Review

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# How will oil palm expansion affect biodiversity?

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**Oil palm is one of the world's most rapidly increasing crops. We assess its contribution to tropical deforestation and review its biodiversity value. Oil palm has replaced large areas of forest in Southeast Asia, but land-cover change statistics alone do not allow an assessment of where it has driven forest clearance and where it has simply followed it. Oil palm plantations support much fewer species than do forests and often also fewer than other tree crops. Further negative impacts include habitat fragmentation and pollution, including greenhouse gas emissions. With rising demand for vegetable oils and biofuels, and strong overlap between areas suitable for oil palm and those of most importance for biodiversity, substantial biodiversity losses will only be averted if future oil palm expansion is managed to avoid deforestation.**

## Oil palm: one of the world's most rapidly expanding crops

Expansion and intensification of agriculture is the greatest current threat to biodiversity [1–3]. Vegetable oils are among the most rapidly expanding agricultural sectors [4], and more palm oil is produced than any other vegetable oil [5]. Global palm oil production is increasing by 9% every year, prompted largely by expanding biofuel markets in the European Union [6] (Box 1) and by food demand in Indonesia, India and China [4].

Oil palm *Elaeis guineensis* is grown across more than 13.5 million ha of tropical, high-rainfall, low-lying areas, a zone naturally occupied by moist tropical forest, the most biologically diverse terrestrial ecosystem on Earth [7,8] (Figure 1a,b). Malaysia and Indonesia produce more than 80% of all palm oil [9] (Figure 1d). Together, they also hold more than 80% of Southeast Asia's remaining primary forests (mainly in Indonesia), where many endemic species are threatened with extinction by some of the highest global rates of deforestation [10–13] (Figure 1a). Environmental groups and industry representatives debate the extent to which oil palm has contributed to deforestation [14,15].

The ecological impact of oil palm depends crucially on the extent to which its expansion causes deforestation, and on the extent to which it is able to support biodiversity. Here we review the contribution of oil palm to deforestation, with a focus on Malaysia and Indonesia. We compare the biodiversity value of oil palm plantations with that of forest and alternative land uses to assess whether biodiversity loss can best be reduced by making plantations more wildlife friendly or by linking yield increases with habitat protection (Box 2). We review emerging opportunities to reduce the biodiversity impact of oil palm, identify obstacles to success and gaps in current knowledge and finally ask whether new initiatives are likely to reduce the ecological cost of oil palm expansion.

## Contribution of oil palm expansion to deforestation

As with other crops [16], it is difficult to quantify the extent to which oil palm has been a direct cause of deforestation because of a lack of reliable data on land-cover change and incomplete understanding of its complex causes. The usefulness of the most widely cited land-cover data sets (those of the Food and Agriculture Organization of the United Nations, FAO [11]) is undermined by changing definitions of forest, minimal independent monitoring of government statistics and a lack of information on the subnational patterns and causes of land-cover change [17–19].

Oil palm expansion could in principle contribute to deforestation in four often indistinguishable ways: (i) as the primary motive for clearance of intact forests; (ii) by replacing forests previously degraded by logging or fire; (iii) as part of a combined economic enterprise, such as with timber, plywood or paper pulp profits used to offset the costs of plantation establishment; or (iv) indirectly, through generating improved road access to previously inaccessible forest or displacing other crops into forests. Land might also be deforested initially for other reasons and then subsequently be planted with oil palm. In such cases, oil palm could easily, but wrongly, be identified as a

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### Box 1. Oil palm as a biofuel

Biofuels derived from palm oil and other biomass from plantations can be used as alternatives to fossil fuels such as diesel. As a substitute for diesel, palm oil is less suitable than other vegetable oils owing to its high viscosity, lower energy density and high flash point [66]. However, oil palm gives high yields at low prices, and hence is likely to be important in meeting biofuel demand [5,67].

Global palm oil production increased by 55% between 2001 and 2006 (see http://faostat.fao.org), and will be further promoted by increases in demand for biofuels generally. Given the substitutability of vegetable oils both for biodiesel production and most edible uses [4], targets such as those set by the European Union to promote biofuel use [6] will increasingly divert edible oils such as rapeseed *Brassica napus* toward biofuel production. An increase in the demand for any vegetable oil increases prices for all of them, and further drives expansion, such as for both oil palm in Southeast Asia and soybean *Glycine max* in Brazil. Even if the European Union sources its palm oil exclusively from certified 'sustainable' sources (such as producers signed up to the Principles and Criteria of the Roundtable on Sustainable Palm Oil; see Box 3), it will be indirectly supporting less responsible producers via higher prices.

The rationale for using biofuels is that they should be carbon neutral, unlike fossil fuels which when burned release carbon stored over millions of years. However, only if oil palm plantations are established on degraded grasslands with low carbon content are they likely to become net carbon sinks [35,68]. There are large greenhouse gas emissions associated with forest clearance, desiccation of peat soils and use of fossil fuels for plantation cropping, processing and transport [62,63,68,69]. It will take decades or centuries for the avoided carbon emissions from fossil fuels to compensate for emissions released when forest or peat soils are converted [35,69]. Until it is demonstrated that oil crops are no longer replacing forests, the use of palm and other vegetable oils as biofuel feedstock is likely to exacerbate climate change, drive up food prices and hasten biodiversity loss.

driver of deforestation. However, oil palm is also used as a pretext by companies to obtain permits to clear land for other purposes, and cannot easily be excluded as a contributing factor.

#### *Malaysia*

Oil palm was first planted commercially in Peninsular Malaysia in 1917, where it replaced rubber plantations and forest [7,20] (Figure 1d). As land became scarce, expansion shifted to Sabah and Sarawak, often in association with logging [18,21,22], and was facilitated by the reclassification of some state forest reserves to allow conversion to plantations [18,21]. Between 1990 and 2005 the area of oil palm in Malaysia increased by 1.8 million ha to 4.2 million ha (see http://www.mpob.gov.my), while 1.1 million ha of forest were lost [11] (Figure 1d). It has been estimated that at least 1.0 million ha of forest were replaced by oil palm over this period [23], but this estimate does not consider forest conversion into unproductive land, nor whether oil palm caused or simply followed deforestation.

#### *Indonesia*

Commercial oil palm cultivation started in Sumatra in 1911; expansion to other parts of Indonesia did not occur until the 1980s [7] (Figure 1d). Today, ambiguities in the land tenure system and corruption [13], combined with increased regional autonomy, have made it easier for timber, plywood and paper pulp companies to obtain permission to clear millions of hectares of forest under the pretext of plantation establishment, without later planting them, especially in Kalimantan [22,24,25]. Oil palm plantations often replace forests previously degraded by fire and logging [17,26], and illegal oil palm development has been reported inside protected areas [4,15]. Between 1990 and 2005 the area of oil palm increased by 4.4 million ha to 6.1 million ha (see http://www.deptan.go.id), while total forest loss was 28.1 million ha [11]. Hence, conversion to oil palm could account for at most 16% of recent deforestation. It has been estimated that 1.7–3.0 million ha of forest were lost to oil palm over this period [23]. The uncertainty surrounding these estimates is high and, as they exclude changes in unproductive land area and include only mature oil palm area, they could be over- or underestimates (see http://faostat.fao.org).

Elsewhere, oil palm has been documented as replacing forest in southern Thailand [27], Myanmar [28] and Papua New Guinea [29].

#### *The future*

Although the extent to which oil palm has been a direct cause of past deforestation is difficult to quantify, its potential as a future agent of deforestation is enormous. Demand for palm oil is predicted to continue increasing [5], and globally, most of the remaining areas suitable for planting are forested. At present, relatively little oil palm is grown outside Southeast Asia, but 410–570 million ha of currently forested land across Southeast Asia, Latin America and Central Africa are potentially suitable for oil palm cultivation (Figure 1c) (http://www.whrc.org/resources/published_literature/pdf/WHRC_REDD_crop_suitability.pdf) and might be increasingly utilised as demand rises and agronomic advances are made.

### Effects of converting forests to oil palm plantations

An understanding of how much biodiversity oil palm plantations can support is essential to direct conservation action. If plantations are consistently depauperate relative to forests, the focus should be on stopping deforestation. Alternatively, if the management of plantations can be adapted so that they support a substantial proportion of forest species while maintaining high yields, conservation effort should focus on ways to enhance biodiversity in plantations [3].

The response of biodiversity to land-cover change depends upon the extent to which natural habitat features are replicated and upon variation in the sensitivities of species to change [30]. Oil palm plantations are structurally less complex than natural forests, with a uniform tree age structure, lower canopy, sparse undergrowth, less stable microclimate and greater human disturbance [31–33] and are cleared and replanted on a 25–30 year rotation [7].

To assess the effect of palm oil on biodiversity, we conducted a literature survey. Publications on biodiversity make up less than 1% of the scientific literature on oil palm since 1970 [34]; we could find no published studies of plants (but see Ref. [35]) and just 13 of animals [23,31–33,35–43] that compared biodiversity in oil palm plantations with that in forest.

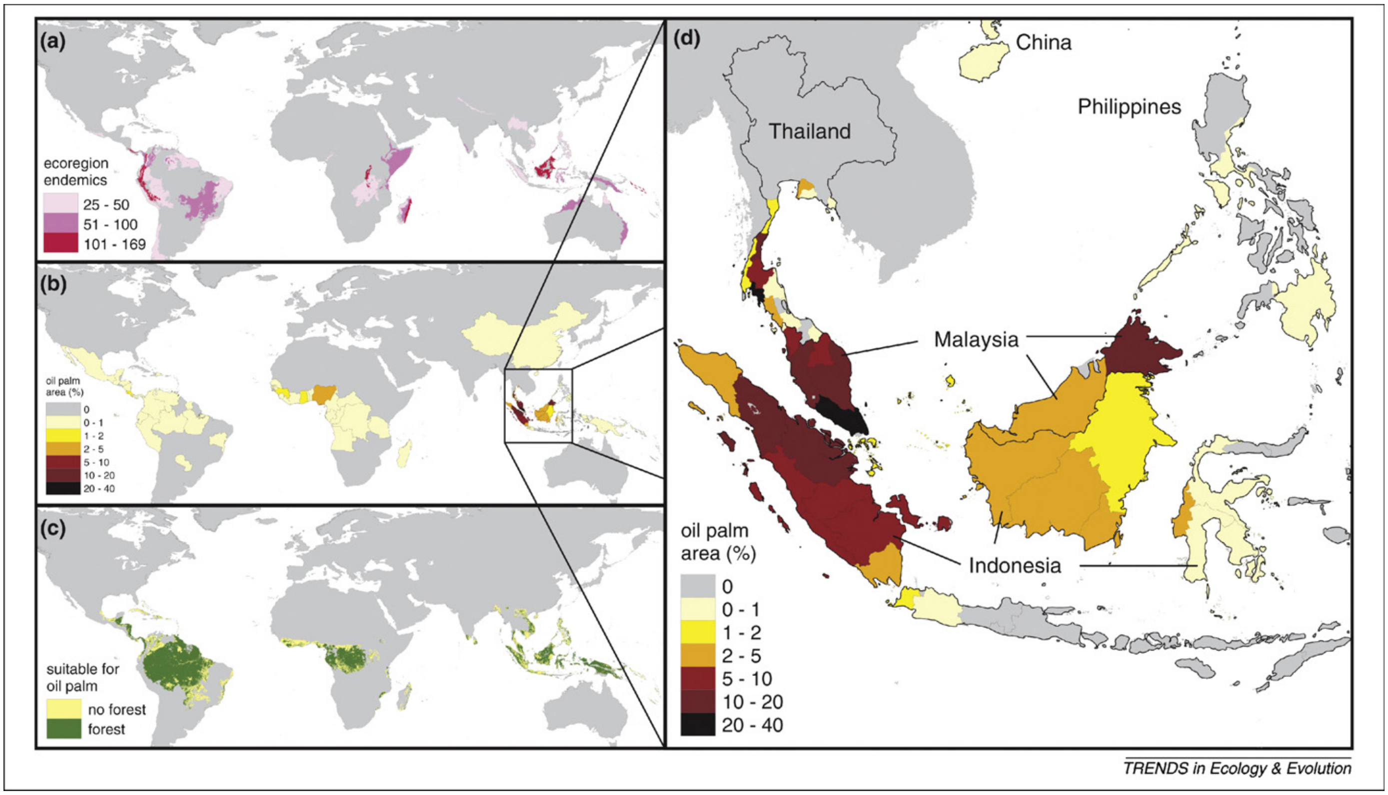


**Figure 1**. Global distribution of oil palm and potential conflicts with biodiversity: **(a)** areas of highest terrestrial vertebrate endemism (ecoregions with 25 or more endemics are shown); **(b)** global distribution of oil palm cultivation (harvested area as percentage of country area); **(c)** agriculturally suitable areas for oil palm (with and without forest); and **(d)** oil palm-harvested area in Southeast Asia. In (b) and (d), Brazil, Indonesia, Malaysia, the Philippines and Thailand are subdivided by province, but other countries are not. Data are for 2006, except for the Philippines and Thailand, where 2004 data are the most recent available. (Sources: [a] World Wildlife Fund (2006) WildFinder: online database of species distributions, version Jan-06, http://www.worldwildlife.org/wildfinder; [b,d] world: http://faostat.fao.org; Brazil: http://www.ibge.gov.br/estadosat; Indonesia: http://www.deptan.go.id; Malaysia: http://econ.mpob.gov.my/economy/annual/stat2006/Area1.7.htm; Philippines: http://www.bas.gov.ph/downloads_view.php?id=127; Thailand: http://www.oae.go.th/statistic/yearbook47/indexe.html; [c] forest area: European Commission Joint Research Centre [2003] Global Land Cover 2000 database, http://www-gem.jrc.it/glc2000; oil palm suitability: updated map from G. Fischer, first published in Fischer *et al.* [65], http://www.iiasa.ac.at/Research/LUC/SAEZ).

*Species richness*

Oil palm consistently held fewer than half as many vertebrate species as primary forests, whereas invertebrate taxa showed more variation [35] (Figure 2a). Oil palm also had much lower species richness than disturbed (logged or secondary) forests, although the differences were not so great (Figure 2b). One study of bees found more species in oil palm than in forests, but might have underestimated species richness in forests because the canopy was not sampled [39]. Across all taxa, a mean of only 15% of species recorded in primary forest was also found in oil palm plantations.

**Box 2. Linking production to conservation**

Increasing the productivity of existing oil palm plantations, for example by better management of harvesting to improve oil yield [7] (see Ref. [70]) could potentially reduce the need for more land to be cleared (the 'land-sparing' option of Ref. [3]). 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. Our review of the value of oil palm plantations for a wide range of taxa suggests that a land-sparing approach that ensures the conservation of intact forests would be more beneficial than the promotion of wildlife-friendly management practices within planted areas.

With higher yields per unit area for both large-scale commercial enterprises and small holders than many alternatives, oil palm might provide a substitute for traditional subsistence agriculture and could reduce the area of land needed to support each household [7,25]. However, rural communities do not always welcome plantation development [17], and care must also be taken that labourers do not increase the pressure on natural habitats near plantations [25]. Successful land sparing is contingent upon inelasticity of demand for agricultural products [3]. The substitutability of vegetable oils ensures that demand for any one oil is elastic and, although future global requirements for edible oils are reasonably predictable, demand will become effectively limitless if driven by new biofuel markets. Estimated annual world biodiesel requirement by 2050 could be 277 million tons, twice current total vegetable oil production and seven times total palm oil production [67].

There are possibilities for conservation partnerships between oil palm producers, conservation practitioners and rural communities which would enable financial resources from oil palm to be channelled into forest conservation efforts, such as local capacity building in legal aspects of forest law and enforcement [50,71,72]. Recent proposals for nongovernmental organisations to use oil palm agriculture to acquire private reserves [9] are unlikely to be the most cost-effective approach [72]. There might be more scope for producers to contribute to payments for environmental services schemes aimed at slowing deforestation [73], and to conserve forest remnants within their plantations. Strategic alliances between multiple stakeholders, such as oil palm producers, environmental organisations, rural communities, government agencies and carbon offsetters, have the largest chance of success [72].

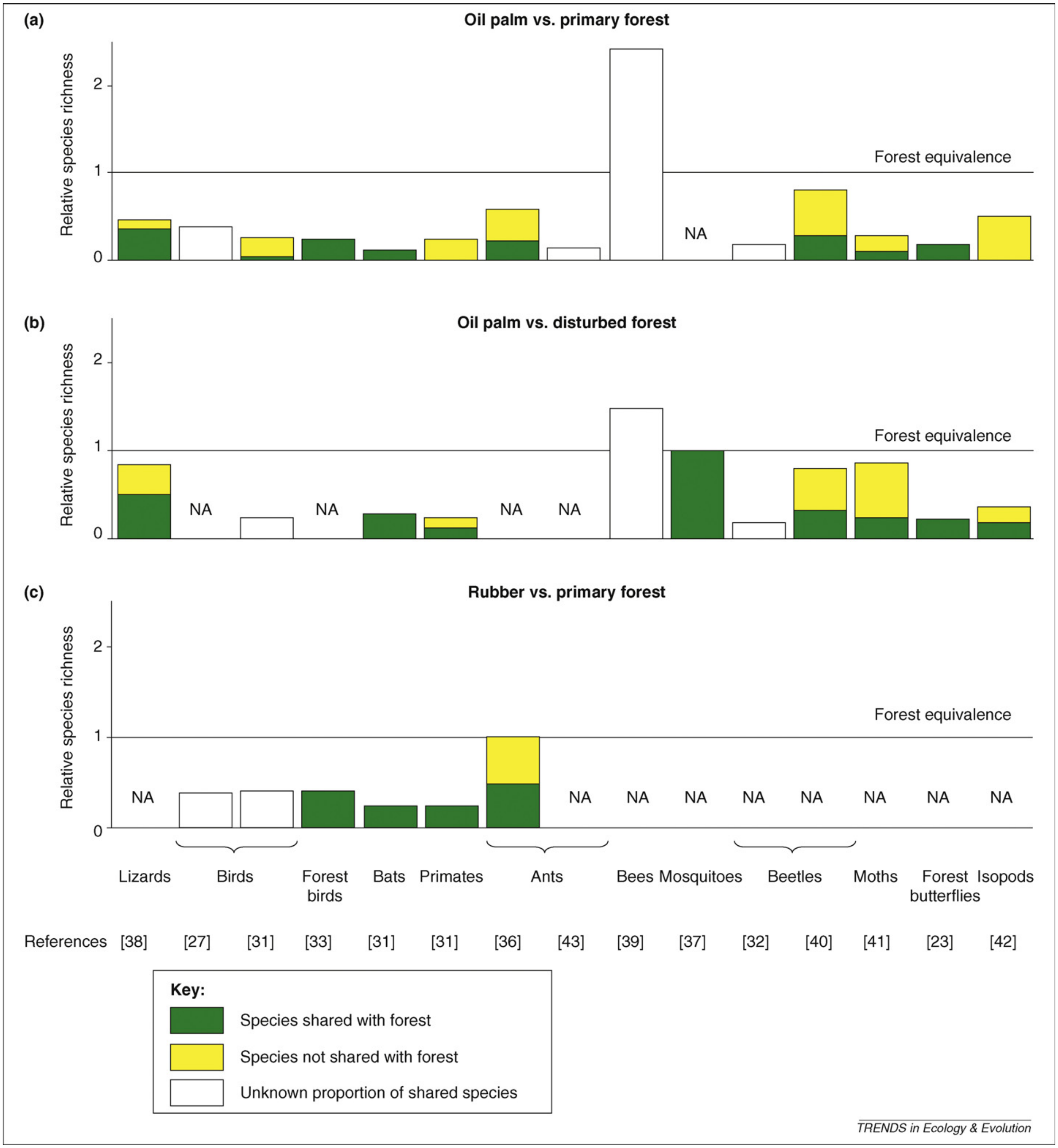


**Figure 2**. The biodiversity impact of converting forests to plantations is shown by comparing species richness and forest species richness in **(a)** oil palm relative to primary forests, **(b)** oil palm relative to degraded (logged and secondary) forests and **(c)** rubber relative to primary forests. Species richness is scaled so that forest richness in primary or degraded forests equals 1. Each vertical column contains a study of one taxon (NA = not applicable). In most taxa, the highest species richness is found in primary forests. There is a large reduction in species richness in oil palm compared with both primary and degraded forests, illustrated by the gap between the bars and the line of forest equivalence. The reduction in forest species richness is even more marked in most taxa. Rubber plantations show a similar loss of species richness compared with primary forests, but retain a higher species richness and/or forest species richness of some taxa. In no study does rubber have lower species richness than oil palm.

### *Species composition and abundance*

Most studies found large differences in faunal species composition between oil palm and forests [27,32,35,36,39,40]. The species lost were not a random subset of the original forest fauna, but tended to include species with the most specialised diets, those reliant on habitat features not found in plantations (such as large trees for cavity-dwelling species), those with the smallest range sizes and those of highest conservation concern [27,31,33,41]. Plantation assemblages were typically dominated by a few abundant generalists, non-forest species (including alien invasives) and pests [27,32,41]. Forty percent of the ant species found in oil palm plantations in Malaysia were aliens, including the highly invasive crazy ant *Anoplolepis gracilipes* [43]. Densities of rats (e.g. *Rattus tiomanicus*) can reach 600 per ha [44], providing abundant food for predators such as blood pythons *Python brongersmai* [45], barn owls *Tyto alba* [44] and leopard cats *Prionailurus bengalensis* [46].

### *Caveats*

Several methodological shortcomings are likely to reduce the apparent difference in biodiversity measures between forest and oil palm, so our estimates of biodiversity loss are likely to be conservative [35,47,48]. For example, it is more difficult to detect many taxa in rain forests, because rain forests have a taller canopy and more structural complexity than plantations [31]. Also, estimates of species richness from small areas of oil palm [32,36,38,42] or near forest edges [27,40] will be artificially inflated by the presence of transient species from nearby forests. Even standardising results based on effort (which was not done in most studies) does not fully remove these biases [27,48], especially when only a small number of species are sampled [31,37,38]. Finally, a time lag between habitat loss and extinction [10] might lead to the recording of some species in oil palm plantations that cannot ultimately persist there.

## Comparison with other land uses

To understand the relative impacts of converting different prior land covers (forest and other crops) to oil palm, and of converting forest to oil palm rather than to other crops, we examined studies which made such comparisons. Rubber *Hevea brasiliensis* supported as many or more species as oil palm, and more forest species (Figure 2a,c). Cocoa *Theobroma cacao* had similar [38] or higher [36] species richness, but not always more forest species. Coffee *Coffea canephora* supported higher ant species richness and more forest species [36]. *Acacia mangium* plantations had higher beetle species richness than oil palm, and species composition was closer to that in forest [32]. There was greater overlap in species composition between oil palm and other tree crops than there was with forest [27,36,40]. Compared with oil palm, pasture and urban mown grassland had lower species richness, gardens of mixed crops had similar or higher species richness and abandoned pasture had more species [33,36,38]. *Imperata cylindrica* grasslands (which cover at least 8.5 million ha in Indonesia alone [49]) had more species of ants than oil palm, but fewer forest species [36].

In summary, oil palm is a particularly poor substitute for either primary or degraded forests, and whereas any conversion of natural forest is inevitably damaging to biodiversity, oil palm plantations support even fewer forest species than do most other agricultural options.

## Landscape scale effects

Because oil palm and other tree crops are unsuitable habitats for most forest species, plantations, where they form part of the landscape matrix, can act as a barrier to animal movements [50,51]. Thus, forest fragments isolated within oil palm plantations supported fewer than half as many ant species as nearby continuous forests, and a greater number of invasive 'tramp' species were found in the smallest fragments [52]. Small, isolated forest fragments surrounded by oil palm had lower species richness and diversity of butterflies than larger, less isolated fragments [53].

As well as decreasing area and connectivity, fragmentation increases the length of forest edge exposed to harmful edge effects [30]. Abiotic edge effects include increased vulnerability to wind, desiccation and fire [30,54], although mature plantations of oil palm and other tree crops might provide more protection to forest edges than treeless habitats. Biotic edge effects include increased tree sapling mortality in forests where densities of wild pigs *Sus scrofa* are elevated by increased food availability in nearby oil palm plantations [55].

## Impacts of plantation development and management

As with other crops, the biodiversity impacts of oil palm depend on how the crop is developed and managed. Many of the greatest impacts result from the initial process of land clearance and preparation. Fire, whether used deliberately to clear forest or spreading accidentally from agricultural land, kills seeds and sedentary animals [54]. Many of the larger palm oil producers (Box 3) have

**Box 3. Regulating development: the RSPO and public disclosure**

Although increasing consumption of palm oil has promoted oil palm expansion, consumer concern has helped stimulate a movement toward more environmentally responsible practices within the industry. The most important initiative is the Roundtable on Sustainable Palm Oil (RSPO; see http://www.rspo.org), whose members manage more than one-third of the global oil palm area, and which has developed a set of environmental and social Principles and Criteria for producers. Commitments to reduce impacts on biodiversity using the High Conservation Values approach to identify forests and other areas for preservation are included [74], but difficulties remain in defining and applying these values consistently. One area of concern is that forests degraded by logging are generally assumed to have low conservation value, when this is often not the case [47]. There are also challenges in ensuring compliance, and in certifying the activities of small-holder farmers who supply palm fruits to RSPO producers. The auditing and certification system was only agreed to in November 2007, and thus RSPO-certified palm oil will not be available before late 2008.

Governments are not directly involved in the RSPO, but have responsibility under international conventions to ensure that neither RSPO members nor other producers contribute to biodiversity loss [12]. It will take time for governments and legal institutions to become more effective and, in the meantime, voluntary or informal methods can be useful in providing some degree of regulation. To this end, 'public disclosure techniques' can help to provide effective environmental governance. A growing body of evidence suggests that in countries where regulatory agencies are weak, such as Indonesia, the regular collection and dissemination of information about the environmental performance of companies can lead to increased compliance with regulations, with minimal burden on regulators [75]. Disclosure works both by increasing external pressures on firms and by improving the access of managers to information about the impacts and mitigation opportunities of their companies. Disclosure for visible, well-known attributes such as forest fire is likely to have the most impact (see e.g. http://www.eyesontheforest.or.id). Public disclosure programmes can quickly lose credibility if information is mishandled, so accurate reporting and independent auditing is essential [75].

committed to avoid using fire in land preparation and when mature, oil palm landscapes are probably less susceptible than *Imperata* grasslands to the spread of uncontrolled fires [17]. Initial land clearance exposes the soil to erosion. Sediment loads in streams increase dramatically after land clearance but return to baseline levels after plantation establishment [56]. Establishment of plantations on peat soils and where they replace forest contributes substantially to greenhouse gas emissions (Box 1), and thus to climate change, a growing global threat to biodiversity [35,57]. Despite these negative impacts, oil palm plantations might be better at providing some ecosystem services (such as carbon sequestration and soil protection) than annual crops or grassland, but not if they replace forest or peatland (Box 1).

Following plantation establishment, the greatest environmental impacts are likely to come from pollution. Water pollution from plantations and onsite mills is likely to affect aquatic biodiversity [58], but such impacts have not been assessed in relation to oil palm. Potential pollutants include palm oil mill effluent (POME), fertilisers, insecticides, rodenticides and herbicides [7,41,44]. Efforts to reduce the impacts of some of these pollutants are already in place in some plantations. POME is usually purified, so it can be harmlessly discharged into rivers; widespread use of integrated pest management and leguminous cover crops reduces use of insecticides and herbicides; and oil palm requires less fertiliser per unit of output than other oil crops [4,7].

There appear to be few biodiversity-friendly management practices which could enhance the value of oil palm plantations for native species. There are fewer animal species in planted areas because of reductions in habitat structural complexity and plant species diversity [27,32,38], and opportunities to increase these while maintaining agricultural productivity are limited [59]. Species richness of birds and butterflies was only marginally higher in oil palm plantations with more epiphytes or undergrowth [27,59]. Planting nonnative plants (such as *Euphorbia heterophylla* in Malaysia) to attract beneficial insects might help in pest control, but does not significantly improve the biodiversity value of plantations [59]. A trade-off might exist between enhancing the biodiversity value of plantations and minimising expansion into forested areas: if biodiversity-friendly management reduces yields, then more land will be needed to achieve production targets [3]. In this context, the limited available evidence suggests that the potential of biodiversity-friendly management is minimal (Box 2).

Of much greater value to biodiversity is the protection of fragments and corridors of native forest within and around plantations, including riverside buffers and remnants on steep slopes [59]. For species able to move through the oil palm matrix, forest fragments can act as ‘stepping stones’ for dispersal, and can be more beneficial than habitat ‘corridors’ [60], especially if they are large and not too isolated from other forests [53]. Although forested areas of tens of thousands of hectares will be needed to avert the extinction of many species [61], even small and degraded fragments can hold considerable biodiversity value and complement the species in larger reserves [50,51,53].

## What can be done to mitigate the impacts?

Although there is value in protecting forest remnants, there seem to be few other opportunities to improve the biodiversity value of oil palm plantations, and the future ecological impact of oil palm will be determined largely by the extent to which it causes large-scale deforestation. Governments, environmental and social organisations, scientists, producers, financial institutions, buyers and consumers together have the capacity to soften the impact of palm oil production on biodiversity. Although the best

### Box 4. Outstanding questions

The value of conservation research depends upon its ability to stimulate informed action by policymakers and practitioners [76]. Robust answers to the following, often multidisciplinary, questions will help to inform policy and conservation action.

**Preventing oil palm-driven deforestation**

Ensuring that the expansion of oil palm plantations does not occur at the expense of tropical forests is of the highest priority if ecological damage is to be minimised, and will be aided by well-informed and effectively implemented strategic landscape planning.

(i) How can the contribution of oil palm development to land-cover change be effectively determined and monitored?
(ii) How is oil palm development linked to other drivers of land-cover change in different regions and at different scales?
(iii) Do current methods of determining High Conservation Value areas ensure the protection of areas of conservation importance?
(iv) Is it safe to assume that marginal non-forest lands, for example *Imperata* grasslands, are of low conservation value?
(v) Where can oil palm expansion be directed to maximise agricultural yields and minimise impacts on biodiversity and climate?

**Conservation strategies in an oil palm-dominated landscape**

There is now sufficient evidence to conclude that the biodiversity value of oil palm plantations is low in comparison with forest, but little is known about the influence of different plantation management strategies and landscape configurations on native species.

(i) What are the impacts of oil palm cultivation on freshwater and marine ecosystems?
(ii) Can oil palm yields be increased while limiting negative externalities such as aquatic pollution?
(iii) Are there economically acceptable ways to make oil palm-dominated landscapes more biodiversity friendly (e.g. by increasing functional connectivity) without reducing yields?
(iv) What is the long-term potential for species persistence within oil palm-dominated landscapes?

**Policy and markets**

The applicability of conservation research depends upon the integration of biological, social, political and economic concerns.

(i) What are the barriers to the implementation of strategic landscape planning and how can they be overcome?
(ii) How can responsible oil palm development be best promoted, monitored and enforced?
(iii) How will the attitudes of consumers in developing palm oil markets (especially in Asia) affect future demand?
(iv) How will biofuel policies and markets affect oil palm expansion?

strategies for impact mitigation will differ within and between countries, there are several emerging opportunities.

Governmental and nongovernmental organisations can work to develop national strategies for land allocation that integrate maps of conservation priorities and agricultural suitability. Such strategies give no assurance that impacts are being minimised unless they are integrated into land-use allocation and coupled with effective regulatory systems. Diverting oil palm expansion into areas of low conservation importance (e.g. degraded *Imperata* grasslands, not to be confused with degraded forests) would avert much ecological damage. However, current international policies are doing nothing to ensure that such areas are being used in preference to natural forests, and difficult issues such as governance and land tenure need to be tackled effectively in producer countries. A challenge for conservation scientists is to understand these issues and identify solutions (Box 4). Nongovernmental organisations can help increase transparency by disseminating information to plantation managers and other stakeholders (Box 3).

Producers must be given access to information that will allow them to locate new plantations in areas where they will cause the least ecological damage. There is considerable scope for more widespread use of comprehensive Environmental Impact Assessments of proposed plantations, including Life-Cycle Analyses, to identify and reduce impacts [62,63]. There are opportunities for identifying ways in which palm oil yield can be increased while minimising negative environmental externalities (Box 2). There might also be wildlife-friendly management practices that do not reduce yields (but sometimes even enhance them [64]), and opportunities for companies to promote awareness of biodiversity among their staff [34]. Some producers have made significant progress toward minimising the adverse impacts of palm oil production, but challenges remain (Box 3). Strategic alliances between producer companies, environmental organisations and other stakeholders will be needed for conservation efforts to be successful (Box 2).

Financial institutions, buyers and consumers can assist by continuing to demand detailed evidence that producers are doing all they can to minimise the negative impacts of palm oil production, and by denying finance and markets to those that are not. Such evidence will be most credible if independently audited, for instance by local nongovernmental organisations (Box 3). It is difficult to predict how quickly emerging markets (e.g. in India and China) will start to demand evidence of environmental responsibility, but this could be critical in determining whether irresponsible and unregulated producers continue to make a profit, and hence whether oil palm expansion comes at great cost to forests.

## Conclusions

For biodiversity, oil palm plantations are a poor substitute for native tropical forests. They support few species of conservation importance, and affect biodiversity in adjacent habitats through fragmentation, edge effects and pollution. There is enough non-forested land suitable for plantation development to allow large increases in production without further deforestation, but political inertia, competing priorities and lack of capacity and understanding, not to mention high levels of demand for timber and palm oil from wealthy consumers, often make it cheaper and easier to clear forests. The efforts of some producers to reduce their environmental impacts, especially by avoiding forest conversion, must be commended. However, unless governments in producer countries become better at controlling logging, protecting forests and ensuring that crops are planted only in appropriate areas, the impacts of oil palm expansion on biodiversity will be substantial.

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