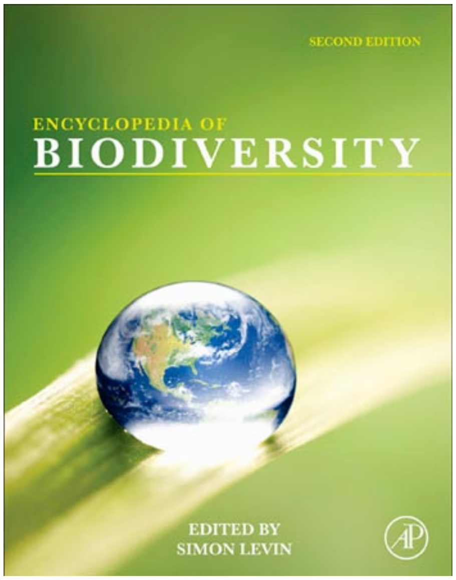

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Oil-Palm Plantations in the Context of Biodiversity Conservation

Erik Meijaard, People and Nature Consulting International, Jakarta, Indonesia; University of Queensland, Brisbane, QLD, Australia, and Center for International Forestry Research, Bogor, Indonesia
Douglas Sheil, Mbarara University of Science and Technology, Kabale, Uganda; Center for International Forestry Research, Bogor, Indonesia, and Southern Cross University, Lismore, NSW, Australia

Glossary

Biofuel Wide range of fuels that are in some way derived from biomass.
Endosperm Nutritive storage tissue in the seeds of most angiosperms.
Epiphyte Plant that grows on another plant nonparasitically or sometimes on some other object.
Hectare (ha) Area equal to 2.47 acres.
Mesocarp Botanical term for the middle layer of the pericarp – for example, comprising the flesh of fruits such as plums and cherries.
Monoecious In the current context, having male and female flowers on the same plant.

Oil Palm: Green Gold or Great Evil?

An Introduction to the Green Gold

Few topics provide as much controversy in tropical forest and wildlife conservation as the rapid expansion of oil palm (*Elaeis guineensis*) plantations. On the one hand, oil palm has been linked to deforestation, peat degradation, biodiversity loss, forest fires, and a range of social issues (Danielsen *et al.*, 2009; Koh and Wilcove, 2008, 2009; Sheil *et al.*, 2009; Sodhi *et al.*, 2010). On the other hand, oil-palm expansion is considered a powerful driver of economic development in tropical countries with low levels of welfare (Casson, 2000; McCarthy and Zen, 2010; Sheil *et al.*, 2009; World Growth, 2011), and it has been referred to as "green gold" (Friends of the Earth, 2008). Economic development can lead to reduced levels of forest loss, and biofuels from oil palm can reduce global carbon emissions, but the unanswered question is whether, at a global scale, do the benefits of oil palm outweigh the environmental costs? With much of Earth's species diversity residing in tropical areas where oil palm thrives, there seems ample reason to closely assess the role that oil palm has played in tropical deforestation and loss of wildlife. Here the authors review the role of oil palm in biodiversity loss and conservation by assessing its impacts over a range of different spatial scales and in different socioecological contexts.

Basics

The origin of oil palm lies in the tropical rain forest region of West Africa in a region about 200–300 km wide along the coastal belt from Liberia to Angola (Duke, 1983). It has been described as "probably the most useful tree in West Africa" (Irvine, 1961). In prehistory, the palm was likely spread by people to a much larger area in Africa, ranging from 16° N latitude in Senegal to 15° S in Angola and eastward to the Indian Ocean, Zanzibar, and Madagascar. It has also been introduced and cultivated outside Africa and now occurs throughout the tropics between 16° N and 16° S latitudes. A distinct, closely related species of the oil palm, *Elaeis oleifera* (also known as *Elaeis melanococca*), is indigenous to Latin America. We will limit our discussion to the African species and refer to it as "oil palm."

Oil palm is a pioneer species that historically appears to replace evergreen rain forest under drier climatic conditions. For example, during the mid-Holocene in western Africa, changes in African monsoon conditions, decreased humidity, and increased fire led to the contraction of wet, evergreen rain forest and the expansion of woodland savannas. On these more-open savanna-type lands, oil palms were the dominating species (Maley, 2002; Ngomanda *et al.*, 2009; Salzmann and Hoelzmann, 2005). These vegetation shifts occurred alongside relatively "warm" regional and global conditions and could be an "analog" to events that might occur under global warming (Maley, 2002). Land clearance and burning act to increase the conditions under which oil palm thrives (Sowumni, 1999).

When fully grown, oil palms are tall, erect, single-stemmed trees that vary in heights from 8 to 20 m, with a stem diameter of as much as 50 cm. The tree is monoecious, with male and female flowers in separate clusters but on the same tree. Ecologically, this is a species of riverine forests and freshwater swamps that can tolerate temporary flooding and a fluctuating water table. The species does not do well in closed forest conditions and requires adequate light and generally open canopy conditions. It grows best in lowland areas with 1780 to 2280 mm rainfall per year, with a 2–4 month dry period, and a mean minimum temperature of 21–24 °C, but the species is adaptable and with proper care can be grown in climatic conditions outside these ranges (Duke, 1983). Its ecological adaptability is also clear from the wide range of tropical soils on which the species grows and thrives, with only waterlogged, highly lateritic, extremely sandy, stony, or peaty soils providing suboptimal growth conditions. Considering the rapid expansion of oil palm into Indonesian and Malaysian peat swamp areas (Koh *et al.*, 2011), it seems clear that even these acidic and often waterlogged conditions under appropriate silvicultural care provide suitable growing conditions for oil palm (Sheil *et al.*, 2009).

The use of oil palm by early humans is well known from the archeological record. Such uses date back to at least 4000

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years BP (Logan and D'Andrea, 2012), and it appears that people in West Africa were actively cultivating oil palm as early as 3600–3200 BP (D'Andrea *et al.*, 2007). These early people were likely encouraging the growth of oil palms and achieving higher yields by clearing land (Logan and D'Andrea, 2012). Oil palm was a "camp follower" because of its ability to regenerate from discarded seeds without any particular horticultural treatment (Zeven, 1972). It was also traded widely, as indicated by finds of palm-oil residues in 5000-year-old Egyptian tombs (Friedel, 1897) far from where the oil was likely produced.

In Africa, palm oil has many traditional uses (Maley and Chepstow-Lusty, 2001). A few written records of the local food use of a palm oil (presumably from *Ela. guineensis*) are available in accounts of European travelers to West Africa from the middle of the fifteenth century (Hartley, 1988). One source describes how oil is produced from seeds by boiling, as well as how the oil-palm kernels are roasted and either eaten directly or made into flour (De Hondt, 1749). Palm oil later became an important item in the provisioning trade supplying the caravans and ships of the Atlantic slave trade, and it apparently remains a popular foodstuff among people of African descent in the Bahia region of Brazil (Northrup, 1978). Palm oil also found its way to Europe. James Welsh first brought 32 barrels of palm oil to England in 1590, and use grew rapidly after that. By the early nineteenth century, palm oil was being used to make soap and candles; later it was used for heating and cooking and in many other products from dynamite to margarine (Henderson and Osborne, 2000).

The increasing commercial use of palm oil is shown in early trade data. In the 1840s, the West African regions of Dahomey and the Niger delta exported approximately 1000 and 13,000 tons per year, respectively; by the 1880s these totals had risen to 5000 and 20,000 (Kiple and Ornelas, 2011). After 1900, European-run plantations were established in Central Africa and Southeast Asia, and the world trade in palm oil continued to grow slowly, reaching a level of 250,000 tons per year by 1930 (Hartley, 1988), still only about 0.5% of what was produced in the early twenty-first century (*see* The Modern Expansion).

The Modern Expansion

Plantations throughout Southeast Asia originate from the seeds of only four trees planted in Java, in present-day Indonesia, in 1848 (Henderson and Osborne, 2000). In 1905, a Belgian agricultural engineer, Adrien Hallet, arrived in Sumatra, another Indonesian island, and noticed that local palms that had originated from the small Javan gene pool grew more quickly and bore a richer fruit than counterparts in the Congo, where he had previously worked (Leplae, 1939). It was obvious that under Asian equatorial conditions, the locally cultured palms held a distinct advantage over the ordinary palms of Africa (Kiple and Ornelas, 2011). Reduced seasonality in island Southeast Asia compared to west Africa has a big impact on yield, with any drought (or even loss of humidity) reducing fruit set. Also, the fact that all the Asian palms were descended from so few parents meant that the early planters could expect fairly uniform results (Kiple and Ornelas, 2011), ensuing easier management. This lowered the risks associated with plantation cultivation, an effect reinforced by the absence of the palm's usual pests and diseases in its new geographic setting. The success of oil palm was quickly noted in neighboring Malaysia, and the first plantations were established in peninsular Malaysia in 1917. By 1919, more than 6000 ha had been planted in Sumatra, rising to 32,000 in 1925, by which time 3400 ha had come under cultivation in Malaysia. Over the next 5 years, a further 17,000 ha were planted in Malaysia, whereas the Sumatran area doubled (Kiple and Ornelas, 2011). By 1998, palm oil contributed more than 5% to Malaysia's gross domestic product (Yusoff, 2006).

Oil-palm seeds were introduced to Central America by the United Fruit Company, which brought seeds from Sierra Leone to Guatemala in 1920, and from Malaysia to Panama in 1926 and Honduras in 1927 (Kiple and Ornelas, 2011). Other introductions from Java and the Belgian Congo followed, but the first commercial planting of 250 ha only took place in Guatemala in 1940. In its tropical American setting, the oil palm, however, proved vulnerable to disease – possibly due to the native American species being almost the same – and difficulties were encountered in identifying suitable growing conditions (Hartley, 1988). By 1992, the total area of oil palm planted in Latin America had grown to 390,000 ha. This is a small fraction of the area in Africa and Southeast Asia (Kiple and Ornelas, 2011), but oil-palm production in the neotropics is viewed by many as a major new force for land-use change and forest conversion in that region.

Production of palm oil in Indonesia rose from 168,000 tons grown on 105,808 ha in 1967, to roughly 16.4 million tons grown on 6.2 million ha in 2006 (Sheil *et al.*, 2009). By 2011, an annual production of 25.4 million tons was estimated for Indonesia, 18.4 million tons for Malaysia, 1450 tons for Thailand, 880 tons for Colombia, and 850 tons for Nigeria, with an additional 3281 tons from a range of countries, adding up to a global production of 50.3 million tons (USDA, 2011). Palm oil takes up about 10% of the global production of vegetable oils, which remains dominated by soybean oil (USDA, 2011). These figures suggest that Indonesia alone underwent a 150-fold increase in palm oil production in 34 years.

Currently, Indonesia is the world's largest and most rapidly growing producer. Indonesia's wet tropical climate provides ideal growing conditions for oil palm. Land is abundant, and labor is cheap (Sheil *et al.*, 2009). About 10% of Indonesia's palm oil production comes from government plantations, 40% from small holders, and 50% from private plantations (IPOC, 2006). Malaysia is the world's second-largest individual palm oil–producing nation. Together, Indonesia and Malaysia account for about 90% of crude palm oil produced globally per annum (Sheil *et al.*, 2009). In the Southeast Asian region, a total of 8.3 million ha of closed canopy oil-palm plantations occur in peninsular Malaysia (2 million ha), Borneo (2.4 million ha), and Sumatra (3.9 million ha) (Koh *et al.*, 2011), suggesting that oil palm takes up about 6.2% of the total landmass of these three regions. We note that the study by Koh and colleagues was unable to detect newly planted oil palm, so that total area of oil palm may be larger.

As a region, Africa is the second-largest producer of oil palm in the world. Data from the Food and Agricultural Organization's FAOSTAT database indicate that about 4.5 million ha of productive oil-palm plantation existed on the continent in 2009. Some 71% of African oil palm is produced in Nigeria, with Ghana, Guinea, Côte d'Ivoire, and the Democratic Republic of the Congo being other important producers.

In addition to Africa and Asia, oil-palm production is also rapidly expanding in the neotropics, with some 700,000 ha of productive plantation in 2009 (FAOSTAT data). Nearly half of the Amazon basin, around 2.3 million km^2, appears suited in terms of climate and soils for oil-palm cultivation (Stickler *et al.*, 2008). Even though the total oil-palm area remains small compared to Asia, the mean annual rate of expansion was an astonishing 7.9% between 1991 and 2001 (Bolivar and Cuellar-Mejia, 2003). Large-scale plantations are already established in Colombia, Ecuador, and Brazil, although the latter was only the world's 14th biggest producer of palm oil in 2009. If the full potential of the Amazon basin was utilized, however, Brazil alone could dwarf the current production of Asia (Butler and Laurance, 2009). Oil-palm planting has been promoted in Colombia, where it is seen as a relatively profitable alternative to cocaine (Gómez *et al.*, 2005). To differentiate it from the less-productive but similar native species *Ela. oleifera* (*see* Uses) *Ela. guineensis* is commonly referred to as the "African palm" or "dendezeiro" (Lopes and Steidle Neto, 2011). As in Asia, oil palm is viewed as a crop that can be profitable under many different levels of management intensity (including small-holders) in a wide range of contexts (Wolff, 1999). However, there are concerns over disease – though it is likely that breeders will be able to develop healthier and more-resistant varieties and hybrids (de Franqueville, 2003).

Uses

In well-managed plantations, oil palm produces 3–8 times more oil from a given area than any other tropical or temperate oil crop (Sheil *et al.*, 2009; Yusoff, 2006). Oil can be extracted from fruit and seed, palm-fruit oil from the outer mesocarp, and palm-kernel oil from the endosperm. Most palm-fruit oil is used in foods. In contrast, most palm-kernel oil is used in various nonedible products such as detergents, cosmetics, plastics, surfactants, and herbicides, as well as in industrial and agricultural chemicals (Wahid *et al.*, 2005). The use of palm oil as a biofuel is also increasing (Persson and Azar, 2010), giving oil palm an aura of environmental sustainability. In fact, if biodiversity losses from land-use changes are disregarded, oil palm is one of the most environmentally sustainable among a range of global biodiesel and ethanol crops (de Vries *et al.*, 2010). Together with sugarcane grown in Brazil and sweet sorghum grown in China, oil palms makes the most efficient use of land, water, nitrogen, and energy resources, whereas pesticide applications are relatively low in relation to the net energy per hectare produced (de Vries *et al.*, 2010).

The traditional red palm oil produced by West African village methods has a wide range of applications. It is mostly used for food (Kiple and Ornelas, 2011). This type of oil, however, has not proved suitable for food use in the importing countries of the West, where consumers require a bland, nearly white cooking fat. Today's plantation-produced palm oil can be treated to meet Western requirements, but this was not possible before the early twentieth century (Vanneck and Loncin, 1951). Once technology had advanced enough, European food manufacturers could exploit palm oil, replacing more-expensive fats such as butter, beef tallow, and lard in central and northern Europe and olive oil in southern Europe (Kiple and Ornelas, 2011). Palm oil was suitable as both liquid oil and solid fat.

Since the late 1960s, plant breeders have taken an interest in the American oil palm *Ela. oleifera* because its oil has a high iodine value and unsaturated fatty acid content, making it especially suitable for food use (Kiple and Ornelas, 2011). However, the fruit is often small, with a thin, oil-yielding mesocarp surrounding a large, thick-shelled kernel. Harvested bunches often contain a low proportion of fruit of quite variable quality. Hybrids between *Ela. guineensis* and *Ela. oleifera* have been trialed and show some advantages over *Ela. guineensis*, despite higher production costs (Amblard *et al.*, 1995).

Concern over greenhouse gases and high prices for fossil fuel have spurred interest in biofuels and alternative sources of energy. Biodiesel from palm oil (palm oil methylester) is currently leading the pack, and major investments are already planned to convert millions of hectares of tropical forests and other land types to oil-palm plantations (Sheil *et al.*, 2009).

Biofuels may have major positive or negative effects on natural forests, forest dwellers, and owners. On the one hand, biofuel from oil-palm plantations could help to promote economic prosperity and alleviate poverty (World Growth, 2011). On the other hand, demand for biofuels could increase competition for land, threaten food production, and exacerbate inequities between rich and poor (Astyk, 2006). Whether or not the use of palm oil as biodiesel yields a net reduction of greenhouse gas emissions remains debated (de Souza *et al.*, 2010; Gibbs *et al.*, 2008) but depends a lot on the type of vegetation that existed prior to oil-palm development.

High global demand feeds the current oil-palm boom. Despite many anti–oil palm campaigns targeting palm-oil consumers and importing countries, it is likely that the sector will expand further, either in Southeast Asia or, if the land bank becomes limited there, in the African and American tropics. At current prices, it has recently been estimated that the opportunity costs of conserving forests in Southeast Asia are US \$9860–12,750 ha^{-1} from logging and a further US \$11,240 ha^{-1} from subsequent conversion into oil palm plantations (Fisher *et al.*, 2011). Others have argued that these figures are overly pessimistic (from a forest conservation point of view) and that payments for carbon sequestration and other environmental services such as clean water supply from forests could realistically offset the opportunity costs of forest development (Ruslandi *et al.*, 2011; Venter *et al.*, 2009).

Production in Small-Holder and Large-Scale Contexts

Oil-palm seedlings are typically raised in a nursery for 1 year before planting out. Planting densities range from 110 to 150 stems per ha (Basiron, 2007). In small-holder settings in Africa, planting densities can be considerably higher; densities of 200 palms per ha were common in the late 1940s, and densities of more than 300 palms per ha were not unknown (Hartley, 1988). Most commercially used oil palms mature rapidly, and fruit can be harvested only 2–3 years after planting (Basiron, 2007) although 9–15 year old trees are most productive (BisInFocus, 2006). After 25–30 years, trees become too tall to harvest and are replaced. Some long-established plantations in Malaysia have already been replanted for the third time (Basiron, 2007).

Labor input over the life of an oil-palm project is about 1397 person day per ha in Southeast Asia; divided by 25 years, this suggests that on average each hectare of oil palm has someone working on it – and thus earning income – 56 days of the year (Ginoga *et al.*, 1999). Unlike most other crops, oil-palm production is not very seasonal, allowing more-efficient, year-round use of labor.

Once harvested, fruit deteriorates rapidly and must be processed within 24 h (Vermeulen and Goad, 2006), so access to a mill is a major factor in determining where commercial plantations can be established. Palm-oil production is therefore most efficient when the crop is grown in a large monoculture around a central processing mill rather than in small holdings interspersed with other vegetation (Maddox *et al.*, 2007). The development of small-scale floating mills may allow companies to plant and process oil-palm fruits in remote areas at smaller scales, but such initiatives have not been taken up yet and are presumably less cost-effective than large-scale plantations.

Public Perceptions

Oil palm is hotly debated. Any internet search on keywords "orangutan" and "oil palm" reveals a plethora of mostly negative attitudes toward this palm and the people behind its boom. Internet titles such as "Palm oil costs the lives of about 50 orangutans every week and its cultivation is a major cause of global warming" and "Orangutans struggle to survive as palm oil booms" further suggests that conservation and oil palm are not happy bed fellows (EIA, 1998; Robertson and van Schaik, 2001; World Growth, 2009). Oil palm has its proponents too, however. These proponents not only include obvious ones such as palm oil producers and their support organizations but also the national governments of Indonesia and Malaysia, which earn significant revenues from palm oil production. It is becoming increasingly clear that small-scale farmers in these countries prefer oil palm to other crops because of high relative returns (Feintrenie *et al.*, 2010; Rist *et al.*, 2010). The strongly divergent viewpoints about the environmental and social costs of oil palm versus its benefits (Koh *et al.*, 2009; Meijaard and Sheil, 2011) has resulted in a situation in which middle-ground solutions of minimizing oil palm's impact have become increasingly difficult (Meijaard, 2010). The situation is not helped by the significant disinformation created on both sides of the debate (Koh and Wilcove, 2009; Sheil *et al.*, 2009). Better science-based information about the positive and negative impacts of oil palm over different temporal and spatial scales is urgently needed for more-informed discussion on the impact of this palm on global biodiversity (Sheil *et al.*, 2009).

Oil Palm and Biodiversity

Value as Wildlife Habitat

Not all aspects of biodiversity are negatively impacted by oil palm, and oil-palm plantations have some conservation benefits. Similar to fig and nectar, palm nuts are considered to be keystone ecological resources, providing crucial links between plant and animal communities (Terborgh, 1986). For example, in its native West Africa, oil palm provides important resources to the chimpanzee (*Pan troglodytes verus*) (Humle and Matsuzawa, 2004; Leciak *et al.*, 2005; Sousa *et al.*, 2011). This mostly occurs in patchy oil-palm groves in a matrix of agricultural land and forests rather than the extensive areas of single-species oil-palm plantation generally found in Asia. Chimpanzees seem to prefer oil palms for building their sleeping platforms or "nests," even when they have access to natural forests; they also use palm fruits as fallback resources (Sousa *et al.*, 2011).

Other African species that feed on oil palm include Thomas's rope squirrels (*Funisciurus anerythrus*) (Pettet, 1969); white-throated bee-eaters (*Merops albicollis*), which catch and eat the epicarp of the fruit dropped by the squirrels (Fry, 1964); southern yellow-billed hornbills (*Tockus leucomelas*); and the aptly named oil-palm vulture (*Gypohierax angolensis*) (Landsborough and Moreau, 1957). Black vultures (*Coragyps stratus*) in northwestern Colombia feed heavily on oil-palm fruit and appear to prefer it to carrion (Elias and Dubost, 1982), whereas several raptor species that feed on rats thrive in oil palm in Honduras (Padilla *et al.*, 1995). In Central America, the white-faced capuchins (*Cebus capucinus*) are well-known users of oil-palm areas (McKinney, 2010; Williams and Vaughan, 2001).

Southeast Asian oil-palm areas also provide resources to certain species, and many species use the oil-palm matrix to move between forest patches, something they might not do in plantings of annual crops or grasslands. A study in Sumatra showed a wide range of species inhabiting the area of an oil-palm plantation, with 40 mammals listed in total (38, not including domestic species) (Maddox *et al.*, 2007). Of these, 63% have an important conservation value or are protected under national law, and 25% are listed as vulnerable or higher on IUCN red lists. The tiger was the most endangered species recorded on site, rated as critically endangered. Asian elephants (*Elephas maximus*) and dhole or wild dog (*Cuon alpinus*) are the next most endangered. Tigers (*Panthera tigris*) and leopards (*Panthera pardus*) in peninsular Malaysia frequently move into oil-palm estates from surrounding forest areas to prey on wild ungulates such as pigs and deer or on domestic cattle (Azlan and Sharma, 2006). In fact, a study in peninsular Malaysia suggested that a hyperabundance of the banded pig (*Sus scrofa vittatus*) in a forest reserve surrounded by oil palm was caused by abundant year-round food supply of oil-palm fruits from the extensive plantations bordering the reserve (Ickes, 2001). The presence of prey species in oil palm is both a benefit and threat to large predators (*see* Charismatic Species).

Considering that oil palm produces highly nutritious nuts, it is surprising that few records exist of Southeast Asian species feeding on oil palm. There are indications that orangutans occasionally eat oil-palm nuts (M. Ancrenaz, pers. comm.), but such use is not extensively documented. Considering that chimpanzees use these fruits extensively, it may just be a matter of time until orangutans similarly learn to do so. Observations in Sumatra suggest that both long-tailed (*Macaca fascicularis*) and pig-tailed (*Macaca. nemestrina*) macaques feed extensively on fallen palm fruit, as do pig species (both *S. scrofa* and *Sus barbatus*) (EM, pers. obs.). A lot more records of species feeding on oil palm are available in the literature on pest species. A book on pest species that affect oil palm globally (Hill, 2008) lists squirrels (*Callosciurus* spp.), rats (*Rattus* spp.), various parrots and parakeets, porcupines (*Hystrix* sp.), and a host of invertebrate species, such as the coconut case caterpillar (*Mahasena corbetti*), the African rhinoceros beetle (*Oryctes boas*), the coconut palm borer (*Melittomma insulare*), the palm leafminer (*Promecotheca cumingii*), the South American palm weevil (*Rhynchophorus palmarum*), and the African palm weevil (*Rhynchophorus phoenicis*). As documented in Southeast Asia, these invertebrates in turn attract bird species such as *Pycnonotus goiavier*, *Prinia* spp., *Parus major*, *Copsychus saularis*, and *Halcyon smyrnensis*, all species feeding primarily on insects and normally common outside forests (Desmier de Chenon and Susanto, 2006).

The obvious issue with some species in an oil-palm plantation context is that they cause damage to plants and palm nuts. For example, population densities of *Rattus tiomanicus* are between 100 and 600 animals per ha in Southeast Asian plantings of a range of ages and localities (Wood and Fee, 2003), and losses in Malaysian palm oil caused by these rodents were valued at US $32 million annually in the 1980s (Basri and Halim, 1985). This benefits threatened species such as blood pythons (*Python brongersmai*) and short-tailed pythons (*Python curtus*) that feed on these rats, and which in Sumatra have increased in abundance because of the establishment of oil-palm plantations (Shine *et al.*, 1999).

Impact on Species Diversity

Most of the world's species diversity is concentrated in humid tropical forest (Hoffmann *et al.*, 2010; Leadley *et al.*, 2010), the ideal habitat for oil-palm fruit production. The expansion of oil palm is therefore most likely to directly impact tropical biodiversity. The same tropical region is also an area where the majority of people are primarily concerned with meeting their basic needs (Kaimowitz and Sheil, 2007; Millennium Ecosystem Assessment, 2005). Economic development in many countries in this region is driven by natural resource exploitation, adding to the pressure on remaining forest areas. With regard to oil palm, this is especially evident in Southeast Asia, where the largest areas have so far been developed. Indonesia and Malaysia's lowland forests are among Earth's most species-rich terrestrial habitats (Sodhi *et al.*, 2004; Whitten *et al.*, 2004). The loss of Southeast Asia's lowland forests threatens the region's exceptional conservation value (Curran *et al.*, 2004; Tinker, 1997) and has long been the principal conservation concern in the region (Jepson *et al.*, 2001).

Surprisingly, despite the apparent impact of oil palm on biodiversity, conservation science is a relative newcomer to this topic. A 2008 review of 678 publications on oil palm published over 35 years found that only six of the publications specifically addressed the biodiversity and species conservation aspects of oil palm (Turner *et al.*, 2008). Since that time, there have been many more scientific study of species diversity and abundance in oil palm.

Because of oil palm's light requirements, plantation development generally requires that all other vegetation is removed. Oil-palm plantations are thus dominated by only one plant species (Danielsen *et al.*, 2009; Fitzherbert *et al.*, 2008; Gillison and Liswanti, 1999). Oil-palm plantations are also structurally less complex than natural forests, with a uniform tree age structure, lower canopy, sparse undergrowth, less-stable microclimate, and greater human disturbance (Danielsen and Heegaard, 1994; Fitzherbert *et al.*, 2008; Peh *et al.*, 2006), and they are cleared and replanted on a 25–30 year rotation (Sheil *et al.*, 2009). It is therefore not surprising that the floral and faunal diversity of these plantations is very low when compared to tropical lowland rain forests.

To give examples, researchers in the province of Jambi recorded 75% less plant diversity in oil-palm plantations than in natural forest (Gillison and Liswanti, 1999). Mammals are also affected, and a 4-year study of terrestrial mammals living in and around an oil-palm plantation concession in Jambi concluded that oil-palm monocultures are very poor habitats for most terrestrial mammal species (Maddox, 2007). Only four mammal species (10% of the number detected within the approximately 80,000 ha landscape) were regularly detected in the oil palm itself, and none of these species had a high conservation value. Some species, including deer (*Cervus unicolor*), macaques (*Macaca* spp.), and pangolin (*Manis javanica*) showed limited tolerance, but, with the exception of pigs (*Sus* spp.), all species showed a general preference for non–oil palm habitats – even heavily degraded forests (Maddox, 2007). In fact, the study highlighted the conservation importance of marginal or degraded habitats often found within palm-oil concessions and highlighted that these areas can retain high conservation values (Maddox, 2007).

Most studies of oil-palm biodiversity show large differences in faunal species composition between oil palm and forests (Fitzherbert *et al.*, 2008). The animal species lost tended to include species with specialized diets and reliance on habitat features not found in plantations (such as large trees for cavity-dwelling species) and also species with the smallest range sizes and those of highest conservation concern (Fitzherbert *et al.*, 2008). Plantation assemblages were typically dominated by a few abundant generalists, nonforest species (including alien invasives), and pests.

These findings of reduced species diversity in oil palm correspond with studies elsewhere. In Malaysia, researchers found that fewer than 20 of 75 mammal species encountered in primary forest also used oil palm (PORIM, 1994). Birds are also negatively affected, with one study in a 5000-ha study site of forests, oil palm, and agricultural lands reporting that conversion of forest to plantations resulted in reduced species richness of at least 60%, which especially affected threatened forest-dependent birds (Aratrakorn *et al.*, 2006). A review study of bird faunas in oil palms and forests found that although bird species richness is lower in oil palm than in forests, bird abundance does not appear to be. Species found in plantations are generally of lower conservation concern than those from forests (Najera and Simonetti, 2010).

Invertebrate communities in oil-palm plantations seem to be similarly influenced. Beetle assemblages in habitat types in Sabah, Malaysia, ranging from primary forest, logged forest, and acacia plantation to oil-palm plantation, had the lowest species diversity in oil palm, with a few species becoming numerically dominant (Chung *et al.*, 2000). Ant species richness in Malaysian Borneo decreased from 309 to 110 species (−64%) between a 43,800-ha primary forest areas and a 2576-ha oil-palm plantation (Fayle *et al.*, 2010), and oil palm can sustain only about 5% of the ground-dwelling ant species of the forest interior (Bruhl and Eltz, 2010). However, the impact of oil palm on species diversity was not the same across all microhabitats that were investigated, with bird's nest ferns occurring in both forests and oil palm maintaining almost the same number of ant species in both vegetation types. Species losses were much more pronounced in canopy and leaf-litter faunas (Fayle *et al.*, 2010). Also, ant communities in oil palm are dominated by nonforest species, with nine of the 23 ant species baited in the plantations never having been recorded inside the forest (Bruhl and Eltz, 2010).

Species diversity *per se* may not always be a relevant measure for ecosystem health. A study of bee diversity in a range of vegetation types, including oil palm, in peninsular Malaysia found that the diversity in oil palm, as measured by a wide range of diversity and evenness indices, was considerably higher than in primary forest, although the absolute abundance of bees was much lower (Liow *et al.*, 2001). The 2500-ha monocultural oil-palm plantation had 17 species of bee, whereas the two natural forest sites (each >2000 ha) had nine and seven, respectively. The absolute number collected, however, was 64 for the oil-palm site and 419 and 444 for the natural forest sites. The authors suggest that absolute numbers of bees rather than species diversity may be more important for maintaining the ecosystem and ecological processes than the absolute number of species, because of their role in pollination.

A recent review of 13 studies summarized how species diversity in oil palm compared to that in other plantation crops (Fitzherbert *et al.*, 2008). Because of the small sample size, control for locations and context was not possible, and the review findings need to be interpreted with caution. Rubber (*Hevea brasiliensis*) supported as many or more species as oil palm and more forest species. Cocoa (*Theobroma cacao*) had similar or higher species richness but not always more forest species. Coffee (*Coffea canephora*) supported higher ant species richness and more forest species than oil palm. Rubber, cocoa, and coffee are often grown in small-holder settings or agroforestry landscapes. Compared to oil palm, their scale of development is generally smaller, and these crops often occur in a matrix of secondary forest regrowth. This might at least partly explain why their species richness is higher than in oil palm. *Acacia mangium* plantations, which are planted for pulp and paper, are generally developed as large (>10,000 ha) industrial plantations. In Indonesia, oil palm is established in monoculture plantations ranging in size from 4000 to more than 20,000 ha (Sheil *et al.*, 2009), which is on a scale similar to industrial tree plantations. Still, acacia plantations have higher beetle species richness than oil palm, and species composition is closer to that in forest (Chung *et al.*, 2000). Similar results were found for studies of birds, which in acacia and albizia (*Paraserianthes falcataria*) plantations resembled the avifauna of secondary forest regrowth, whereas oil palm attracted few bird species (Sheldon *et al.*, 2010).

Fitzherbert *et al.*'s (2008) review suggested that only pasture and urban mown grassland had lower species diversity than oil palm, whereas gardens of mixed crops had similar or higher species richness, and abandoned pasture had more species than oil palm. *Imperata cylindrica* grasslands, a fire-induced vegetation type that commonly replaces deforested land, had more species of ants but fewer forest ant species than oil palm (Fitzherbert *et al.*, 2008). Compared to other monocultural plantation species that harbor significant native species diversity (Hobbs *et al.*, 2006; Lugo, 1992), oil-palm plantations appear to resemble the other extreme of exotic plantation species that have limited value to native biodiversity conservation (Mascaro *et al.*, 2008). The overall conclusion about biodiversity in oil-palm plantations is that, at a local scale, it is as low as the most degraded and human-altered tropical vegetation types and therefore has limited local conservation importance.

Charismatic Species

A number of species, including orangutans (*Pongo* spp.) and the Sumatran tiger (*P. tigris sumatrae*) are the focus of international concern. The conservation of these species is often mentioned in relation to the expansion of oil palm (Linkie *et al.*, 2003; Nantha and Tisdell, 2009; WWF, 2011), and these species have played an important role in shaping the public attitude toward oil palm. Although industrial oil-palm development has been ongoing for decades, it was not until the 1990s when environmental campaigns started to focus on the role that oil palm plays in the demise of iconic conservation species and their forest habitats that the public mood began to change. These campaigns initially focused on the impacts on orangutans (Buckland, 2006; EIA, 1998) but also addressed other species, primarily tigers and elephants (Friends of the Earth, 2005). The authors discuss the impacts of oil palm on these species relative to other threats.

Orangutans

The main impact of oil palm on orangutans is habitat loss, with human–orangutan conflicts associated with oil-palm development a secondary threat (Meijaard *et al.*, 2011, 2012). Orangutans are primarily arboreal creatures, using relatively large territories and mostly feeding on fruits, leaves, and barks originating from hundreds of plant species (Rijksen and Meijaard, 1999). In 2008 in Kalimantan, oil palm threatened 750,000 ha of orangutan forest, representing 5.5% of the Bornean orangutan distribution (Venter *et al.*, 2009).

Recent studies have shown unexpected ecological resilience in orangutans in selectively harvested timber concessions and plantations of *Acacia mangium* (Ancrenaz *et al.*, 2010; Meijaard *et al.*, 2010). Surprisingly, very few studies exist of orangutan use of oil-palm habitats. One report focuses on management and the avoidance of human–orangutan conflict in oil-palm areas (Yuwono *et al.*, 2007), but it does not clarify how orangutans are affected. A recent study in Sumatra investigated crop-raiding by a population of Sumatran orangutans (*Pongo abelii*) that had become isolated from natural forest in an agricultural landscape, including oil-palm plantations (Campbell-Smith *et al.*, 2011). This study showed that the oil-palm patches in this landscape offered few, if any, benefits to orangutans.

Aerial surveys in eastern Sabah, Malaysian Borneo (M. Ancrenaz, unpublished data), identified large numbers of orangutan nests in oil-palm plantations, especially in small forest patches within the oil-palm matrix. The size of these patches fluctuated from a single tree to a few hectares and the forest was highly degraded and lacked the typical forest structure. It was estimated that at least a couple of hundred individuals were using the oil-palm landscape at the time of the surveys.

As long as oil palm does not offer a food resource to orangutans and forest fragments within the oil palm are small, degraded, and few, it is doubtful that an oil-palm landscape can sustain a viable resident orangutan population in the long-term. The nests seen during aerial surveys were most probably built by "transient" orangutans that are roaming through the oil-palm estates in search of forest during their dispersal phase. Indeed, young males leave their native community when they become mature and establish their own territory in a new forest area (Goossens *et al.*, 2006). These orangutans are "connectors" in fragmented metapopulations, and oil palm could therefore have some benefits in maintaining overall connectivity.

Tigers

Tigers are threatened worldwide by habitat loss, reduction in prey, and hunting (Chundawat *et al.*, 2010) and in Malaysia and Indonesia also by expansion of oil palm (Linkie *et al.*, 2003). Like orangutans, tigers do reasonably well in selectively logged or otherwise degraded forests, but they favor areas with little human use (Linkie *et al.*, 2008). Compared to natural forests, oil-palm estates have relatively high human use. It is therefore not surprising that tigers have much higher densities in forest than in oil palm (Maddox *et al.*, 2007).

Tigers do use oil-palm areas, however, especially when these are adjacent to good-quality forest. The attraction is in the food resources such as deer, pigs, and also domestic animals. For example, tigers killed at least 60 cattle in a 27-month period in an oil-palm estate in peninsular Malaysia (Azlan and Sharma, 2006). Where large predators and oil palm coincide, this often leads to conflict and there are regular reports in Malaysian and Indonesian newspapers of oil-palm workers having been killed. Generally, tigers are unwelcome in oil palm and are often killed if they threaten workers (Brown and Jacobson, 2005). Also, crop predation by wild ungulates such as pigs and deer leads to crop protection measures, which often include nonselective techniques such as snaring, poisoning, and drive netting. These, in turn, harm or kill tigers and reduce their prey (Wibisono, 2005). In fact, it is thought that one of the main threats to the conservation of Sumatran tigers is the response to crop depredation by large ungulates in agricultural lands, including oil-palm plantations, near protected areas (Wibisono and Pusparini, 2010).

A recent study modeled extinction risk of Sumatran tiger in a landscape containing a protected area, logging concessions, pulp-wood plantations, agroforestry, oil palm, and settlements (Imron *et al.*, 2011). The study used information on tiger hunting and breeding behavior and found that the longest survival times occurred in mixed landscapes of protected areas, logging concessions, and pulp-wood plantations rather than models based on a single land use. Selectively logged forests contributed most to the survival chances of tigers in the protected area, concurring what was found by Meijaard and Sheil (2008) elsewhere. The settlement and oil-palm plantation scenarios clearly showed the detrimental effect of these land-uses on tiger persistence. Both single land use and combined scenarios resulted in extinction within a relatively short period of time, confirming that oil-palm plantations do not provide good habitat for tiger prey, provide poor tiger habitat, and experience high human pressure, which lead to the absence of tigers (Imron *et al.*, 2011).

Asian Elephants

Asian elephants (*Ele. maximus*) are primarily a forest-edge species (Rood *et al.*, 2011), suggesting they prefer to feed on the type of vegetation found in disturbed areas. Potentially, this could include oil-palm areas, but the evidence for this is unclear. On the one hand, they are reported to avoid oil palm. In a study in Sumatra, elephants were only ever recorded once on the fringes of the oil palm (Maddox *et al.*, 2007). On the other hand, another study reported that elephants are considered to pose a risk to oil-palm plantations because they often destroy palms and feed on the oil-rich palm nuts (Susanto and Ardiansyah, 2003). In fact, it has been suggested that such agricultural conflicts may pose as big a threat to Asian elephants as habitat loss (Hedges *et al.*, 2005; Linkie *et al.*, 2007). An internet search reveals many stories of elephants causing damage to oil palm and dead elephants being found in or close to oil-palm plantations, several reportedly killed by poisoning. Often the conservation authorities assist local farmers and oil-palm companies by capturing elephants and either moving them to other areas or keeping them in captivity. Trials in Malaysian Borneo, where the tamer Bornean subspecies of *Ele. maximus* uses oil-palm areas to move between forest patches, show that the use of electrical fencing to protect small-holder crops combined with the replanting of forest corridors provides an effective means to reduce elephant conflict (Ancrenaz and Lackman, 2011). This is expensive, however, and may only work in small plots. Chili grease–covered fences may be a cheaper alternative (Hedges and Giunaryadi, 2010).

Beneficial Wildlife

Oil-palm estate managers actively promote the presence of some species because they increase the production of oil palm or at least make it cheaper. Owls and snakes are the most important among these beneficial species. Barn owls (*Tyto alba javanica*) have been widely encouraged in Malaysian oil-palm plantations to control rodent pests. They were formerly considered vagrants in peninsular Malaysia, but they became established following the increase in rats with the advent of oil-palm plantations (Lenton, 1984). It is estimated that a pair of barn owls together with their chicks consume around 1300 rats per year (Duckett and Karuppuah, 1989), but it apparently remains doubtful whether these owls truly regulate rodent populations or whether rodent populations are more strongly affected by other factors such as food supply (Puan *et al.*, 2011).

Certain species of snakes are also attracted to the many rodents and other species feeding in oil-palm areas (Akani *et al.*, 2008; Shine *et al.*, 1999), and some plantations actively use snakes to control rodents, although not as commonly as owls or baiting (Hafidzi and Saayon, 2001). How effective such pest control is remains unclear.

Exclosure studies in Sabah, Malaysia, show that insectivorous birds deliver a natural pest-control service for oil-palm agriculture (Koh, 2008a). Where birds were excluded from oil-palm seedlings, herbivory rates from insects increased between 1.2- and 17.2-fold – significantly higher than that in control treatments.

Koh (2008a) reports that many companies adopt an integrated pest-management approach that favors the use of nonchemical pest control methods such as the establishment of ''beneficial plants'' (e.g., *Euphorbia heterophylla*) to attract the insect predators and parasitoids of oil-palm pests such as the wasp *Dolichogenidea metesae* (Basri *et al.*, 1995).

Finally, the native pollinator of oil palm (the weevil *Elaeidobius kamerunicus*) did not originally occur in Asia. When it was introduced from Africa, production increased and the cost of artificial pollination was saved (Dhileepan, 1994; Southworth, 1985).

Notes of Caution

One of the constraints on interpreting research on species diversity in oil palm is that there are few scientific case studies (Fitzherbert *et al.*, 2008). For example, there are no scientific studies that address plant diversity in oil palm. This introduces confounding factors that often cannot be controlled for. Research is required that addresses questions such as, what is the effect of area on species diversity when one compares species in a 50,000-ha natural forest with those in a 2500-ha oil-palm plantation? Would the species diversity of a 1000-ha oil-palm plantation be the same as a 10,000-ha one? What is the effect of fragmentation when areas of natural forests to which oil-palm diversity is compared are fragments themselves in a matrix of nonforests (Liow *et al.*, 2001)? How does species diversity vary in different oil-palm contexts, from the mixed-forest gardens settings often found in Africa to the large (>20,000-ha) monocultural plantings sometimes found in Indonesia?

Broader Environmental Impacts of Oil Palm

Oil Palm and Deforestation

Information on how much forest has been displaced by oil palm is hard to come by. Considering that oil palm is a crop of the humid tropics, one could argue that all planted oil palm has ultimately replaced tropical forest. Some forests, however, were cut down centuries ago and only recently planted with oil palm. Oil palm is developed under a wide range of field conditions, varying from old degraded grasslands, secondary scrubland, forest regrowth, degraded and overlogged forest, and relatively intact forests. In our experience, rarely has oil palm been established in areas that were primary forest (i.e., visually untouched by human activities) directly prior to oil-palm development. Therefore, the more-pertinent question regarding oil palm and forest wildlife is how much forest has recently been cut down and directly been replaced by oil palm? A recent analysis of agricultural and deforestation statistics for the period 1990–2005 suggested that more than half the area of oil-palm developed in Malaysia and Indonesia had resulted in deforestation (Koh and Wilcove, 2008). Others, however, argue that the data are too poor to draw such conclusions and that these estimates do not account for other causes that triggered deforestation before oil-palm plantations were established (Wicke *et al.*, 2011).

To estimate future impacts, we need to know how much of the oil-palm expansion will be in forested areas. Future demand for edible oil is estimated at around 240 Mt in 2050, requiring an additional 12 million ha of palms, if average yields continue to rise as in the past (Corley, 2009). This demand could at least partly be met on existing nonforest lands (Wicke *et al.*, 2011). However, Corley (2009) also points out that biofuel demand might greatly exceed that for edible use, and the interchangeability of the major oils for edible and biofuel uses means that this demand will drive oil-palm expansion, whether or not palm oil is actually used for biodiesel.

Without a clear definition of oil palm–induced deforestation, better data on forest cover and the distribution of oil-palm plantations, and future expansion potential of oil palm, it remains impossible to accurately quantify the impact of oil-palm development on forest wildlife.

Some have argued that oil-palm plantations are forests. Malaysia, for example, has considered (but ultimately rejected) including oil-palm plantations in the country's national statistics on forest cover (Simamora, 2010). Many conservation bodies highlighted this as unacceptable (Biofuels Watch, 2010; World Rainforest Movement, 2010), and the Food and Agricultural Organization excludes oil palm from global forest estimates because it considers it an agricultural crop, not a planted forest (FAO, 2010). Meijaard and Sheil (2011) pointed out that in much of the temperate world pulpwood plantations are included as forests, and there is an obvious need to develop and agree on such definitions (Sasaki and Putz, 2009).

Broader Environmental Impacts of Oil-Palm Plantations

Palm-oil production has environmental impacts that could potentially affect wildlife beyond the actual plantation. Extraction of palm oil results in large amounts of effluent that is often returned to natural water courses without treatment (Sheil *et al.*, 2009). Palm-oil mill effluent is a colloidal suspension of water, oil, grease, and solids: it is fairly acidic (pH 4–5) and is typically discharged hot (80–90 °C) (Ahmad *et al.*, 2005). Although most mills have treatment areas, leaks of effluent can have significant negative impacts on water quality. How this affects the ecological functioning of waterways remains largely unstudied (Sheil *et al.*, 2009).

The oil-palm industry is one of the largest consumers of mineral fertilizers in Southeast Asia (Hardter and Fairhurst, 2003). A typical oil-palm plantation planted on both mineral and peat soils requires around 354 kg ha^{-1} of nitrogen over the first 5 years to increase and maintain yields (Guyon and

Simorangkir, 2002). Pesticides and herbicides also increase pollution, especially with repeated use (Hartemink, 2005). Most of the reports on impacts are generated by companies and may not be objective because they wish to be seen as minimizing damage to the environment (Sheil *et al.*, 2009).

The environmental impact of oil-palm plantations could be less than most alternative crops if considered in terms of production – more can be produced on less land. Given the necessary trade-offs between conservation and economic growth, this is important. Better management, higher yields from improved varieties, and planting on land that is already degraded could improve yields significantly without further deforestation (Hardter *et al.*, 1997). Concentrating oil-producing crops on those lands with the highest yields could reduce the need for land elsewhere, offering potential conservation benefits

Could Oil-Palm Development Reduce Biodiversity Impacts Elsewhere?

Large-scale oil-palm production has documented benefits. The plantation sector in Malaysia is one of the largest employers, providing income and employment for many rural people. Basiron (2007) comments that "involvement in cultivation or downstream activities has uplifted the quality of life of people." Decreasing rural poverty may reduce deforestation, although this is highly context-specific (Sunderlin *et al.*, 2007; Wunder, 2001). Also, assuming a certain global demand for vegetable oil – for food and biofuel – producing it in areas with plant species that maximize yields could potentially reduce pressure on land elsewhere. The interactions between the various economic, trade, environment, and political factors remain too complex to reliably determine overall global impacts of oil palm on biodiversity compared to the alternative of producing oils with different crops. This is an important area of research to guide the different oil industries.

Enhancing the Biodiversity Values of Oil Palm

An important question regarding the biodiversity of oil-palm plantations is whether this can be boosted by retaining patches of natural forest within the oil-palm matrix, the so-called wildlife-friendly strategy (Edwards *et al.*, 2010; Fitzherbert *et al.*, 2008; Koh, 2008b). Oil palm developed in large estates can create monocultural stands of 50,000 ha or more. Such areas have very limited ecological variation and create large areas mostly devoid of wildlife. In a small-holder setting, oil palm is planted on much finer scales, often in plantations of 1 or 2 ha. If such plantations are part of a broader multifunctional landscape with remaining forest stands and secondary regrowth, the overall species diversity is likely to be higher. If a certain total area of oil-palm plantation is targeted to fulfill global demands, an important ecological question is whether for wildlife conservation purposes it is better to concentrate all oil palms into large monocultural stands (potentially leaving more space for natural forests) or to spread oil-palm plantings over much larger multifunctional landscapes.

A study comparing bird diversity in oil palm, forest fragments within oil palm, and contiguous natural forest indicated that abundances of imperiled bird species in oil palm were 60 times lower in fragments and 200 times lower in oil palm than in contiguous forest. Forest fragments did not increase bird abundances in adjacent oil palm, and they had lower species richness than contiguous forest and an avifaunal composition that was more similar to oil palm than to contiguous forest. The study concluded that, from a perspective of maximizing biodiversity conservation, any investment in the retention of fragments would be better directed toward the protection of contiguous forest (Edwards *et al.*, 2010) – that is, the land-sparing strategy.

Increasing the productivity of existing oil-palm plantations – for example, by better management of harvesting to improve oil yield – could potentially reduce the need for more land to be cleared. However, this will only generate a conservation gain if it is linked to the protection of natural habitats – for example, through strategic land-use planning and implementation (Fitzherbert *et al.*, 2008). Fitzherbert et al (2008) argue that with higher yields per unit area for both large and small scale enterprises, oil palm might provide a substitute for traditional subsistence agriculture and could reduce the area of land needed to support each household. They also point out that successful land sparing is contingent on inelasticity of demand for agricultural products (Green *et al.*, 2005). The substitutability of vegetable oils ensures that demand for any one oil is elastic and, although future global requirements for edible oils – depending much on demand from China and India – may be reasonably predictable, demand will become effectively limitless if driven by new biofuel markets. Proposals for nongovernmental organizations to use oil-palm agriculture to acquire private reserves (Koh and Wilcove, 2007) are unlikely to be the most cost-effective approach (Venter *et al.*, 2008).

Meanwhile, several new international and national initiatives are under way to improve practices in establishing oil-palm plantations and using forests. One national initiative is Sawit Watch (*sawit* meaning oil palm), which campaigns for the rights of indigenous people in land disputes and highlights the social ramifications of oil-palm developments in Indonesia (Sheil *et al.*, 2009). International initiatives include the Roundtable for Sustainable Palm Oil (RSPO), which was established in 2004 by Malaysian and Indonesian companies to ensure palm oil "contributes to a better world." The RSPO has developed a verifiable standard for sustainable palm oil and encourages oil-palm companies to adopt more-responsible practices. This standard consists of the RSPO Principles and Criteria (P&C) for Sustainable Palm Oil Production, which set out the requirements that must be met and against which certification assessments are made. To define sustainability in the oil-palm sector, the RSPO has developed 39 sustainability criteria organized under eight general principles that are designed to limit environmental impacts of growing and processing palm oil (Laurance *et al.*, 2010). Of these, principle four is of direct relevance to biodiversity. Among others, it requires that growers maintain soil fertility, minimize and control erosion and degradation of soils, maintain the quality and availability of surface and groundwater, regulate the use of agrochemicals, and effectively manage pests, diseases, weeds, and invasive introduced species (RSPO, 2007). Most importantly for biodiversity in oil palm, however, is principle five, which concerns the environmental responsibility and conservation of natural resources and biodiversity. This focuses primarily on the design of plantations, most relevantly the clearing of natural vegetation and how this affects the status of rare, threatened, or endangered species and habitats of high conservation value. Specifically, if such species or habitats are present, the standard requires that any legal requirements relating to the protection of the species or habitat are met, damage to and deterioration of applicable habitats is avoided, and any illegal or inappropriate hunting, fishing, or collecting activities is controlled, including the development of responsible measures to resolve human–wildlife conflicts. Such conflicts are frequent – as has, for example, been indicated by the many reported cases of orangutan killing in association with oil-palm development (Meijaard *et al.*, 2011).

Despite its ambitious environmental goals, the RSPO has been criticized for failing to stop clearing of natural forests and, more generally, for noncompliance by its members (Laurance *et al.*, 2010). Also, many companies have experimented with the RSPO standard since it was ratified in November 2005 but have found it to be complicated, costly, and hard to implement (Nikoloyuk *et al.*, 2010; Paoli *et al.*, 2010). Recently, RSPO has channeled activities toward developing a standard for smallholders because they cannot afford the additional oversight required for mainstream RSPO certification. Smallholders also struggle to adopt best practices, such as zero burning, because such practices require upfront capital and are more expensive at the onset. It remains to be seen whether the lofty goal of ''sustainable'' palm-oil management can be attained through the RSPO process. Countries such as Indonesia that investigated ways of integrating RSPO principles into current policies (McCarthy and Zen, 2010) have apparently concluded that this was not possible and subsequently developed their own standards: the Indonesian Sustainable Palm Oil Foundation (ISPO).

Conclusions

The scientific evidence suggests that oil-palm plantations in equatorial Asia have low biodiversity value compared to most other tropical land uses. A few species do well in oil palm, but these generally have little conservation value. Species that lose out in oil palm are forest-dependent species with specific habitat requirements and low abundance, and many are of conservation significance (Persey, 2011).

It is possible to make the oil-palm industry more biodiversity-friendly. It is most important, however, that oil palm should be developed on already deforested or degraded lands rather than in areas of tropical forest. Oil palm itself can also be made more hospitable for biodiversity – for example, by increasing structural and faunistic diversity (e.g., allowing the growth of epiphytic ferns and maintaining weed cover) and retaining as much natural forest in and around the planted areas as possible.

Ultimately, the global impact of oil palm on biodiversity can only be judged in relation to the alternatives. There is an increasing demand for vegetable oils for food and other uses, and demand for biofuels is growing. Oils and biofuels can be generated with different crops, and oil palm has the highest yield per unit land area and per unit of financial investments. If oil palm is not expanded further, then either the demand for oil will not be met or it will be fulfilled with other crops that require more land than would the oil palm.

See also: Agriculture, Sustainable. Agrobiodiversity. Biodiversity-Rich Countries. Deforestation and Land Clearing. Hotspots. Land-Use Issues. Mammals, Conservation Efforts for. Market Economy and Biodiversity. Poverty and Biodiversity. Primate Populations, Conservation of. Rainforest Ecosystems, Animal Diversity. Rainforest Ecosystems, Plant Diversity. Rainforest Loss and Change. Sustainability and Biodiversity

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