2

The Impact of Oil Palm Expansion on Environmental Change: Putting Conservation Research in Context

Edgar C Turner[1,2], Jake L Snaddon[1,3], Robert M Ewers[2], Tom M Fayle[1,2] and William A Foster[1]
[1]*University Museum of Zoology, Cambridge, Cambridge,*
[2]*Imperial College London, Silwood Park Campus, Ascot, Berkshire,*
[3]*Biodiversity Institute, University of Oxford, Oxford,*
United Kingdom

1. Introduction

Agricultural expansion is one of the major drivers of tropical biodiversity loss worldwide (Foley et al., 2005; Green et al., 2005). Oil palm cultivation is among the main culprits, owing to its huge increase in cultivation in recent years (Food and Agriculture Organisation of the United Nations [FAO], 2011) and its centre of production being within the most biodiverse regions and habitats on the planet (Sodhi et al., 2010; Turner et al., 2008). Increasing demand for palm oil in food products and as a biofuel is likely to result in accelerating environmental change in the future (Koh & Ghazoul, 2008). Despite the importance of this crop and increasing global concern for environmental change, surprisingly little research has focussed on the actual impacts of conversion of forest to oil palm on biodiversity (Fitzherbert et al., 2008; Foster et al., 2011; Turner et al., 2008). In particular much still needs to be studied if we are to understand how human-modified landscapes can be managed to allow continued sustainable production of this globally important crop as well as maintenance of biodiversity. The development of more sustainable oil palm landscapes containing higher levels of biodiversity is not an alternative to conserving large areas of intact primary forest, as only these forested areas can provide a habitat for many rare and threatened species (Edwards et al., 2010). Rather it will allow preservation of a higher level of biodiversity within plantations, a greater connectivity and permeability for species to travel between reserve areas, and crucially the maintenance of important ecosystem functions within the agricultural landscape such as pollination, biological control, decomposition, maintenance of water quality, and environmental enrichment for people living in the vicinity of plantations. Central to the development of landscapes which support biodiversity and oil palm cultivation is increasing the dialogue between the oil palm industry, scientists and conservationists, as only this will allow new research findings to be applied to oil palm cultivation practices effectively.
In this chapter we will

- Describe in detail the change in palm oil production that has taken place over the last 30 years, the key regions where cultivation has taken place, and options for future conservation in the tropics

- Present an up-to-date review of the literature relating to the impacts on biodiversity of forest conversion to oil palm
- Assess how the focus of research relating to oil palm has changed in recent years
- Highlight gaps in existing knowledge and priorities for future research effort
- Assess the relationship between the oil palm industry, academic researchers and conservationists
- Highlight the importance of forging links between industry, science and conservation to understand and maintain functional tropical landscapes
- Introduce a new long-term large-scale collaborative research project between industry and science, the Stability of Altered Forest Ecosystems [SAFE] Project (Ewers et al., 2011; SAFE Project, 2010), which experimentally investigates landscape-scale biodiversity changes associated with the establishment of a new oil palm plantation in Sabah, Malaysia.

2. Global patterns of palm oil production

Agricultural ecosystems are now among the dominant habitat types on the planet (Foley et al., 2005). An expanding global population and a burgeoning demand for food have resulted in agricultural areas increasing dramatically in the tropics (Green et al., 2005), with 80% of the world's new agricultural land coming from the conversion of tropical forest (Gibbs et al., 2010). Conversion of natural ecosystems to agricultural landscapes has had a severe negative impact on global biodiversity (Sodhi et al., 2004, 2010), with losses of species already occurring and further regional and global extinctions predicted to occur. At the same time, global concerns for climate change have resulted in an accelerating demand for biofuel (Koh & Ghazoul, 2008), placing more pressure on remaining natural habitats.

Among the most important agricultural crops in the tropics is oil palm. Palm oil is used in a wide range of products, is a particularly important source of vegetable oil (Corley, 2009) and is increasingly used as a feedstock for biofuel production (Basiron, 2007; Henderson & Osborne, 2000; Koh, 2007). Globally, oil palm cultivation is centred in the tropics with the highest levels of production in Indonesia and Malaysia (Basiron, 2007). Both Indonesia and Malaysia are located in global biodiversity hotspots (Myers et al., 2000), so expansion in these areas is likely to have a large negative impact on biodiversity at the global scale (Sodhi et al., 2004).

Based on data from the Food and Agriculture Organisation of the United Nations [FAO] (FAO, 2011), we present trends in the global production of oil palm fruit over a 48-year period from 1961 to 2008 (Figure 1), as well as individual per country production for the top two palm oil producing nations in Southeast Asia, Africa and South America (Figure 2). In terms of quantity, these six nations are among the top ten oil palm producing countries worldwide (Figure 3). We present information on oil palm land area and yield per hectare. Where available, we also present trends in the producer prices for palm oil in each country. Global palm oil prices were estimated as the mean producer price from the 14 countries listed on the price domain of the FAOSTAT database (FAO, 2011).

Between 1961 and 2008 production of oil palm fruit has increased from 13 million tonnes to around 207 million tonnes worldwide (FAO, 2011). This rise has corresponded with substantial increases in land area under oil palm cultivation, with centres of oil palm production located throughout the tropics. Concerns for species losses as a result of palm oil expansion should therefore not be restricted to Southeast Asia, but rather to all tropical regions where forest is being converted (Wilcove & Koh, 2010). Although there have been increases in yield per unit area in most countries, this is not consistent and is very variable between nations and regions, with the well-developed oil palm industry in Malaysia and Indonesia showing the most marked increases in yield (Figures 2 & 3). Prices commanded for palm oil, although very variable, also continue to rise.

Between the 1960s and 1980s increases in global palm oil production were probably primarily obtained by increased yield per area. However since the 1980s this trend has shifted, with increased global production being driven instead by further conversion of land to oil palm cultivation (Murphy, 2009), threatening remaining forest habitats. The large difference in yield per area between different countries raises the possibility that, if yield can be increased in those regions at the lower end of the range, pressure on remaining forest habitats may be reduced. The recent development of higher-yielding seedling stock and more efficient processing technology (Donough et al., 2009; Mathews & Foong, 2010; Murphy, 2009) could enhance yield and productivity further, thereby also relaxing pressure to convert further natural habitats to oil palm cultivation. However, the rise in crop prices, which are closely linked to demand (Rudel et al., 2009), indicate that the market for palm oil is still expanding. This is probably owing to the continued high demand of palm oil as a source of edible oil and a biofuel feedstock (Corley, 2009; Koh, 2007), and diversification of its uses (Basiron, 2007; Henderson & Osborne, 2000). If further expansion of the area under oil palm cultivation is to be reduced, any rise in yield per area must therefore meet not only today's demand for palm oil, but also increased demand in the future.

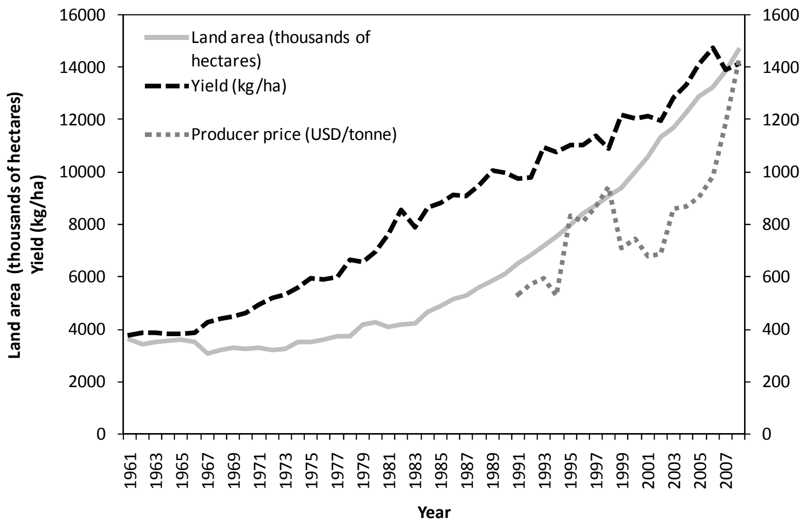

Fig. 1. Global oil palm land area under harvested cultivation, yield per unit area, and producer price of palm oil (in US Dollars per tonne produced). Land area under production has more than quadrupled since 1961, while yield and price have also increased substantially. Data from Food and Agriculture Organisation of the United Nations [FAO] (FAO, 2011)

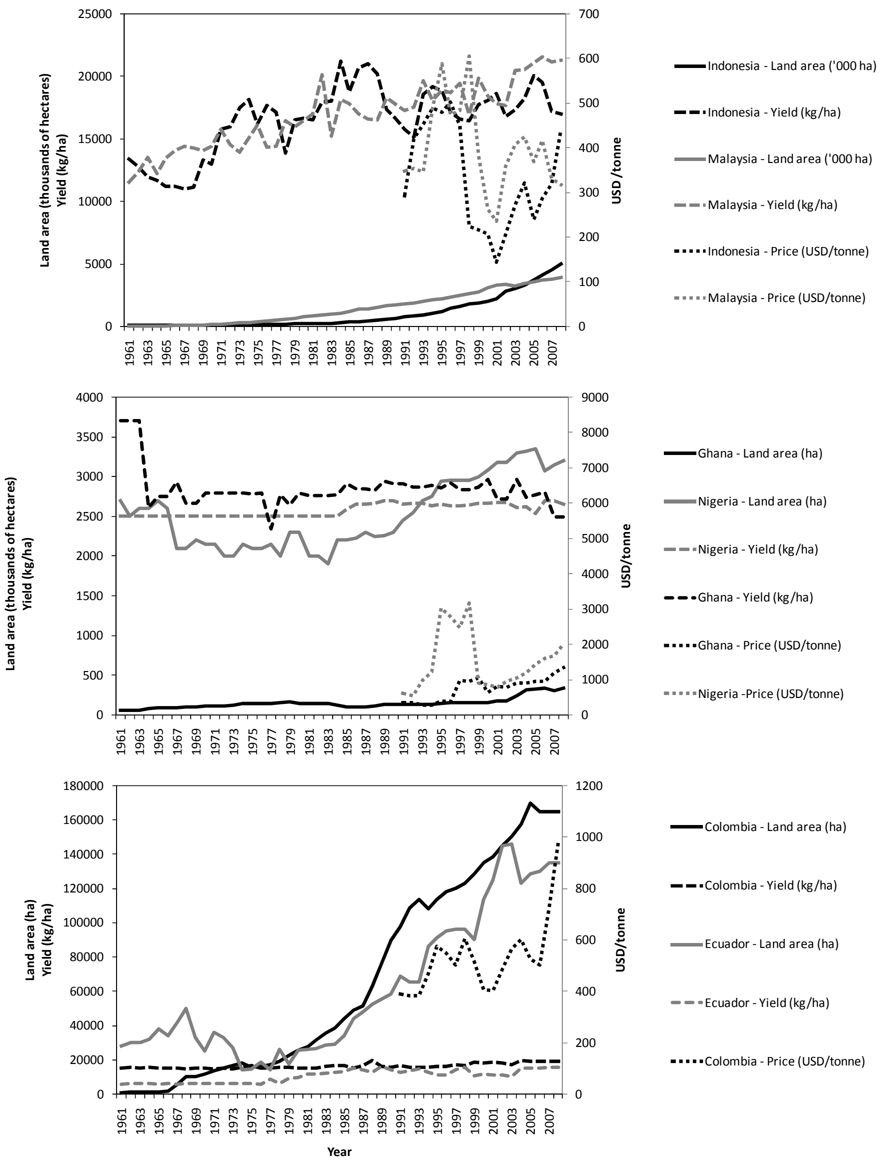

Fig. 2. Oil palm production, area under harvested cultivation, yield per unit area, and price of palm oil in US Dollars per tonne produced for the top two palm oil producing countries in each of the main tropical regions of production (SouthEast Asia, Africa and South America). Although production of palm oil has expanded in all countries, the level of productivity between regions varies widely, as does the price commanded by palm oil produced. Data from Food and Agriculture Organisation of the United Nations [FAO] (FAO, 2011). Note differing scales on the y-axes for different regions

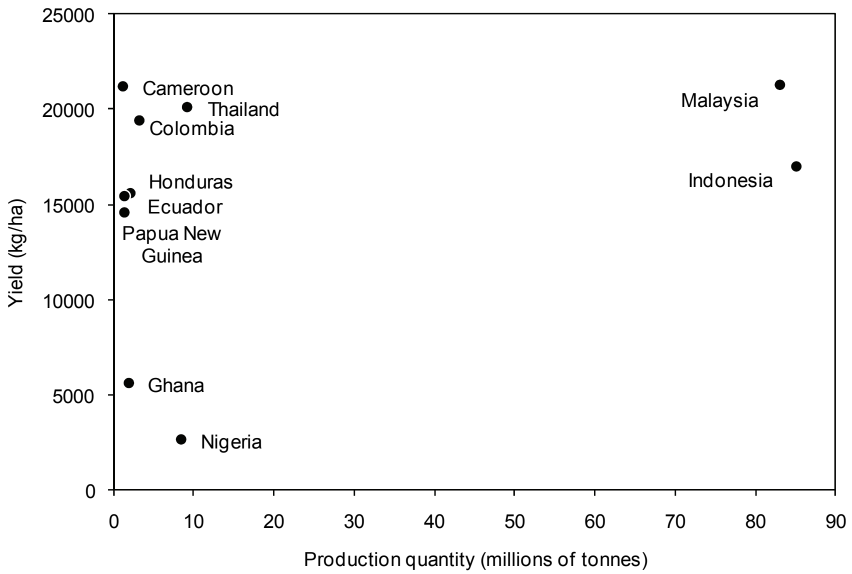

Fig. 3. Oil palm fruit production (in millions of tonnes) in relation to oil palm fruit yield per area (2008) for the top ten oil palm producing countries worldwide (FAO, 2011)

3. Oil palm impacts on biodiversity

Studies investigating the impacts of forest conversion to oil palm on biodiversity are surprisingly sparse (Foster et al., 2011; Turner et al., 2008). Despite this, there is now overwhelming evidence that conversion of natural or semi-natural habitats to oil palm has severe negative impacts on biodiversity (Fitzherbert et al., 2008; Foster et al., 2011)(Table 1). This is particularly the case if the land being converted is natural forest, but is also generally true if the land is under timber or another forest crop, which house higher levels of biodiversity than oil palm (Aratrakorn et al., 2006; Chung et al., 2000a, 2000b; Danielsen & Heegaard, 1995; Davis & Philips, 2005; Glor et al., 2001; Hassall et al., 2006; Peh et al., 2006; Room, 1975; Sheldon et al., 2010; Taylor, 1977). Studies have now been carried out on a diverse range of taxa including insects (ants, beetles, bees, butterflies and moths), other arthropods (woodlice), mammals (primates, tree shrews, squirrels and bats), birds, and lizards (Table 1). All of these taxa, with the exception of bees, show a decline in species richness from other habitats to oil palm, signalling a very high level of biodiversity loss as a result of oil palm expansion globally.

The majority of taxa also show a reduction in overall abundance in plantations compared to forest habitats, although this effect is more variable (Table 1). For example, in one study comparing arthropod abundance and biomass between forest habitats and oil palm plantations, some arthropod taxa showed the same levels of abundance and biomass in plantations, and others actually increased (despite arthropod numbers being reduced overall)(Turner & Foster, 2009). Similarly, in other studies, the total number of bats (Danielsen & Heegaard, 1995), dung beetles (Davis & Philips, 2005), woodlice (Hassall et al., 2006), and lizards (Glor et al., 2001) all increased in abundance as a result of habitat conversion. However, such increases are likely to be driven by an expansion in the populations of a few disturbance-tolerant species. These tend to be more wide-ranging "tramp" and invasive species and therefore have limited conservation value (e.g. Fayle et al., 2010). Despite this, disturbance-tolerant species may still be important in mediating ecosystem functioning in plantations and merit management to ensure their continued survival.

Group	Habitats compared to oil palm	Diversity	Abundance	Study location	Source
Arthropods					
All arthropods	Primary and secondary forest	-	↓	Sabah, Malaysia	Turner and Foster 2009
Ants	Primary forest	↓	-	Sabah, Malaysia	Brühl and Eltz 2010
Ants	Primary forest	↓↔	↓	Sabah, Malaysia	Fayle et al. 2010
Ants	Mangrove	↔	-	Peninsula Malaysia	Hashim et al. 2010
Ants	Primary forest, rubber and oil plantations, grassland, savanna, urban areas	↓	↓	Papua New Guinea	Room 1975
Ants	Primary/secondary forest and kola, cashew, coffee and plantain plantations	↓	-	Nigeria	Taylor 1977
Bees	Primary and secondary forest	↑	↓	Peninsula Malaysia and Singapore	Liow et al. 2001
Beetles	Primary and secondary forest and acacia	↓	↓	Sabah, Malaysia	Chung et al. 2000a
Rove beetles	Primary and secondary forest and acacia plantation	↓	-	Sabah, Malaysia	Chung et al. 2000b
Dung beetles	Primary and secondary forest and cacao plantation	↓	↑	Ghana	Davis and Philips 2005
Butterflies	Forest	↓	-	Sabah, Malaysia	Danielsen et al. 2008
Butterflies	Primary and secondary forest	↓	-	Peninsula Malaysia and Borneo	Koh and Wilcove 2008
Moths	Primary and secondary forest	↓	↓	Sabah, Malaysia	Chey VK 2006
Mosquitoes	Primary forest	↔	↓	Sarawak, Malaysia	Chang et al. 1997
Woodlice	Primary and secondary forest and fruit orchard	↓	↑	Sabah, Malaysia	Hassall et al. 2006

Group	Habitats compared to oil palm	Diversity	Abundance	Study location	Source
Mammals					
Primates	Primary forest and rubber plantation	↓	↓	Sumatra, Indonesia	Danielsen and Heegaard 1995
Squirrels	Primary forest and rubber plantation	↓	↓	Sumatra, Indonesia	Danielsen and Heegaard 1995
Tree shrews	Primary forest and rubber plantation	↓	↓	Sumatra, Indonesia	Danielsen and Heegaard 1995
Bats	Primary forest and rubber plantation	↓	↑	Sumatra, Indonesia	Danielsen and Heegaard 1995
Large mammals	Secondary forest and scrub	↓	-	Sumatra, Indonesia	Maddox et al. 2007
Small mammals	Primary forest and secondary forest	↓	↓	Sabah, Malaysia	Bernard et al. 2009
Small mammals	Forest	↓	-	Indonesia	Danielsen et al. 2008
Birds					
Birds	Primary forest and rubber plantation	↓	-	Thailand	Aratrakorn et al. 2006
Birds	Primary forest and rubber plantation	↓	-	Sumatra, Indonesia	Danielsen and Heegaard 1995
Birds	Primary forest and rubber plantation	↓	↓	Peninsula Malaysia	Peh et al. 2006
Birds	Secondary forest and acacia plantation	↓	-	Sabah, Malaysia	Sheldon et al. 2010
Reptiles					
Lizards	Secondary forest, cacao plantation, pasture, home gardens, undisturbed hilltops	↓	↑	Dominican Republic	Glor et al. 2001

Table 1. Species richness and abundance of various animal taxa compared between forest or plantation habitats and oil palm. – response not recorded; ↓ richness or abundance declines, ↔ richness or abundance is unchanged, ↑ richness or abundance increases

Biodiversity in most components of the forest ecosystem is likely to be negatively affected by habitat change. However, owing to varying levels of disturbance across the plantation landscape and differences in the environmental tolerances of species from different components of the forest ecosystem, some habitat components are more adversely affected than others. For example, one study comparing arthropods between forest and oil palm habitats, collected from the canopy, epiphytic bird's nest ferns and the forest floor, found that different sub-habitats exhibited differing levels of decline, with the forest floor arthropod community being the most severely affected and the epiphyte community the least affected (Turner & Foster, 2009). This was probably due to the high levels of disturbance that occur on the plantation floor and regular applications of herbicides at the base of individual palms. It is also likely that canopy species are comparatively less impacted by conversion of forest to plantation, as microclimatic conditions in the forest canopy are generally more similar to an oil palm plantation than the forest floor (Foster et al., 2011), and therefore canopy species may be better adapted to cope with habitat conversion. Epiphytes can also establish easily in oil palm plantations (Piggott, 1988), probably due to high light conditions and because the frond stumps, which are left on the trunks of the oil palms, trap organic matter and provide an attachment point for the plants. In fact some epiphytes, such as bird's nest ferns, can reach higher densities in plantations than in forests (Turner & Foster, 2009), although it is likely that only a subset of the forest species persist (Fayle et al., 2009). Epiphytes have also been found to modify the microclimatic conditions around them and therefore provide a more equitable temperature and humidity regime (Turner & Foster, 2006). It is therefore not surprising that epiphytes can house considerable densities of arthropods and act as an important habitat for species in plantations (Turner & Foster, 2009). The number of arthropod species living in plantation epiphytes can also be high. For example, the number of ant species in bird's nest ferns is the same in forest and oil palm plantation habitats (Fayle et al., 2010). However, the species found in plantation epiphytes are not the same as those in forests (Fayle et al., 2010). Therefore, although biodiversity as a whole was maintained in epiphytes, plantation communities were still fundamentally different from forest environments.

3.1 Drivers of biodiversity loss

Reasons for such a dramatic loss of species are almost certainly due to the simplification of the habitat that occurs when a forest is converted to oil palm (Foster et al., 2011). This includes the obvious loss of the diverse tree community that forms the basic structure of a forest (important in maintaining herbivore diversity for example (Novotny et al., 2006)), a reduction in above ground structural complexity, and a reduced canopy height. Partly due to this loss of canopy cover, microclimatic conditions are harsher for species in plantations with temperatures being on average hotter and humidity levels lower. Fluctuation in both temperature and humidity is also greater over 24 hours in plantations compared to forest habitats (Koh et al., 2009; Turner & Foster 2006). Direct disturbance effects, such as cutting and spraying of understory vegetation, and a higher proportion of invasive species probably also contributes to species' declines and extinctions.

3.2 Impacts of biodiversity loss on ecosystem functioning

The impact of reduced biodiversity on the healthy functioning of oil palm ecosystems has been little studied. However, there is considerable support from theoretical models and experimental systems that reductions in biodiversity can have significant negative impacts on ecosystem functioning (Schmid et al., 2009). Reliance on the function carried out by a single species or a few species is risky as if these species go extinct the function will fail. A higher diversity of species adds resilience to ecosystem processes and allows systems to adapt to future changes (Jackson et al., 2010). It is therefore likely that the documented losses in animal biodiversity associated with oil palm cultivation will have a detrimental effect, perhaps through a reduction in biological control of pest species or reduced pollination efficiency. For example, a wide and increasing range of species have been reported to attack oil palm (Corley, 2003; Mariau, 2001; Turner & Gillbanks, 2003), and it is clear that predators and parasitoids can have an important role in controlling their outbreaks. In oil palm management such species have long been included in Integrated Pest Management strategies (Wood, 2002), with examples including the use of the fungus *Metarhizium anisopliae* in the control of rhinoceros beetles, adult assassin bugs (Heteroptera) in the control of herbivorous insects, and barn owls (*Tyto alba*) in the control of rats (Turner & Gillbanks, 2003). The role of naturally occurring suites of predators, termed "Conservation Biological Control" (Jonsson et al., 2008; Tscharntke et al., 2007), in controlling pest species has been less studied. However, in one study where birds were excluded from young palms with netted cages, herbivory levels increased significantly, indicating that birds had an important effect in controlling herbivores (Koh, 2008b). Although the majority of oil palm pollination in Malaysia is said to be carried out by a single species of introduced weevil (*Elaiedobius kamerunicus* (Coleoptera: Curculionidae); Greathead, 1983), many other species of insects also visit oil palm flowers (Bulgarelli et al., 2002; Mariau & Genty, 1988; Mayfield, 2005; Syed et al., 1979) and may have a role in maintaining pollination (Caudwell et al., 2003). Taxa that show increases in abundance in oil palm systems might be important in maintaining ecosystem processes and have the potential to buffer functioning against losses of other species, even if they are of little direct conservation interest (e.g. are tramp or invasive species).

4. Strategies for conservation of global biodiversity

Since oil palm is widespread and its expansion is accelerating, the choice of tactics to mitigate the effects of oil palm cultivation on biodiversity is paramount. In recent years two alternative strategies for conservation in the tropics have emerged (Green et al., 2005). Generally referred to as "land sparing" and "land sharing", these competing ideas are that biodiversity can be best maintained by either setting aside (sparing) large areas of land in the tropics for reserves and intensifying production as much as possible elsewhere, or by developing agriculture over much larger areas but in a more wildlife-friendly way (sharing). A general consensus is now emerging in the conservation sector that the only way to conserve species of high conservation value in the tropics is by land sparing and the provision of large forest reserves (e.g. Edwards et al., 2010). However, it is important that these two approaches are not viewed as alternatives, but rather as opposite ends of a continuum of strategies that can be employed for different species and with different conservation outcomes in mind. There is no doubt that many species cannot be conserved in fragmented habitats and that intact forest reserves must therefore be maintained. However, the biodiversity still existing within plantation areas can be substantial, and a more biodiversity friendly environment can help to buffer and provide a foraging resource for species from forest reserves (e.g. Maddox et al., 2007). Most importantly as far as industry is concerned, biodiversity within plantation areas can provide important ecosystem functions and increase productivity within the crop area itself (Zhang et al., 2007). Finally the oil palm industry employs millions of workers and plantations are one of the commonest landscapes that people actually see or spend time in within the tropics (Koh & Wilcove, 2007). If popular engagement with conservation in oil palm producing countries is to be maintained, it is therefore vital that plantation diversity is not written off as unimportant. Koh et al. (2009) suggested that oil palm landscapes should be viewed more inclusively and could include both large reserves and also smaller forest patches within oil palm plantations. Such an approach paves the way to "designing" tropical landscapes with both agriculture and biodiversity in mind. However, these ideas have met with criticism by some conservationists, as funding and implementation of such research could divert resources away from land-sparing conservation projects (Struebig et al., 2009).

Decisions on optimal strategies for maintaining crop production while protecting global biodiversity will also depend on the level of demand for different commodities in the future. For example, central to the land sparing argument is the condition that if global demands for palm oil are met by intensified production in existing regions, then no more natural habitat need be converted. However, the price of oil palm is increasing rather than reaching an asymptote or declining as global production accelerates (Figures 1 & 2). Therefore demand is still rising and higher production in intensively farmed areas may not spare land in unconverted regions (Rudel et al., 2009). Indeed it would make sense economically for nations to clear more land and farm it intensively, as this yield would continue to command a high price on global markets.

4.1 Management strategies to reduce biodiversity loss in oil palm plantations

There has been little research effort to date focussing on methods that can be employed to maintain and enhance biodiversity in and around oil palm plantations. Increasing habitat complexity at both the local and regional scale can increase biodiversity within managed landscapes (Tscharntke et al., 2008). For example, leaving forest fragments in plantations (as is often done on steep slopes and riverine margins) can provide a habitat for non-plantation species (e.g. Maddox et al., 2007). Such areas may also provide source populations for species to "spill over" into the crop (e.g. Ricketts et al., 2004). Perhaps as a result of this, the level of forest cover surrounding oil palm areas has been shown to predict species richness of butterflies and birds (Koh, 2008a). The age structure of the oil palm could also be manipulated to increase landscape heterogeneity and therefore biodiversity. Oil palm is a long-lived crop and stands may exist for up to 30 years. Over its lifespan considerable biodiversity may therefore develop, with communities of animals and plants altering as a plantation ages (De Chenon & Susanto, 2006; Koh, 2008a; Mariau, 2001). Therefore management practices that maintain a diverse age structure (e.g. by clearing and replanting areas in rotation) could also increase plantation biodiversity.

Heterogeneity at the local scale may also be manipulated in long-lived agricultural ecosystems such as oil palm. Understory vegetation is usually cleared around individual palms, but if this is maintained it can be an important habitat for insect communities, as has been found for beetles (Chung et al., 2000a). This vegetation also produces more leaf litter, which itself may support a higher diversity and abundance of litter-dwelling arthropods. Finally, as has been mentioned before, epiphytes are numerous in plantations and can support diverse insect assemblages (Turner & Foster, 2009). Therefore, maintaining these plants in plantations rather than clearing them, as is sometimes done as part of management practices (Piggott, 1988), could also increase local biodiversity.

5. The changing focus of oil palm research

5.1 Oil palm research until 2007

In 2008 we used the scientific search engine ISI Web of Science (Web of Science [WoS], 2008) to assess the changing focus of oil palm research since 1970 (Turner et al., 2008). By entering the search term ""palm oil" or "oil palm"" we accessed over 3000 oil palm research papers published between 1970 and 2006. For each of these we recorded their main research focus as interpreted through their title, abstract, key words, journal title and subject classification. Based on this we classified each publication as belonging to one of the following categories:

1. Biodiversity and conservation
2. Environment
3. Social/human welfare
4. Diet and health
5. Pests, diseases and pollination
6. Industry improvements and oil palm biology
7. Chemistry, engineering and biotechnology
8. Biofuels
9. Alternative uses and by-products
10. Other

Based on analysis of these categories it was therefore possible to visualize how the focus of oil palm research had changed since 1970.

It was clear that there had been a dramatic increase in publications on oil palm over that time with a concurrent broadening in the scope of research. Surprisingly we found that less than 1% of publications related to biodiversity and species conservation, but that this number was increasing. There was also a marked increase in the number of publications on the subject of biofuel (Turner et al., 2008).

5.2 Oil palm research since 2007

Since 2007 there have been another 1722 new publications on oil palm featured in ISI Web of Science (WoS, 2011). Using the same methods as we employed before, we classified these new papers into the ten different research categories and examined those on the subject of biodiversity and conservation in greater detail. Since 2007 there has been a significant number of new publications on biodiversity and conservation (another 71 papers, 4% of the total), and biofuel (280 papers, 16% of the total) (Figure 4). There has also been a substantial increase in the number of publications investigating alternative uses of palm oil (153 publications, 9%). If these do indeed lead to more palm oil use in alternative industries, it will also result in increased demand for palm oil in the future.

The new studies have boosted our understanding of the impacts of oil palm expansion on biodiversity and have particularly provided information on a more diverse range of taxa, including arthropods (Turner & Foster, 2009), ants (Brühl & Eltz, 2010; Fayle et al., 2010; Hashim et al., 2010), butterflies (Danielsen et al., 2008; Koh & Wilcove, 2008), small mammals (Bernard et al., 2009; Danielsen et al., 2008), and birds (Sheldon et al., 2010). Results have illustrated unambiguously the severe threat that oil palm cultivation represents to global biodiversity. There have also been publications on the role of forest fragments in maintaining biodiversity in plantations, although this important subject is still little studied. These show that non-plantation species can be maintained in such areas (Struebig et al., 2008), although communities are markedly different from those in intact forest (Edwards et al., 2010) and genetic diversity may be reduced (Benedick et al., 2006; Bickel et al., 2006). Maintenance of large forest reserves is therefore essential for the conservation of tropical forest diversity.

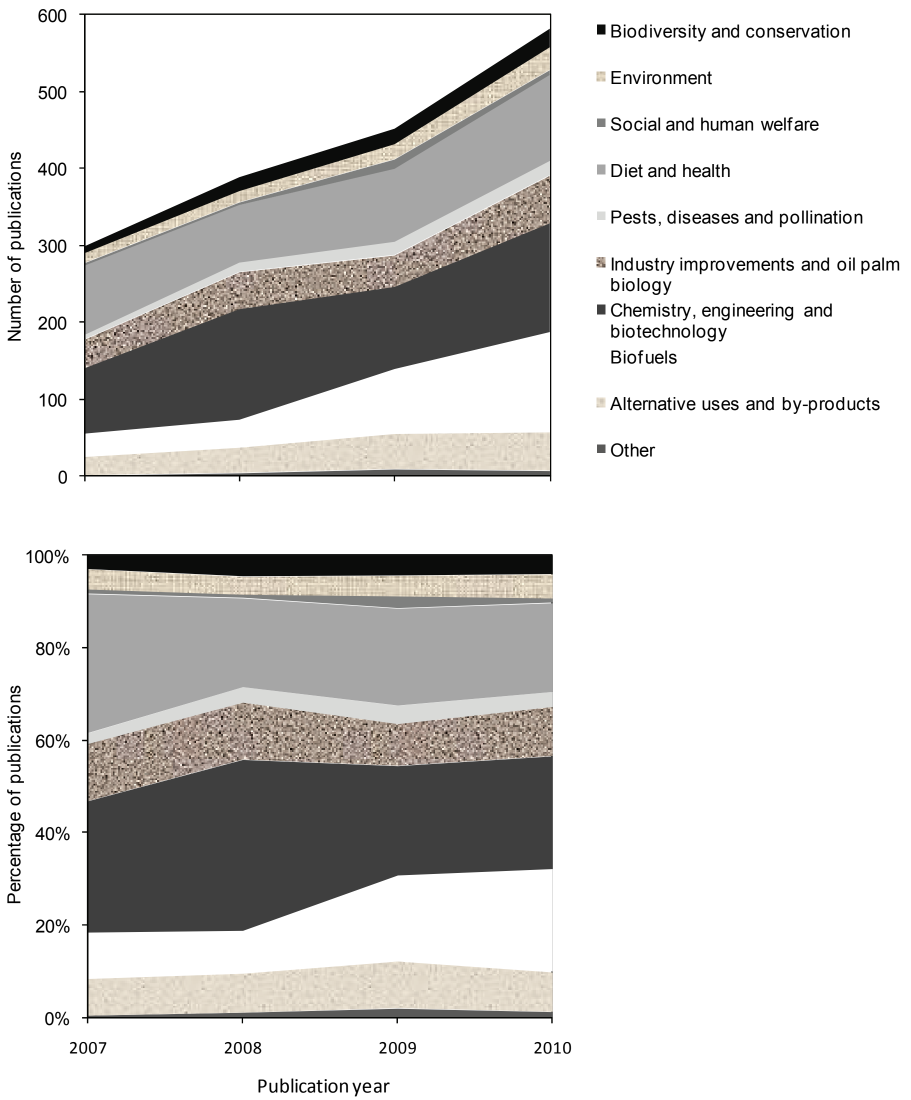

Fig. 4. Number and percentage of publications on oil palm in different research areas published since 2007. Papers were accessed using the scientific search engine, ISI Web of Science (WoS, 2008), by entering the search term ""palm oil" or "oil palm"" and assigned to categories based on their title, abstract, key words, journal title and subject classification

5.3 Gaps in existing knowledge and future research priorities

Despite this increase in knowledge, substantial gaps still exist in our understanding of the impacts of oil palm expansion and the functioning of oil palm ecosystems. In particular, it is still not clear how communities and ecosystem functions fare as plantations develop, although limited research indicates that communities change as oil palm matures (De Chenon & Susanto, 2006). Indeed only half of the publications directly comparing biodiversity between oil palm and forest habitats actually report the age of oil palm in which the study was carried out. There are still no publications linking habitat management to biodiversity and ecosystem functioning in plantations, although this is a crucial topic for the continued sustainable production of palm oil. Finally, few studies in oil palm have investigated the role of non-crop habitats in maintaining biodiversity, although again these areas can be important in maintaining biodiversity in oil palm plantations, may provide corridors for species to move between forest reserves, and could act as reservoirs for species which may spill out into plantations to perform important ecosystem functions (Ricketts et al., 2004) or indeed act as pests.

6. Links between the oil palm industry, scientists and conservationists

It is clear that much more research must be carried out if we are to move towards the development of tropical landscapes which sustainably produce palm oil and have minimal detrimental impacts on tropical biodiversity. Central to this goal is forging more links between the oil palm industry, conservation and science bodies; an aim which has proved difficult to achieve in the past, owing to widely diverging philosophies and knowledge bases (Koh et al., 2009; Struebig, 2010). Only by working closely together, can these different stakeholders ensure that their respective goals are met. For example, conservation scientists must be free to work in plantations if they are to understand how these ecosystems function and this requires industry collaboration and involvement. Similarly, industry stakeholders must be free to advise conservation researchers on existing management practices and the economic realities of oil palm cultivation if unrealistic and uneconomic policy advice is to be avoided. Finally, more links must be made between the conservation and industry-grounded research that is taking place, to ensure a free exchange of ideas and to avoid duplication of research effort. Indeed many additional studies on oil palm ecosystems probably exist within the grey literature that are not cited in this chapter owing to difficulties in locating such material (Anderson, 2008). The impact of such work outside of the industry on conservation and international policy is therefore limited. Similarly, many of the publications in academic journals are not readily available to industry workers, reducing their impact on policy implementation. Such a disparity in the circulation of literature can increase differences in the knowledge-bases between industry, conservation and science, exacerbating misunderstandings and direct conflicts between stakeholders (Koh et al., 2009). Implementation of new policies, informed by novel research also requires close engagement with the industry as well as with industry regulating bodies. The Round Table on Sustainable Palm Oil [RSPO] (RSPO, 2011), with a mission statement to promote the growth of sustainable palm oil, is already actively engaged with major oil palm producers and consumers, and can provide a platform for the launch of such new policies.

Closer collaboration between industry, research and conservation can also have potential mutual benefits as far as funding is concerned. The oil palm industry makes considerable profits each year and it has been suggested that these could be used in part to fund conservation practices at the plantation scale (Koh & Wilcove, 2007). Such work, if properly implemented, could also help plantations achieve sustainability criteria and therefore command a higher price for their products. Collaboration of this kind can also provide access to international funding designed to minimize further conversion of forest: these include identifying and protecting High Conversion Value forest, Reducing Emissions from Deforestation and Forest Degradation (REDD), and biodiversity banking (Yaap et al., 2010).

6.1 Analysis of the relationship between conservation and industry research

Despite the potential benefits of closer collaboration, there is still a wide divide between conservation and industry in the oil palm sector. To determine the level of engagement between the oil palm industry and conservation science, we examined the top 10 most cited research papers on the subject of biodiversity and conservation that we found during a Web of Science search with the search terms ""oil palm" or "palm oil"" and "biodiversity" and "conservation". For each publication, we recorded which papers had cited it and assigned each of these to biodiversity and conservation or industry sectors, based on the focus of the journal the paper was in and the home institution of the first author (Figure 5).

We found that a quarter of the citations were from the industry sector, indicating a fairly high level of engagement of industry with conservation research. This also indicates that conservation research results are being disseminated successfully to the oil palm industry, hopefully signalling a greater level of understanding between these sectors in the future. More now needs to be done to increase collaboration between conservation and industry to increase the transfer of ideas and results. Central to this is a greater awareness of industry grey literature by conservation scientists.

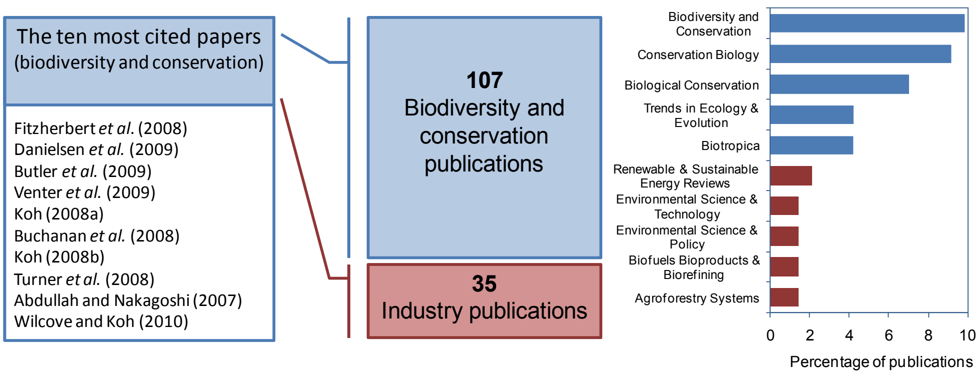

Fig. 5. Citation map showing the links between the top ten most cited biodiversity and conservation publications on the subject of oil palm accessed using the Web of Science search engine (WoS, 2011) (see reference list for full reference details). Between them, the ten papers were cited 142 times, with one quarter of citations being in industry publications. The histogram on the right shows percentage of citations by the different conservation and industry journals. Although there is overlap between conservation and industry research, there is clearly scope for more collaboration

7. The SAFE Project

The Stability of Altered Forest Ecosystems [SAFE] Project (SAFE Project, 2011; Ewers et al., 2011) has recently been set up in Sabah, Malaysia to investigate the impacts of tropical habitat change on biodiversity and ecosystem functioning in tropical ecosystems – with a particular focus on forest fragmentation and conversion to oil palm plantation. The success of this project relies on a close working relationship between the oil palm industry, academic research institutions, and the Malaysian Government and provides a template for collaboration between oil palm stakeholders. Development of such large-scale, long-term projects is crucial in developing scientific understanding of the impacts of forests to environmental change (Clark et al., 2001).

The project itself is based within a concession area managed by the Sabah Foundation (a state government body charged with the socio-economic development of the Malaysian state of Sabah (Yayasan Sabah, 2011)), and includes areas of logged forest and oil palm plantation managed by Benta Wawasan and Sabah Softwoods (subsidiary companies of the Sabah Foundation). Funding for the project has been guaranteed for ten years by the Sime Darby Foundation (Sime Darby Foundation, 2011), with in kind contributions from Benta Wawasan. Academically, the project is led by Imperial College London in collaboration with the Royal Society South East Asia Rainforest Research Programme [SEARRP] (SEARRP, 2011). Finally, the research itself is carried out by an international team of scientists, with the help of a team of 15 full-time Malaysian research assistants. The majority of these researchers come from independent institutions: to date more than 150 scientists from over 50 different institutions in 13 countries have worked on or expressed an interest in working on the project. In addition to these independent researchers, the project funds both Malaysian and international Ph.D. students and post-doctoral researchers.

Research plots for the project range from pristine primary rainforest around Maliau Basin Studies Centre (an area of over 58,840 hectares of unlogged forest), logged forest and areas of established oil palm. In addition to logged forest areas which will remain under forest, research plots are also located in a 7200 ha area of the Benta Wawasan forestry estate that has been earmarked for conversion to oil palm plantation in 2011. Working closely with Benta Wawasan, the SAFE Project has designed a landscape in which 800ha of forest will be spared clearance, and will be maintained in an arrangement of circular fragments of 100ha, 10ha and 1ha (42 experimental fragments in total). This design allows the comparison of biodiversity and ecosystem functioning across a range of disturbances, as well as direct experimental tests of the impacts of tropical forest fragmentation and conversion. Within this major topic the project has a wide remit, including research on biodiversity, carbon and nutrient dynamics, ecosystem services within plantations, and disease transfer. The project also encompasses research on a very wide range of taxa including plants (trees, epiphytes and vines), insects (particularly beetles, termites and ants), birds, mammals and amphibians. By setting up an experimentally-designed landscape, which includes forest fragments within the oil palm matrix, the project will directly investigate the importance of habitat heterogeneity in maintaining biodiversity and ecosystem functioning in human-managed landscapes. This will provide answers to key research questions for conservationists and agronomists alike. As well as representing an important step forward in collaboration between stakeholders, this project is on a scale that would not be possible without industry involvement, and will directly facilitate knowledge transfer between science and industry. We hope that collaborative research projects such as this and others (for example the

Zoological Society of London's [ZSL] Biodiversity and Oil Palm Project (ZSL, 2011)) will become more common in the future, facilitating conservation in the tropics, as well as spearheading sustainable development projects.

8. Conclusion

The rapid expansion of agriculture in the tropics poses a huge threat to tropical and therefore to global biodiversity. However, it also presents opportunities for conservation and research through closer collaboration between industry players and conservationists. Until now there has been only a limited transfer of ideas and knowledge between different oil palm stakeholders. It is vital that this situation changes to ensure that landscapes can be designed to fulfil the functions of production and conservation. This is not only important for biodiversity conservation within and outside of reserves, but also represents the best opportunity for palm oil to be produced sustainably.

9. Acknowledgement

We would like to thank Sime Darby, Yayasan Sabah and Benta Wawasan, the Sabah Forestry Department and the Royal Society South East Asia Rainforest Research Programme for supporting the SAFE Project. Researchers interested in collaborating on the SAFE Project should visit the SAFE Project website (www.safeproject.net) for more information.

10. References

Anderson, JM. (2008). Eco-Friendly Approaches to Sustainable Palm Oil Production. *Journal of Oil Palm Research,* Special Issue, (October 2008), pp.127-142, ISSN 1511-2780

Aratrakorn, S.; Thunhikorn, S. & Donald, PF. (2006). Changes in bird communities following conversion of lowland forest to oil palm and rubber plantations in southern Thailand. *Bird Conservation International,* Vol.16, No.1, (March 2006), pp. 71-81, ISSN 0959-2709

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science Technology,* Vol. 109, No.4, (Apil 2007), pp. 289-295, ISSN 1438-7697

Benedick, S.; Hill, JK.; Mustaffa, N.; Chey, VK.; Maryati, M.; Searle, JB.; Schilthuizen, M. & Hamer, KC. (2006). Impacts of rain forest fragmentation on butterflies in northern Borneo: species richness, turnover and the value of small fragments. *Journal of Applied Ecology,* Vol.43, No.5, (October 2006), pp. 967-977, ISSN 0021-8901

Benedick, S.; White, TA.; Searle, JB.; Hamer, KC.; Mustaffa, N.; Chey, VK.; Mohamed, M.; Schilthuizen, M. & Hill, JK. (2007). Impacts of habitat fragmentation on genetic diversity in a tropical forest butterfly on Borneo. *Journal of Tropical Ecology,* Vol.23, No.6, (November 2007), pp.623-634, ISSN 0266-4674

Bernard, H.; Fjeldså, J. & Mohamed, M. (2009). A case study on the effects of disturbance and conversion of tropical lowland rain forest on the non-volant small mammals in north Borneo: Management implications. *Mammal Study,* Vol34, No.2, (June 2009), pp.85-96, ISSN 1343-4152

Bickel, TO.; Brühl, CA.; Gadau, JR.; Hölldobler, B. & Linsenmair, KE. (2006). Influence of Habitat Fragmentation on the Genetic Variability in Leaf Litter Ant Populations in

Tropical Rainforests of Sabah, Borneo. *Biodiversity and Conservation*, Vol.15, No.1, (January 2006), pp.157-175, ISSN 0960-3115

Brühl, CA. & Eltz, T. (2010). Fuelling the biodiversity crisis: species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo). *Biodiversity and Conservation*, Vol.19, No.2, (February 2010), pp.519-529, ISSN 0960-3115

Bulgarelli, J.; Chinchilla, C. & Rodríguez, R. (2002). Male inflorescences, population of *Elaeidobious kamerunicus* and pollination in a young commercial oil palm plantation in a dry area of Costa Rica. *ASD Oil Palm Papers*, Vol.24, pp.32-37

Caudwell, RW.; Hunt, D.; Reid, A.; Mensah, BA. & Chinchilla, C. (2003). Insect pollination of oil palm - a comparison of the long term viability and sustainability of *Elaeidobious kamerunicus* in Papua New Guinea, Indonesia, Costa Rica, and Ghana. *ASD Oil Palm Papers,* Vol.25, pp.1-16

Chang, MS.; Hii, J.; Buttner, I. & Mansoor, F. (1997). Changes in abundance and behaviour of vector mosquitoes induced by land use during the development of an oil palm plantation in Sarawak. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* Vol.91, pp.382-386

Chey, VK. (2006). Impacts of forest conversion on biodiversity as indicated by moths. *Malayan Nature Journal,* Vol.57, pp.383-418

Chung, AYC.; Eggleton, P.; Speight, MR.; Hammond, PM. & Chey, VK. (2000a). The diversity of beetle assemblages in different habitat types in Sabah, Malaysia. *Bulletin of Entomological Research,* Vol.90, No.6, (December 2000), pp.475-496, ISSN 0007-4853

Chung, AYC.; Hammond, PM.; Eggleton, P.; Speight, MR. & Chey, VK. (2000b). A general survey of the Staphylinidae (Insecta: Coleoptera) assemblage in Sabah, Malaysia . *Malayan Nature Journal,* Vol.54, pp.355–368

Clark, JS.; Carpenter, SR.; Barber, M.; Collins, S.; Dobson, A.; Foley, JA.; Lodge, DM.; Pascual, M.; Pielke, R.; Pizer, W.; Pringle, C.; Reid, WV.; Rose, KA.; Sala, O.; Schlesinger, WH.; Wall, DH, &Wear, D. (2001). Ecological forecasts: an emerging imperative. *Science*, Vol.293, No.5530, (July 2001), pp.657-660, ISSN 0036-8075

Corley, RHV. (2009). How much palm oil do we need? *Environmental Science & Policy,* Vol.12, pp.134-139, ISSN: 1462-9011

Corley, RHV. & Tinker, PBH. (2003). *The Oil Palm,* Blackwells, ISBN 0632052120. Oxford, UK

Danielsen, F. & Heegaard, M. (1995). Impact of logging and plantation development on species diversity: a case study from Sumatra, In *Management of tropical forests: towards an integrated perspective*, O. Sandbukt, (Ed.), Centre for Development and the Environment, ISBN 8290391250, Oslo, Norway.

Danielsen, F.; Beukema, H.; Burgess, ND.; Parish, F.; Brühl, CA.; Donald, PF.; Murdiyarso, D.; Phalan, B.; Reijinders, L.; Struebig, M. & Fitzherbert, EB. (2008). Biofuel Plantations on Forested Lands: Double Jeopardy for Biodiversity and Climate. *Conservation Biology,* Vol.23, No.2, (April 2009), pp.348-358, ISSN 0888-8892

Davis, ALV. & Philips, TK. (2005). Effect of Deforestation on a Southwest Ghana Dung Beetle Assemblage (Coleoptera: Scarabaeidae) at the Periphery of Ankasa Conservation Area. *Environmental Entomology*, Vol.34, No.5, (October 2005), pp.1081-1088, ISSN 0046-225X

De Chenon, RD. & Susanto, A. (2006). Ecological observations on diurnal birds in Indonesian oil palm plantations. *Journal of oil palm research.* Special Issue, pp.122-143

Donough, CD.; Witt, C.; Fairhurst, TH. (2009) Yield intensification in oil palm plantations through best management practice. Better Crops, Vol.93, No.1, pp.12-14, ISSN 0006-0089

Edwards, DP.; Hodgson, JA.; Hamer, KC.; Mitchell, SL.; Ahmad, AH.; Cornell, SJ. & Wilcove, DS. (2010). Wildlife-friendly oil palm plantations fail to protect biodiversity effectively. *Conservation Letters,* Vol.3, No.4, (August 2010), pp.236-242, ISSN 1755-263X

Ewers, RM.; Didham, RK.; Fahrig ,L.; Ferraz, G.; Hector, A.; Holt, RD.; Kapos, V.; Reynolds, G.; Sinun, W.; Snaddon, JL. & Turner, EC. (2011). A large-scale forest fragmentation experiment: the Stability of Altered Forest Ecosystems Project. *Philosophical Transactions of the Royal Society of London B*, in press

FAO (2011). In: *FAOSTAT Online Statistical Service. Food and Agriculture Organization of the United Nations,* Accessed March 2011, Available from: http://faostat.fao.org

Fayle, TM.; Chung, AYC; Dumbrell, AJ.; Eggleton, P. & Foster, WA. (2009). The effect of rain forest canopy architecture on the distribution of epiphytic ferns (*Asplenium* spp.) in Sabah Malaysia. *Biotropica,* Vol.41, No.6, (November 2009), pp.676-681, ISSN 0006-3606

Fayle, TM.; Turner, EC.; Snaddon, JL.; Chey, VK.; Chung, AYC.; Eggleton, P. & Foster, WA. (2010). Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. *Basic and Applied Ecology,* Vol.11, No.4, (2010), pp.337-345, ISSN 1439-1791

Fitzherbert, EB.; Struebig, MJ.; Morel, A.; Danielsen, F.; Brühl, CA.; Donald, PF. & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution,* Vol.23, No.10, (October 2008), pp.538-545, ISSN 0169-5347

Foley, JA.; DeFries, R.; Asner, GP.; Barford, C.; Bonan. G.; Carpenter, SR.; Chapin, FS.; Coe, MT.; Daily, GC.; Gibbs, HK.; Helkowski, JH.; Holloway, T.; Howard, EA.; Kucharik, CJ.; Monfreda, C.; Patz, JA.; Prentice, IC.; Ramankutty, N. & Snyder, PK. (2005). Global consequences of land use. *Science,* Vol.309, No.5734, (July 2005), pp.570-574, ISSN 0036-8075

Foster, WA.; Snaddon, JL.; Turner, EC.; Fayle, TM.; Cockerill, TD.; Ellwood, MDF.; Broad, GR.; Chung, AYC.; Eggleton, P.; Chey, VK.; & M. Yusah, K. (2011). Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia *Philosophical Transactions of the Royal Society of London B*, in press

Gibbs, HK.; Ruesch, AS.; Achard, F.; Clayton, M.K.; Holmgren, P.; Ramankutty, N. & Foley, JA. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, Vol.107, No.38, (September 2010), pp.16732-16737, ISSN 0027-8424

Glor, RE.; Flecker, AS.; Benard, MF. & Power, AJ. (2001). Lizard diversity and agricultural disturbance in a Caribbean forest landscape. *Biodiversity and Conservation,* Vol.10, No.5, (May 2001), pp.711-723, ISSN 0960-3115

Greathead, DJ. (1983) The multi-million dollar weevil that pollinates oil palms. *Antenna,* Vol.7, pp.105-107

Green, RE.; Cornell, SJ.; Scharlemann, JPW. & Balmford, A. (2005). Farming and the fate of wild nature. *Science,* 307, No.5709, (January 2005), pp.550-555, ISSN 0036-8075

Hashim, NR.; Akmal, WF.; Jusoh, W. & Nasir, MNSM. (2010). Ant diversity in a Peninsular Malaysian mangrove forest and oil palm plantation. *Asian Myrmecology,* Vol.3, No.3, (2010), pp:5-8, ISSN 1985-1944

Hassall, M.; Jones, DT.; Taiti, S.; Latipi, Z.; Sutton, SL. & Mohammed, M. (2006). Biodiversity and abundance of terrestrial isopods along a gradient of disturbance in Sabah, East Malaysia. *European Journal of Soil Biology,* Vol.42, No.1, (November 2006), pp.S197-S207, ISSN 1164-5563

Henderson, J. & Osborne, DJ. (2000). The oil palm in our lives: how this came about. *Endeavour,* Vol.24, No.2, (2000), pp. 63-, ISSN 0160-9327

Jackson, L.; van Noordwijk, M.; Bengtsson, J.; Foster, W.; Lipper, L.; Pulleman, M.; Said, M.; Snaddon, J. & Vodouhe, R. (2010). Biodiversity and agricultural sustainagility: from assessment to adaptive management. *Current Opinion in Environmental Sustainability,* Vol.2, No.1-2, (May 2010), pp.80-87, ISSN 1877-3435

Jonsson, M.; Wratten, SD.; Landis, DA. & Gurr, GM. (2008). Recent advances in conservation biological control of arthropods by arthropods. *Biological Control,* Vol.45, No.2, (May 2008), pp.172-175, ISSN 1049-9644

Koh, LP. (2007). Potential habitat and biodiversity losses from intensified biodiesel feedstock production. *Conservation Biology,* Vol.21, pp.1373–1375, ISSN 1523-173

Koh, LP. & Wilcove, DS. (2007). Cashing in palm oil for conservation. *Nature,* Vol.448, No.7157, (August 2007), pp.993-994, ISSN 0028-0836

Koh, LP. & Wilcove, DS. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters,* Vol.1, No.2, (June 2008), pp.60-64, ISSN 1755-263X

Koh, LP. & Ghazoul, J. (2008). Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. *Biological Conservation,* Vol.141, No.10, (October 2008), pp.2450 – 2460, ISSN 0006-3207

Koh, LP. (2008a). Can oil palm plantations be made more hospitable for forest butterflies and birds? *Journal of Applied Ecology,* Vol.45, No.4, (2008), pp.1002-1009, ISSN 0021-8901

Koh, LP. (2008b) Birds defend oil palms from herbivorous insects. *Ecological Applications,* Vol.18, No.4, (June 2008), pp.821- 825, ISSN 1051-0761

Koh, LP.; Levang, P. & Ghazoul, J. (2009) Designer landscapes for sustainable biofuels. *Trends in Ecology and Evolution,* Vol.24, No.8, (August 2009), pp.431-438, ISSN 0169-5347

Koh, LP.; Ghazoul, J.; Butler, RA.; Laurance, WF.; Sodhi, NJ.; Mateo-Vega, J. & Bradshaw, CJA. (2010). Wash and spin cycle threats to tropical biodiversity. *Biotropica,* Vol.42, No.1, (January 2010), pp.67-71, ISSN 0006-3606

Liow, LH.; Sodhi, NS. & Elmqvist, T. (2001). Bee Diversity along a Disturbance Gradient in Tropical Lowland Forests of South-East Asia. *Journal of Applied Ecology,* Vol.38, No.1, (February 2001), pp.180-192, ISSN 0021-8901

Maddox, T.; Priatna, D.; Gemita, E.; & Salampessy, A. (2007). The conservation of tigers and other wildlife in oil palm plantations. *ZSL Conservation Report,* No.7

Mariau, D. & Genty, P. (1988). IRHO contribution to the study of oil palm insect pollinators in Africa, South America and Indonesia. *Oleagineux,* Vol.43, No.6, (June 1988), pp.233-240, ISSN 0030-2082

Mariau, D. (2001) *The fauna of oil palm and coconut: insect and mite pests and their natural enemies*. CIRAD, ISBN 2-87614-478-6, Montpellier, France

Mathews, J. & Foong, LC. (2010). Yield and harvesting potentials. *The Planter*, Vol.86, No.1015, pp.699-709, ISSN 0126-575x

Mayfield, MM. (2005) The importance of nearby forest to known and potential pollinators of oil palm (*Elaeis guineensis* Jacq.; Areceaceae) in southern Costa Rica. *Economic Botany,* Vol.59, No.2, (Summer 2005), pp.190- 196, ISSN 0013-0001

Murphy, DJ. (2009). Oil palm: future prospects for yield and quality improvements. *Lipid Technology,* Vol.21, No.11-12, (November/December 2009), pp.257–260, ISSN 1863-5377

Myers, N.; Mittermeier, RA.; Mittermeier, CG.; de Fonseca, GAB. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature,* Vol.403, No.6772, (February 2000), pp.853-858, ISSN 0028-0836

Novotny, V.; Drozd, P.; Miller, SE.; Kulfan, M.; Janda, M.; Basset, Y.& Weiblen, GD. (2006). Why are there so many species of herbivorous insects in tropical rainforests? *Science,* Vol.313, No.5790, (August 2006), pp.1115-1118, ISSN 0036-8075

Peh, KS-H.; Sodhi, NS.; Jong, JD.; Sekercioglu, CH.; Yap, CA-M. & Lim SL-H. (2006). Conservation value of degraded habitats for forest birds in southern Peninsular Malaysia. *Diversity and Distributions,* Vol.12, No.5, (September 2006), pp.572-581, ISSN 1366-9516

Piggott, AG. (1988). *Ferns of Malaysia in Colour*. Tropical Press, ISBN 9677300296, Kuala Lumpur, Malaysia

Ricketts, TH.; Daily, GC.; Ehrlich, PR. & Michener CD. (2004). Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the United States of America,* Vol.101, No.34, (August 2004), pp.12579-12582, ISSN 0027-8424

Room, P M. (1975). Diversity and organization of the ground foraging ant faunas of forest, grassland and tree crops in Papua New Guinea. *Australian Journal of Zoology,* Vol.23, No.1, (1975), pp.71-89, ISSN 0004-959X

Round Table on Sustainable Palm Oil (RSPO) (2011). Accessed March 2011, Available from www.rspo.org

Royal Society South East Asia Rainforest Research Programme (SEARRP) (2011). Accessed March 2011, Available from www.searrp.org

Rudel, TK.; Schneider, L.; Uriarte, M.; Turner, BL.; Defries, R.; Lawrence, D.; Geoghegan, J.; Hecht, S.; Ickowitz, A.; Lambin, EF.; Birkenholtz, T.; Baptista, S. & Grau, R. (2009). Agricultural intensification and changes in cultivated a2, 1970-2005. *Proceedings of the National Academy of Sciences*, Vol. 106, No.49, pp.20675-20680, ISSN-0027-8424

Sheldon, FH.; Styring, A. & Hosner, PA. (2010). Bird species richness in a Bornean exotic tree plantation: A long-term perspective. *Biological Conservation,* Vol.143, No.2, (February 2010), pp.399-407, ISSN 0006-3207

Schmid, B.; Balvanera, P.; Cardinale, BJ.; Godbold, J.; Pfisterer, AB.; Raffaelli, D.; Solan, M. & Srivastava, DS. (2009). Consequences of species loss for ecosystem functioning: meta-analyses of data from biodiversity experiments, In: *Biodiversity, Ecosystem Functioning, and Human Wellbeing an Ecological and Economic Perspective,* S. Naeem; DE. Bunker; A. Hector; M. Loreau & C. Perrings (Ed.), 14-29, Oxford University Press, ISBN 0199547955, Oxford, UK.

Sime Darby Foundation (2011). Accessed March 2011, Available from www.yayasansimedarby.com

Sodhi, NS.; Koh, LP.; Brook, BW. & Ng, PKL. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution,* Vol.19, No.12, (December 2004), pp.654-660, ISSN 0169-5347

Sodhi, NS.; Posa, MRC.; Lee, TM.; Bickford, D.; Koh, LP. & Brook, BW. (2010). The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation,* Vol.19, No.2, (February 2010), pp.317-328, ISSN 0960-3115

Stability of Altered Forest Ecosystems (SAFE) Project (2011). Accessed March 2011, Available from www.safeproject.net

Struebig, M.; Kingston, T.; Zubaid, A.; Adnan, A. & Rossiter, A. (2008). Conservation value of forest fragments to Palaeotropical bats. *Biological Conservation,* Vol.141, No.8, (August 2008), pp.2112-2126, ISSN 0006-3207

Struebig, MJ.; Paoli, G. & Meijaard, E. (2009). A reality check for designer landscapes. *Trends in Ecology and Evolution*, Vol.25, No.1, (January 2010), pp.7-8, ISSN 0169-5347

Struebig, MJ. (2010). Reassessing the "real scenario" regarding the environmental sustainability of palm oil. *Renewable and Sustainable Energy Reviews*, Vol.14, No.8 (October 2010), pp.2443-2444, ISSN 1364-0321

Syed, RA. (1979) Studies on oil palm pollination by insects. *Bulletin of Entomological Research,* Vol.69, No.15, (1979), pp.213-224, ISSN 0007-4853

Taylor, B. (1977). The ant mosaic on cocoa and other tree crops in Western Nigeria. *Ecological Entomology*, Vol.2, No.3, (1977), pp.245-255, ISSN 0307-6946

Tscharntke, T.; Bommarco, R.; Clough, Y.; Crist, TO.; Kleijn, D.; Rand, TA.; Tylianakis, JM.; van Nouhuys, S & Vidal, S. (2007). Conservation biological control and enemy diversity on a landscape scale. *Biological Control,* Vol.43, No.3, (December 2007), pp.294-309, ISSN 1049-9644

Tscharntke, T.; Sekercioglu, CH.; Dietsch, TV.; Sodhi, NS.; Hoehn, P. & Tylianakis, JM. (2008). Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. *Ecology,* Vol.89, No.6, (June 2008), pp.944-951, ISSN 0012-9658

Turner, EC. & Foster, WA. (2006). Assessing the influence of bird's nest ferns (*Asplenium* spp.) on the local microclimate across a range of habitat disturbances in Sabah, Malysia. *Selbyana,* Vol.27, No. 2, (2006), pp.195-200, ISSN 0362-185X

Turner, EC.; Snaddon, JL.; Fayle, TM. & Foster, WA. (2008). Oil palm research in context: identifying the need for biodiversity assessment. *PLoS ONE,* Vol.3, No.2, (Feb 2008), ppe2579, ISSN 1932-6203

Turner, EC. & Foster, WA. (2009). The impact of forest conversion to oil palm on arthropod abundance and biomass in Sabah, Malaysia. *Journal of Tropical Ecology*, Vol.25, No.1, (January 2009), pp.23-30, ISSN 0266-4674

Turner, PD. & Gillbanks, RA. (2003). *Oil palm cultivation and management*. The Incorporated Society of Planters, ISBN 0-632-05212-0, Kuala Lumpur, Malaysia.

Web of Science (2011). ISI Web of Science for UK Education, Thomson Scientific Product, Accessed September 2007, January 2008 and March 2011, Available from http://wos.momas.ac.uk/

Wilcove, DS. & Koh, LP. (2010). Addressing the threats to biodiversity from oil-palm agriculture. *Biodiversity and Conservation,* Vol.19, pp.999-1007

Wood, BJ. (2002). Pest control in Malaysia's perennial crops: A half century perspective tracking the pathway to integrated pest management. *Integrated Pest Management Reviews,* Vol.7, pp.173-190

Yaap, B.; Struebig, MJ.; Paoli, G. & Koh, LP. (2010). Mitigating the biodiversity impacts of oil palm development. *CAB Reviews,* Vol.5, pp.1-11

Yayasan Sabah (2010). Accessed March 2011, Available from www.ysnet.org.my

Zhang, W.; Ricketts, TH.; Kremen, C.; Carney, K. & Swinton, SM. (2007). Ecosystem services and dis-services to agriculture. *Ecological Economics,* Vol.64, No.2, (December 2007), pp.253-260, ISSN 0921-8009

Zoological Society of London (ZSL) (2011). Biodiversity and Oil Palm Project. Accessed March 2011, Available from http://oilpalm-biodiversity.info/?page_id=38