<td>Rollers and nocturnal species were particularly affected</td>
</tr>
<tr>
<td>Pfeiffer et al., 2008</td>
<td>Sampling of vegetation</td>
<td>Arboreal ant (site 1)</td>
<td>Plots</td>
<td>90.91%</td>
<td>Palm plantations were filled with dominant invasive species</td>
</tr>
<tr>
<td></td>
<td>Sampling of vegetation</td>
<td>Arboreal ant (Site 2)</td>
<td>Plots</td>
<td>89.87%</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Sampling of vegetation</td>
<td>Arboreal ant (Site 3)</td>
<td>Plots</td>
<td>86.49%</td>
<td>NA</td>
</tr>
</tbody>
</table>
**DISCUSSION**

**Impacts of habitat conversion**

The results clearly show that conversion of primary forest to palm plantations would adversely affect biodiversity, which is a consistent result from the previous reviews that compared species richness between oil palm plantations and forest habitats (Danielsen et al., 2009; Fitzherbert et al., 2008; Savilaakso et al., 2014). The species lost in habitat conversion were not some random forest species, but they were the species with special diets, habitat features and those with small ranges and high conservation concern (Aratrakorn et al., 2006; Danielsen and Heegaard, 1995; Peh et al., 2006; Chey, 2006). The floral diversity in oil palm plantations were found to be heavily impoverished compared to forest habitats (Danielsen et al., 2009). Danielsen et al. (2010) found pteridophytes in all habitats of oil palm and forest, but species composition and abundance were different. The pteridophytes found in oil palm were very common species, generally grown on disturbed grounds and along roadsides (Danielsen et al., 2009).

All the four studies on birds included in the review showed very low number of species in oil palm habitats. The conversion of forest to oil palm has resulted in elimination of 48-60% of bird species (Azhar et al., 2011). Even the abundance of many bird species found in oil palm were lower than the abundance of birds in heavily logged peat swamp plantations, especially insectivorous, omnivorous and granivorous species (Azhar et al., 2013). Despite the low species richness in oil palm, certain species of birds were more abundant in oil palm habitats (Azhar et al., 2011). Raptors and wetland taxa were higher in oil palm plantations (Azhar et al., 2013). The abundant bird species in oil palm were of low conservation interest (Sheldon et al., 2010; Edwards et al., 2013; Azhar et al., 2011 & 2013). The less abundance of insectivorous birds might be attributed to less species richness of insects in palm plantations (Hassall et al., 2006). Along with species richness and abundance, the functional diversity of birds in oil palm is much lower than both primary and secondary forests (Edwards et al., 2013). The fewer remaining species in oil palm had disproportional functional traits, resulting in lower functional evenness (Edwards et al., 2013). The functionally unique birds found in oil palm were generalists with vast geographical range and very less conservation concern, whereas functionally

<table>
<thead>
<tr>
<th>Authors</th>
<th>Species</th>
<th>Transects</th>
<th>NA</th>
<th>NA</th>
<th>Lack of Structural complexity and richness of lower vegetation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azhar et al., 2013</td>
<td>Birds</td>
<td>Transects</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Bruhl and eltz, 2010</td>
<td>Ground dwelling ants</td>
<td>Tuna baits</td>
<td>NA</td>
<td>NA</td>
<td>Absence of leaf litter. Reduced availability of nest sites for litter nesting species</td>
</tr>
</tbody>
</table>
unique birds found in forest habitats require special habitat features and were of smaller ranges and high conservation concerns (Edwards et al., 2013).

The industrial plantations and small holdings contained similar species of birds with high species richness in the latter (Azhar et al., 2013). The larger species of kingfisher, woodpeckers and canopy frugivores were absent in industrial plantations (Sheldon et al., 2010). Frugivorous species were of higher abundance in small holdings, may be due to the presence of native trees (Azhar et al., 2013). Peh et al. (2006) observed that species richness of the birds in oil palm plantations depend on the presence of the native trees in the plantation and the distance to the nearest forest. Each foraging bird guild responded uniquely to different management regimes (Azhar et al., 2013). The research by Azhar et al. (2013) also found that only arboreal omnivorous and terrestrial frugivorous birds were affected by the proximity to the forest. There was no scientific study on how management regimes affect avian biodiversity (Azhar et al., 2011).

Small mammals play major ecological role in primary forests, by dispersing seeds of large rain forest trees (Cusack, 2011). Small mammal communities in both logged and unlogged forests contained more diverse and specialised species than palm oil plantations (Cusack, 2011; Bernard et al., 2009). The forest specialised species were the species which were found to respond faster to the environmental change in primary forest, and disappear first (Wells et al., 2007). Most small mammals in palm oil plantations were of invasive Rattus species (Cusack, 2011). The Rattus species is considered as a pest and chemicals were used in agricultural landscapes to reduce the population (Wood and Gait Fee, 2003). The study by Bernard et al. (2009) found only one species of small mammal in oil palm plantation and concluded that palm oil acts as a barrier for movement of small mammals. Gillespie et al. (2012) concluded that the amphibian species richness in palm oil plantations were considerably lesser than primary forests and logged forests. There was a hefty difference between the amphibian species present in forest, non-forest and plantation habitats (Gillespies et al., 2012). Microhydrids were completely absent in palm plantations and there were also lesser number of arboreal species (Gillespie et al., 2012). There was no evidence of amphibians breeding in non-forest habitats (Gillespie et al., 2012). Though the studies conducted by Faruk et al. (2013) shows higher amphibian species richness in oil palm habitats, the oil palm habitats were dominated by generalist and human commensal species, which are of least conservation concern (Gillespie et al., 2012; Faruk et al., 2013).

Large mammals like orang-utans and tigers might be completely absent on palm oil plantations (Andau et al., 1994), though the presence of other large mammals like Leopards are reported in palm oil plantations (Rajaratnam et al., 2007). Bateman et al., (2010) and Azlan and Sharma (2003) report that tigers and orang-utans do not even migrate through oil palm plantations, eventually getting pocketed into fragmented forests. The oil palm plantations were also reported to affect orang-utan population in neighbouring forest through anthropogenic
disturbances (Andau et al., 2007). Usually these charismatic forest mammals are used as conservation symbols in green markets (Bateman et al., 2010). These large mammals survey on palm oil plantations would increase global awareness on biodiversity loss. Such charismatic species play a socio-economic role in getting broad support for nature conservation (Caro and O’Doherty, 1999), as they help in effective presenting of complex problems to wider audience (Bateman et al., 2010).

The study conducted by Rajaratnam et al. (2007) shows that oil palm covers nearly 50% of the individual territories of adult leopards in Borneo, though they needed patches of secondary forest within their territories for resting and breeding. This shows the importance of forest fragments within oil palm plantations. The large percentage of palm oil in leopard territories were due to the increased ease of movement and prey ‘catchability’ in agricultural plantations (Rajaratnam et al., 2007), though the density of the prey is low in oil palm plantations (Cusack, 2011). The study by Rajaratnam et al., (2007) did not compare abundance and species richness of large mammals between forests and plantations.

The results from the survey conducted on bats showed that bat species rarely use agriculture land for feeding (Fukuda et al., 2009; Juliani et al., 2011). Particularly frugivorous bats and micro chiropterans were less or absent in oil palm habitats (Fukuda et al., 2009). The study by Danielsen and Heegaard (1995) states that conversion of forest to oil palm plantations resulted in the decline of species richness and alteration in the bat community structure. Almost all the bat species found in oil palm can be classified as common species in disturbed sites (Juliani et al., 2011). All the study results show lower species richness of beetles in oil palm plantation compared to the forests (See Figure 9). Telecoprid beetles were completely absent in oil palm habitats (Edwards et al., 2014). There was a decrease in number of nocturnal foragers and increase in proportion of species with small body sizes (Edwards et al., 2014). The palm oil plantations were dominated by herbivorous beetles, while forest habitats were dominated by Predatory beetles (Chung et al., 2000).

There was a 54% reduction in species richness of butterflies in palm plantations compared to the forest (Lucey and Hill., 2012). The species richness of butterflies was directly related to the proximity of the forest due to spill over of vagrant species from forest (Lucey and Hill, 2012). The spill over strengthens the importance of forest patches for conservation within the plantations. 67% of moth species found in forests were not found in oil palm plantations and the distribution of moth species were more even in forest habitats (Chey, 2006). The study by Liow et al. (2001) show very high species richness of bees in palm plantations compared to forest habitats, but the abundance is higher in forest habitats. Termite species richness in oil palm plantations were much lower than that of the forest habitats (Vaessan et al., 2011; March, 2013). Most of the termite species present in palm plantations were not found in the forest habitats (Vaessan et al., 2011), signifying very high number of non-forest or non-native species. Termite species richness is found to be positively influenced by the forest quality (March, 2013).
The studies conducted by Bruhl (2001) and Hashim et al. (2010) on ants species richness showed higher species richness in palm plantations compared to the forest, but ant communities in oil palm habitats were heavily impoverished with many invasive tramp species (Bruhl and Eltz, 2010), including the crazy invasive ant, *Anoplolepis gracilipes*, which is well known for its adverse effects on other species (Pfeiffer et al., 2008; Bruhl & Eltz, 2010; Bruhl, 2001). The other two dominant invasive species found in oil palm habitats were *Oecophylla smaragdina* and *Technomyrmex albipes*. Ant species did not show any spill over effects from adjacent forests (Lucey and Hill, 2012). Only 59 of 309 forest ant species were found in oil palm habitats, showing 81% species loss due to habitat conversion (Fayle et al., 2010). Most ant species found in oil palm plantations were invasive species (Bruhl and Eltz, 2010; Pfeiffer et al., 2008; Fayle et al., 2010). The species richness in oil palm habitats were consistently less for every species surveyed including birds (Azar et al., 2011; Edwards et al., 2013), Small mammals (Bernard et al., 2009), Amphibians (Gillespie et al., 2012), Bats (Fukuda et al., 2009; Juliani et al., 2011), beetles (Gray et al., 2014; Chung et al., 2000), Butterflies (Koh and Wilcove, 2008; Lucey and Hill, 2012), moths (Chey, 2006), Termites (Vaessan et al., 2011; March, 2013), Isopods (Hassall et al., 2006), Ants (Fayle et al., 2010) and mosquitoes (Brant, 2011). Another consistent factor in the analysis of species richness is irrespective of the species, though species richness in oil palm habitats were higher than forest habitats in some of the studies, the most species present in oil palm were non-native invasive species or generalist species of low conservation interest (Faruk et al., 2013; Cusack, 2011; Chey, 2006; Fayle et al., 2010; Bruhl and Eltz, 2010; Bruhl, 2001).

**Causes for the impact**

The primary cause for the reduction in species richness of many species in oil palm was found to be the absence of dense ground vegetation. The absence of ground vegetation affects the microclimate, affecting invertebrate species richness in the habitat (Chung et al., 2000). The low species richness of invertebrates, eventually affects the species richness of vertebrates feeding on them like insectivorous birds and amphibians (Edwards et al., 2013).

The lower diversity of foraging bird guild was explained by stand level attributes like age, vegetation cover, epiphyte persistence and canopy cover (Azhar et al., 2013). The structural complexity of the habitat plays a major influence in avian diversity (Azhar et al., 2013). The different bird guilds responded differently to different environmental attributes (Azhar et al., 2013). An observation by Azhar et al. (2013) shows that foraging bird guild diversity is inversely related to canopy cover. The low canopy cover allows more light to enter understory, encouraging lower vegetation growth, giving favourable microclimate for insects, which in turn helped insectivorous birds (Sheldon et al., 2010). Rubber plantations were found to be more open than palm oil plantations allowing more sunlight, thus supporting more bird species (Peh et al., 2006).
There was no scientific information on the relation between grazing and biodiversity in oil palm habitats. Most palm plantations do not allow grazing. However, some allow cattle of workers and locals (Azhar et al., 2013). The cattle grazing did not have any significant effect on avian biodiversity (Azhar et al., 2011). Azhar et al. (2013) also found that forest fragments within plantations provide refuge to birds. In addition, oil palm plantation may help seed eating birds with the wild grasses found along the harvesting paths (Azhar et al., 2013). Peh et al. (2006) argues that agroforestry with complex vegetation would increase the occurrence of forest birds in palm plantations. Thiollay (1995) reported the presence of 58% of forest birds in rubber plantations mixed with at least 12 different forest and fruiting trees, while the study by Peh et al. (2006) reported only 34% of forest birds in oil palm plantation. The conservation value of palm plantations for bird biodiversity depends on the nearest forest distance and number of native tree species found in the plantation (Peh et al., 2006).

The low species richness of small mammals in palm plantations might be due to low density of understorey plants, which provide cover from predators and also act as a food source. Leopard cats preferred relatively open palm oil habitats over forest habitats for hunting due to easier catch of the prey (Rajarathnam et al., 2007). The oil palm habitats lack diversity of arboreal and terrestrial aquatic or moist microhabitats, which is crucial for sheltering, foraging and reproduction of amphibians (Gillespie et al., 2012). The oil palm habitats got very high microclimate flux (Chung et al., 2000; Peh et al., 2006), which affects amphibian biodiversity in oil palm plantations (Gillespie et al., 2012). The other factors affecting amphibian diversity are the complete absence of forest plant species, lack of availability of invertebrate prey and lack of protection from predators (Gillespie et al., 2012; Chung et al., 2000; Rajarathnam et al., 2007). There is continuous cycle of disturbance in oil palm habitat, as oil palms cleared every 25-30 years and high usage of pesticides affecting amphibian population (Gillespie et al., 2012).

The low bat species diversity in oil palm plantations was explained by the fact that some megachirotterans are not found to feed on agricultural habitats (Fukuda et al., 2009). Megachirotterans are sustained in the forest by the presence of roosts and various other food sources for feeding (Fukuda et al., 2009). Bats are found to use rivers as migrating flyways (Furmankiewicz and Kucharska, 2009). So, riparian zones might have high bat diversity as the migrating bats might stop over at riparian forests (Juliani et al., 2011). The study by Gray et al. (2014) revealed that there was no significant relationship between species richness of beetles and dung removal, which was in contrast with earlier studies by Slade et al. (2011) and Braga et al. (2013). The reduction in roller and nocturnal beetles might be due to high temperature in oil palm habitats (Gray et al., 2014; Edwards et al., 2014). The species richness of subterranean beetles, understorey beetles and arboreal beetles depend on leaf litter density, tree density and canopy cover respectively (Chung et al., 2000). These features did not favour oil palm habitat for the beetles (Chung et al., 2000).
Butterflies were found to be more sensitive to land use change with distinct communities in oil palm habitats and forest habitats (Lucey and Hill, 2012; Benedick et al., 2006). Butterflies were found to be more abundant in oil palm habitats near forest, but that may be due to the fruit baits attracting more butterflies from nearby forests (Lucey and Hill, 2012). However, it was believed that there were more rotten fruits in the forest than the baits in the oil palm (Lucey and Hill, 2012). Higher the temperature, lower the termite species richness (March, 2013). This hypothesis is evident from the fact that termite species richness is highest in primary forests, lower in secondary forests and the lowest in oil palm plantations with old growth forest being the coolest and oil palm habitats, being the hottest (March, 2013). Hassall et al. (2006) argues that more close the canopy, higher the termite species richness, as open canopy would cause extreme environments for the termites. But the study results by March (2013) is in contrast to Hassall et al. (2006)’s observation, as more open secondary forest habitat had higher termite species richness than closed palm oil habitat. This might be due to poorer lower vegetation cover and soil structure in oil palm habitats compared to the secondary forests. The structure of the soil is important for soil feeding termites (Eggleton et al., 1997). The higher termite species richness in old growth forest might be related to good canopy cover and leaf litter, eventually more organic soil and protection from environmental fluxes (March, 2013).

Same like most invertebrates, ground-dwelling ants’ distribution and community structure was highly influenced by the microclimate and microhabitat features (Bruhl and Eltz, 2010; Lucey and Hill, 2012; Fayle et al., 2010). The forest ants were not tolerant to the higher temperature in oil palm habitats (Bruhl and Eltz, 2010). Along with the loss of forest species, there were tremendous shift in ant community compositions in palm oil plantations (Bruhl, 2001; Bruhl and Eltz, 2010; Hashim et al., 2010; Fayle et al., 2010; Lucey and Hill, 2012). The alien dominant tramp species were more frequently found in oil palm than any native species (Pfeiffer et al., 2008; Bruhl et al., 2003). The loss of native ant species in oil palm may be due to the complete absence of leaf litter with hot and dry climate in oil palm habitats (Bruhl and Eltz, 2010). These characteristic of palm habitat affect nesting and also reduce colony survival (Bruhl and Eltz, 2010). The establishment of invasive tramp species is due to the total destruction of native flora and fauna and the creation of exotic plant monoculture (Pfeiffer et al., 2008). These invasive non-native ant species present in oil palm habitats adopt better to the disturbed environment and have a marked impact on native ant communities (Pfeiffer et al., 2008). The high temperature of unprotected soil in oil palm habitats even blocks the movement of ants from fragmented forests within the oil palm plantations (Bruhl et al., 2003). Bickel et al. (2006) reported the isolation of ant communities and lack of gene flow between two forest ant species in Sabah. The observed reasons in all the studies state the importance of forest fragments or native trees within the plantations for the conservation of biodiversity. There is no significant scientific evidence on the relation between different management regimes and biodiversity (Azhar et al., 2013). It is suggested that the management of palm plantations should be directed towards
preserving native species within plantation and improving microclimate by encouraging diverse lower vegetation.

Evidence on the importance of secondary forest

The forest degraded by repeated logging are considered less important and provided limited protection against conversion to palm oil plantations (Woodcock et al., 2011; Koh and Wilcove, 2008). The secondary forests are highly underestimated of their biodiversity value (Cusack, 2011). Secondary forests retained a large number of amphibian species found on primary forests (Gillespie et al., 2012). The species richness of amphibians especially endemic species richness was much higher in secondary forests compared to the palm oil plantations (Gillespie et al., 2012), apparently signifying the importance of secondary forests in amphibian conservation. The logging altered the community structure and composition but significantly retained the functional diversity of beetles (Edwards et al., 2014).

There was markedly high species richness of small mammals, especially arboreal species in logged forest than in unlogged forest (Cusack, 2011). This may be because of the sampling technique used for the survey. The traps were placed on the forest ground (Cusack, 2011). This hypothesis is supported by the study conducted by Wells et al. (2006), which showed vertical segregation of arboreal species in unlogged forests, with most being found in greater heights. The ground traps helped catching more arboreal species in logged forests because of the lower height of trees in regenerating logged forest (Cusack, 2011). This proves that even the lower canopy cover in logged forest would support arboreal forest species of small mammals. The higher density of small mammals in logged forest may be attributed to lower density of predators in logged forest (Terborgh et al., 2001; Rajaratnam et al., 2007). Bernard et al. (2009) concluded that there is no marked difference in small mammal communities between logged and unlogged forests. Most small mammals feed on seeds, and affect forest regeneration especially in newly logged forest (Wells and Bagchi, 2005). The fact that logged forests support internationally threatened small mammal species like spine rat (Cusack, 2011), outweigh the concern on forest regeneration and succession.

Another reason for high small mammal species richness is logged forests are relatively open, allowing sunlight and supporting dense underground vegetation, which provides cover against predation and optimum microhabitat for small mammals (Lambert et al., 2006; Cusack, 2011). The importance of secondary forest for small mammals stated by Cusack (2011) is consistent with other studies conducted in different places at different time periods (Berry et al., 2010; Meijard and Sheil, 2008; Bernard et al., 2009; Dunn, 2004). The study by Styring and Hussain (2004) found 12 species of woodpeckers in primary forest and 10 of them were retained in 10 years logged forest with lower abundance. All the 12 species found in unlogged forest were found in 5 years logged forest, but with lower abundance (Styring and Hussain, 2004). The lower abundance of woodpeckers in logged forest was explained by the lower abundance of dead wood (Styring and
Hussain, 2004). No study on woodpecker species richness in oil palm was found to compare oil palm habitat with forest habitat. Different bat species showed different patterns of abundance. The 5 years logged forest had more dense ground vegetation, which favoured some species, while arboreal species were least abundant in 5 years old logged forest (Styring and Hussain, 2004).

The secondary forest retained all the bird species found in primary forest; however, there is a slight reduction in avian functional diversity in secondary forest (Edwards et al., 2014). The conversion of secondary forest to oil palm not only reduced species richness, but also functional diversity and functional evenness of birds were drastically reduced (Edwards et al., 2014), showing the importance of secondary forests in the conservation of forest birds. The study by Turner (2011) revealed that the secondary forest retained all the bat species present in primary forest, though there is a significant reduction in abundance. Two bat species namely *Kerivoula hardwickii* and *Murina suilla* were found to benefit from logging (Turner, 2011). The conversion to oil palm reduces bat species richness, leading to loss of many forest species (Juliani et al., 2011). Juliani et al. (2011) also found some new bat species in oil palm plantations, which are not found in forest habitats. Unlike beetle community in oil palm habitats, beetles in secondary forest did not differ much from primary forest In terms of abundance, species richness, functional diversity and functional evenness (Edwards et al., 2014). The study by Gray et al. (2014) found that logged forest had more abundance and species richness of beetles than riparian reserves.

In contrast to other species, abundance, species richness and functional diversity of termites were much lower in secondary forests compared to primary forests (March, 2011). The termite community in secondary forest was similar to the termite community in oil palm habitat (March, 2011). This may be attributed to open canopy in secondary forest, which would expose termites to extreme microclimate, despite having higher density of lower vegetation than oil palm plantations (March, 2011). Ants are more resistant to habitat disturbance (March, 2011). Bishop (2012) reported higher ant genus richness in secondary forest than primary forest. This different results for termite and ants might be due to the factor that termites and ants are affected by different environmental characteristics i.e., the stress factor for ants are low temperature and high humidity, while the stress factor for termites are high temperature and low humidity (Bishop, 2012; March, 2011). The open canopy and low density of leaf litter in secondary forest supports more ant species (March, 2011). The survey conducted by Floren (2005) shows that arboreal ants are severely reduced in secondary forests compared to the primary forest, which is in contrast to the finding of Bishop (2012) on ground ant species richness. Floren (2005) also observed changes in ant species interactions in relation to the forest disturbance, which he found to be recognizable even after 40 years of forest regeneration, suggesting that it takes longer time to recover from anthropogenic disturbance. The 5 years old logged forest contained only 12% of arboreal ant species present in primary forest, while 40 years old logged forest contained only about 40% of
primary forest arboreal ant species (Floren, 2005). Woodcock et al. (2011) found 80% of primary forest leaf litter ant species in twice logged forest; however, the community structure was altered.

The study by Juliani et al. (2011) showed that there was only 22% difference in species richness between secondary forest and palm oil plantations, but 67% bat of species present in secondary forest were absent in oil palm plantations. Although there were some reductions in species richness in secondary forests compared to the primary forest, the secondary forest had similar community structure and retained most forest species (Edwards et al., 2013; Edwards et al., 2014; Turner, 2011; Bishop, 2012; Gillespie et al., 2012; Cusack, 2011) while oil palm had much lower species richness and entirely different community structure with more invasive tramp or generalist species and very less forest species (Bruhl and Eltz, 2010; Edwards et al., 2014; Juliani et al., 2011). Clearly, these degraded and logged forests provide abode for numerous forest species. The secondary forest should be given more importance and protection against conversion to agriculture land while designing a conservation plan.

Species richness: comparison with previous studies

This is the first ever review to evaluate biodiversity loss associated with palm oil plantations, exclusively in Malaysia. The previous reviews and meta-analyses on biodiversity in palm plantations by Fitzherbert et al. (2008), Danielsen et al. (2009) and Savilaakso et al. (2014) included oil palm biodiversity data from different tropical countries. All the three previous reviews were biodiversity comparison between oil palm plantations and primary or secondary forest. In the current review biodiversity of oil palm habitat is compared with primary forest and secondary forest separately. There is no significant difference between the results of the present study and the previous studies (See Figures 12 & 13). The analysis of the new studies, which were conducted in recent years and not included in any of the previous reviews, shows noticeable reduction in overall invertebrate species richness in palm plantations with very negligible increase in the mean proportion of shared species with the forest (See Figure 12). There is no noticeable difference in the final results of invertebrate species richness between the three reviews including all the studies (See Figure 13).
Figure 12. Mean proportion of invertebrate species in comparison with previous reviews. The error bars represent standard deviation. The numbers in the brackets represent the numbers of studies.

There is significant increase in the vertebrate species richness of palm oil plantations in the recent studies, which are not included in the previous Meta-analyses, with no noticeable change in the proportion of shared species compared to the previous reviews (See Figure 13). This result suggests the increase in the number of non-native or invasive vertebrate species in palm plantations, while the forest vertebrate species richness remains the same in palm plantations. As only 4 studies on vertebrate species richness in Malaysia, which were included in the previous reviews were added to the new studies in the present review, the proportion of species richness of palm oil is markedly high in the result of present review, including all the vertebrate surveys conducted in Malaysia. There is no noticeable increase in the proportion of shared vertebrate species from previous studies. This result reveals that palm plantations in Malaysia has more non-forest vertebrates in palm plantations than other palm oil growing countries included in the previous reviews. Overall, the results are mostly consistent with previous studies, stating that the conversion of forest land to palm oil plantations would severely affect vertebrate and invertebrate biodiversity (Fitzherbert et al., 2008; Danielsen et al., 2009; Savilaakso et al., 2014; Koh and Wilcove, 2008), and necessary steps should be taken to prevent the conversion of forest land.
Figure 13. Mean proportion of vertebrate species in comparison with previous reviews. The error bar represents standard deviation. The number within the brackets represent the numbers of studies.

Caveats

The review was based only on species richness value of oil palm plantations in only one country, Malaysia. Most studies included in the review were conducted in Sabah and Sarawak. This might be due to the relatively lesser forest cover in Peninsular Malaysia. So, these findings cannot be generalised to other places. However, other reviews combining data from oil palm plantations in different countries gave similar results (Fitzherbert et al., 2008; Danielsen et al., 2009; Savilaakso et al., 2014). When species richness is surveyed in two different habitats, there are many factors that can affect the generality of the conclusion. The review combining several species richness comparisons have even more factors affecting the authenticity of the results. The sample size, survey techniques and number of surveys were different in every study, potentially affecting general comparison of species richness. No information is available on seasonality effect on the surveys. No reliable information was available on the scale of human disturbance in different studies and the use of chemicals in plantation management. Very less information were available on whether the oil palm habitats surveyed were established on previous plantations or forest, which would have had a marked effect on the species richness. Some forest species might have been found on recently converted oil palm plantations, which in the long run cannot persist there. It is considered that the estimates of biodiversity loss in palm plantations were conservative (Fitzherbert et al., 2008), owing to the difficulty in detecting many species in dense and tall primary rainforests. The species richness surveys conducted in small holdings and forest edges may have higher values because of transient species from nearby forests. These biases would have
underestimated the biodiversity loss on oil palm plantations, making the conclusion even sturdier.

CONCLUSIONS

It is evident from the results got from different studies on species richness, that palm oil plantations support much lesser biodiversity than primary or secondary forests in Malaysia. The species richness estimates show that even the heavily logged forest can support more number of forest species than oil palm plantations. The future conservation actions should give importance to secondary forests, preventing them from conversion to palm plantations. Along with species richness, the forest conversion has also affected functional diversity, functional evenness and community structure of both vertebrate and invertebrate species. The increase in palm plantation area along the forest also resulted in the fragmentation of habitats of big charismatic species like orang-utans and Malaysian tigers, which are used as conservation awareness symbols by many organizations. These results on Malaysian palm plantations are consistent with previous reviews including species richness studies from palm plantations of different countries by Fizherbert et al. (2008) Danielsen et al. (2009) and Savilaakso et al. (2014).

Palm oil has the potential to become a leading vegetable oil in terms of biodiesel and food, owing to its high productivity and lower cost (Tan et al., 2009). The palm oil plantations in Malaysia are expected to increase with increasing global demand and increasing economic dependence of Malaysia on palm oil. The prevention of plantation expansion into forests in Malaysia is more complicated than other countries because of the direct involvement of the government in the regulation and production of palm oil (Lopez and Laan, 2008). Both the primary forests and the secondary forests should be protected against the conversion to palm oil plantations. The palm plantations should be sustainably managed to support as much biodiversity as possible.

The RSPO regulations for sustainable palm oil practices were followed by some palm oil plantations from 2007 and new regulations were updated on 2013, but the lack of scientific research or knowledge on the RSPO sustainability practices makes one to doubt the credibility of RSPO in producing environmentally sustainable palm oil. The past surveys did not research on the relation between species richness and different management regimes. As the present study and previous reviews made it clear that conversion of forest to palm oil plantations adversely affects biodiversity, the future research should be focussed on the species richness supported by palm oil plantations following different management regimes to find the best practice for biodiversity in palm plantations.

From the observed causes for the species reduction in oil palm habitats, it is recommended that management regimes for oil palm plantations should focus on maintaining ground layer vegetation and conserving the forest patches and native
trees within the plantations. The periodic pruning of palm canopy would allow sunlight, thus encouraging ground vegetation. The structural complexity of vegetation has very high influence on species richness. So, the re-vegetation of native trees along and within the plantations would help to improve the complexity of the vegetation, supporting larger number of species.

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