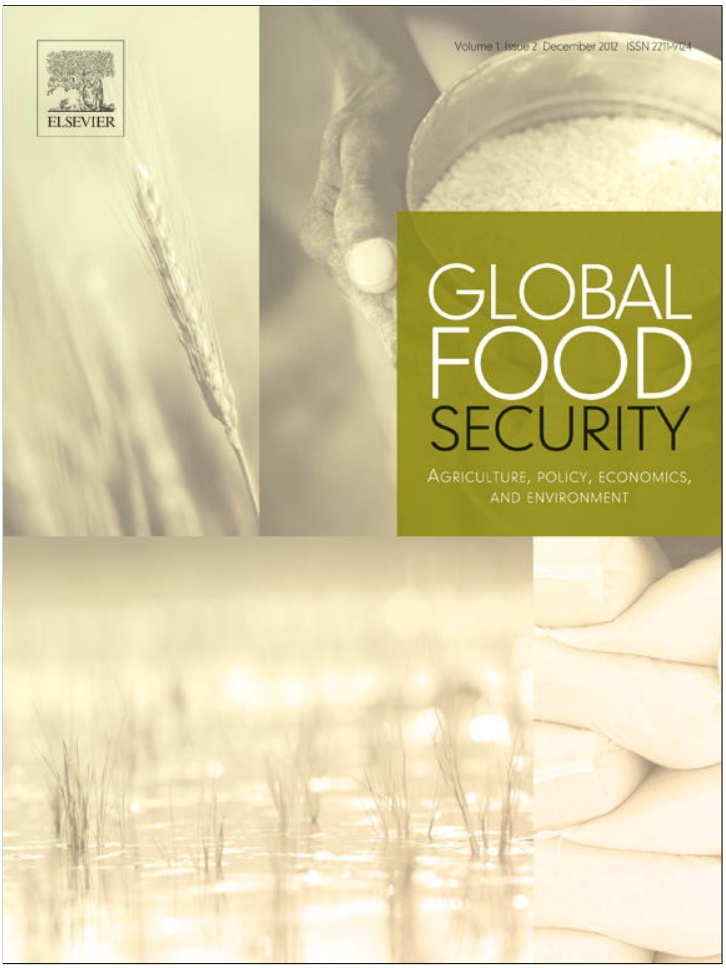

Global Food Security 1 (2012) 114–119

Contents lists available at SciVerse ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Oil palm expansion transforms tropical landscapes and livelihoods

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ARTICLE INFO

Article history:
Received 2 June 2012
Accepted 18 October 2012

Keywords:
Oil palm
Biodiversity
Carbon
Poverty alleviation
Smallholders
Land sparing

ABSTRACT

Oil palm is a highly profitable crop adapted to the humid tropics and the area devoted to this crop is likely to expand significantly in the future. It has many environmentally favourable attributes over its full life cycle. When well managed it has a positive carbon balance and when grown in a landscape mosaic it can play a role in biodiversity conservation. It has driven rapid economic growth in several tropical developing countries and contributed to the alleviation of rural poverty. Abuses during periods of rapid estate expansion into areas of natural forest and onto the lands of poor rural communities have led to criticism by environmental and social activists. With good governance oil palm can make valuable contributions to development and the resulting prosperity may free people to invest in better environmental practices.

1. Introduction

In less than 100 years oil palm has moved from being a relatively minor subsistence crop in West and Central Africa to one of the world's major agricultural commodities. While oil palm in Africa has been cultivated for centuries by deliberate plantings and selective clearing (Zeven, 1972; Smith et al., 1992), it has recently expanded dramatically in Southeast Asia (Wicke et al., 2011), and increasingly in Africa and Latin America (Fig. 1). The expansion is driven by producers responding to real and anticipated increase in consumer demand (Corley, 2009), much of which is from India and China. Oil palm provides much needed revenue to rapidly developing countries, and is an economic boon to thousands of people in tropical rural regions, although economic benefits are not distributed evenly (Rist et al., 2010; Obidzinski et al., 2012). As a major contributor to the economies of several developing countries, the expansion of oil palm cultivation is now a government priority throughout the humid tropics including some of the world's poorest countries. Oil palm expansion has mostly taken place in biodiversity-rich tropical rainforest areas (Carlson et al., 2012). It is also often planted by large corporations, some of whom pay little heed to the rights of local populations (Barr and Sayer, 2012). It has consequently become the latest battleground between environmentalists on the one hand and developers on the other. Claims and counter-claims, often poorly supported, have muddied the waters and polarised opinions (Koh et al., 2010). The reality is, as always, complex, and the oil palm controversy has the elements of a "wicked problem" in the sense that there are no clear solutions, stakeholders hold conflicting views, information is incomplete and contradictory and contexts are constantly changing (Balint et al., 2011).

Here, we emphasise four oil palm 'truths' that we believe should be acknowledged in any meaningful debate. We then consider how management, policy and planning interventions have the potential to improve oil palm production systems from the perspectives of both development and environment. We acknowledge at the outset that solutions that will satisfy everyone are almost certainly impossible; rather the challenge is to minimise negative impacts of continuing oil palm expansion while maximising its benefits.

2. The four oil palm truths

In view of trends in consumer demand, we present the **first oil palm truth** as: *demand for oil palm will continue to increase in response to a growing and increasingly affluent global population.* The implication is that the area under oil palm production will continue to expand, albeit mitigated somewhat by improvements in productivity. Indeed, improving production per unit area is an important topic of research that could benefit producer communities while sparing land for conservation (Griffiths and Fairhurst, 2003; Fischer et al., 2008; Gutierrez-Velez et al., 2011). There is some debate about whether this is better achieved through production on large estates or by smallholders: constraints and opportunities apply to both strategies, towards which research could make valuable contributions.

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http://dx.doi.org/10.1016/j.gfs.2012.10.003

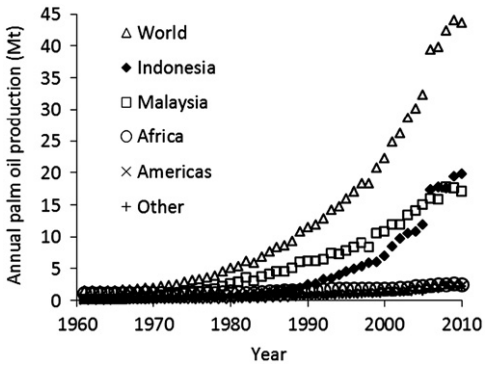

Fig. 1. Global palm oil production, 1961–2010 (source data from FAOSTAT).

Following on from this is the **second oil palm truth**: *Oil palm is one of the most profitable land uses in the humid tropics*. This profitability underpins the desire for local people to plant it, corporations to invest in it, and nations to promote it. While profitability drives expansion of the industry, it also contributes potential for land-saving. High profitability of oil palm implies that forest protection for biodiversity conservation or carbon storage will have high opportunity costs (Butler et al., 2009), but this should be set against the reality that it is generally easier to secure conservation outcomes when people are prosperous. It remains to be seen whether increased societal wealth will facilitate better conservation outcomes (Sayer and Collins, 2012), and progress may come too late for much of Southeast Asia's lowland forests.

National policy is influenced by many factors, including the international communities' efforts to mitigate carbon emissions, particularly through schemes such as REDD. In this respect, oil palm producers have argued that oil palm plantations deliver a net carbon sequestration benefit. Such statements require careful critique, but we suggest that this provides a basis for the **third oil palm truth**: *Oil palm plantations store more carbon than alternative agricultural land uses.* We do not claim that forest conversion to oil palm has no net effect on carbon emissions—indeed we acknowledge that large carbon emissions occur during the establishment phase where oil palm replaces relatively undisturbed forest. Rather we argue that, in terms of carbon emissions alone, and given the need to meet future demands, oil palm is preferable to other agricultural alternatives for oil production.

Carbon storage is, of course, only one of several important environmental objectives. It is biodiversity conservation, alongside carbon emissions, that most attracts scrutiny in the media. There is justified international concern for loss of forest biodiversity through expansion of oil palm. Hence the **fourth oil palm truth** is: *native biodiversity within oil palm plantations is far lower than the natural forests they often replace*. While this seems very evident, oil palm has often been marketed by some companies as being 'environmentally friendly'. The fundamental truth, however, is that biodiversity is drastically reduced following conversion of rainforest habitat to any large scale commercial agricultural system. As with carbon storage, biodiversity loss due to oil palm expansion should be presented relative to that associated with alternative crops for oil or energy (e.g. soybean, rapeseed, maize, sugar cane), and in this respect oil palm compares favourably (de Vries et al., 2010).

Having accepted these four truths we can begin to explore avenues and scenarios by which palm oil cultivation can play a role in improving livelihoods and enriching landscapes in the humid tropics.

3. Global demand and the continuing expansion, and profitability, of oil palm

The recent expansion of the oil palm industry has been in response to global demand for vegetable oil, driven by increasing population, income, and more recently a growing biofuel market. This trend is set to continue. Demand for vegetable oil is expected to be around 240 Mt yr^{-1} by 2050, twice the 2009 value (Corley, 2009); palm oil is particularly favoured on account of its low production cost. In 2011 global production of palm oil was 50.2 Mt, or about 28% of total vegetable oil production (Mielke, 2012). The demand for palm oil as a biofuel feedstock has risen from zero in 2000 to about 10% of crude palm oil in 2011 (Mielke, 2012). Most of the interest in the use of palm oil as biofuel was generated in the 2005–2006 period when crude mineral oil prices surpassed crude palm oil prices. Since then palm oil has consistently traded at higher prices than crude mineral oil; current demand for biofuel is largely driven by government policy rather than market signals (Sheil et al., 2009; Mielke, 2012). The possible effects on food security of using significant quantities of palm oil for biofuel are difficult to predict (Naylor et al., 2007). Yet, regardless of crude oil prices, demand for palm oil is likely to continue to grow due to increasing demands for cooking oil, soap, cosmetics and processed food. As human populations move to cities and switch to diets of processed foods the demand for crops such as palm oil may increase at the expense of staple carbohydrates.

In Southeast Asia oil palm has become a major contributor to the economies of Malaysia and Indonesia. In 2010, 5.4 million ha had been planted with oil palm in Indonesia (3% of total land area), 4.0 million ha in Malaysia (12% of land area), 3.2 million ha in Nigeria (3% of land area) and 2.8 million ha in the rest of the world (FAOSTAT). While recent expansion of oil palm has been in tropical Asia, it is likely that future expansion will be pan-tropical. Peninsular Malaysia is reaching the limits of land available for oil palm, and also suffers labour shortages with a large part of the current labour force coming from Indonesia. The cost of palm oil production is increasing in Malaysia, though it will remain highly profitable if global prices maintain their present levels. Despite these constraints, both Malaysia and Indonesia plan to expand oil palm cultivation through 2020, with projections of annual expansion rates over the next decade ranging between 3 and 8% (Wicke et al., 2011).

Limited land availability has forced Indonesian and Malaysian companies to pursue new options for increasing production. These include expanding estates elsewhere, notably in Africa and South America. Companies such as Golden Veroleum (Indonesia), Equatorial Palm Oil (UK), Sime Darby (Malaysia), OLAM (Singapore) and Herakles Farms (USA), as well as Malaysia's state plantation agency (Federal Land Development Authority) are in the process of negotiating or establishing oil palm plantations (of between 60,000 to well over 100,000 ha) in Liberia, Cameroon and Congo Basin countries. South American nations are also quickly expanding oil palm acreage. Colombia is now the fifth largest producer of oil palm, and production is projected to increase dramatically over the coming decade (Garcia-Ulloa et al., 2012).

These scenarios are alarming for conservationists concerned about the impacts of forest conversion on biodiversity. Decisions on where to locate oil palm plantations are driven more by economics than by environmental suitability. Even so, some recent studies suggest that substantial expansion could be accommodated in Indonesia without necessarily impacting natural forests or biodiversity, although trade-offs with other agricultural crops might have to be accepted (Koh and Ghazoul, 2010). Others have suggested that oil palm expansion in

Indonesia to 2020 can be accommodated on degraded lands, such as *Imperata cylindrica* grasslands (Wicke et al., 2011). The problem is that most of these so-called degraded lands support the livelihoods of poor local people. Although these people may secure employment in the oil palm estates they often fail to do so as the large companies prefer to bring in migrant labourers with experience in estate work. Pressure on companies to reduce their greenhouse gas emissions might make the development of degraded lands a more attractive option. Yet large companies have considerable political influence in Southeast Asia, and this has shaped the policy environment within which production and conservation strategies are implemented and debated. The expansion of oil palm is politically, and to a large extent socially, acceptable to most people within these countries for whom economic growth and food production are higher priorities than conservation.

4. Possibilities for increasing palm oil production: estates versus smallholders

An alternative to expanding the land area under oil palm is to intensify production and raise yields, allowing more oil palm to be produced on a smaller land area. The potential for yield increases in both smallholdings and industrial plantations is substantial. A realistic value for palm oil yield potential in favourable environments, averaged over the economic life of planting after canopy closure, is around 10–11 t ha^{-1} yr^{-1} (Breure, 2003). Oil palm breeders estimate potential yields of 18 t ha^{-1} (Corley and Tinker, 2003). Yet the average yield of industrial oil palm plantations is currently about 3.9 t ha^{-1} in Indonesia and 4.5 t ha^{-1} in Malaysia (Mielke, 2012), with the best yields rising only to around 7–8 t ha^{-1}.

Oil palm is often viewed as an industrial crop, but in many areas it is a valuable smallholder crop (a smallholding being up to around 5 ha). Indeed, the profitability of oil palm offers considerable potential for rural development in the humid tropics (Arif and Tengku Mohd Ariff, 2001; Feintrenie et al., 2010a; Dayang Norwana et al., 2011). On the other hand, the establishment of contractual arrangements between companies and smallholder has resulted to some loss of resource tenure and autonomy, and has had impacts on local social and gender relations (Cramb, 2010; Cramb and Sujang, 2011; Cramb, 2012; White and White, 2012).

Smallholder farmers may have a comparative advantage in the production of oil palm fruit. Compared to estate workers, smallholders are more readily able to monitor individual trees frequently, and thus harvest fruit bunches at optimum ripeness. Government policies in Indonesia and Malaysia have long favoured nucleus (industrial plantation) and plasma (neighbouring smallholders who supply the mill) oil palm schemes. In the past prices for oil palm were sometimes state-regulated, but independent smallholders located far from a mill were forced to sell their production to intermediaries who operate outside of such arrangements (McCarthy, 2010). The proliferation of mills now provides better access to mills, and hence better prices, for many more smallholders (Jelsma et al., 2009). Both Indonesia and Malaysia have policies to favour smallholder involvement in the oil palm industry and Indonesia has a target of 40% of production coming from smallholders, although this target is far from being met.

The extent to which smallholders can engage depends on the interaction among smallholders and oil palm companies. Smallholder palm oil producers operate in a variety of relationships with milling companies; for example, they may be contractually tied to one milling company, associated with a company (there may be only one company nearby), independent and able to choose which company they sell to, or organised into cooperatives (Vermeulen and Goad, 2006; Jelsma et al., 2009; World Bank, 2010). Supported smallholders are contractually bound to a specific company or mill but benefit from the access they gain to inputs and expertise. In Sumatra, average palm oil yields are around 40% higher in supported smallholder systems (Lee et al., in prep), so incentives to become contractually tied to a company are high. Recently independent smallholders appear to be gaining ground in Indonesia as they accumulate expertise and, with access to an increase in the number of mills, are able to negotiate better prices.

Large oil palm companies exert considerable power in shaping the expansion of the oil palm industry, and their actions may be to the detriment of landowners and smallholders (Sheil et al., 2009). But they also provide benefits and opportunities essential for commercially viable smallholder production systems, such as infrastructure, credit for inputs, technical advice, regular fruit pickup and a contracted price formula.

There is an abundant recent literature on the issues surrounding smallholder cultivation of oil palm (Jelsma et al., 2009; McCarthy and Cramb, 2009; Feintrenie et al., 2010a; Feintrenie et al., 2010b; Rist et al., 2010; Cramb, 2011; McCarthy et al., 2012). In Indonesia, smallholder farmers are converting existing rubber and other tree crops to oil palm in response to market prices. Smallholder farmers can achieve incomes that enable them to improve their livelihoods significantly (Feintrenie et al., 2010a; Feintrenie et al., 2010b). Smallholdings also support more people than industrial plantations: in PNG, for example, there are 34.3 smallholders per square km of oil palm compared to 14.5 employees on company plantations (Nelson et al., 2010). If associated employment and infrastructure are included, then the impacts on rural economies can be very positive (Ghazoul et al., 2010; Hunt, 2010).

A barrier to meeting global palm oil demands through smallholder production systems is that in areas such as Indonesian Papua, the Congo basin and many other areas where industrial producers are now beginning to operate, the potential for smallholders to be active in oil palm production is much lower. In these areas smallholders can be limited by insufficient expertise, labour, fertiliser and other essential inputs. In this difficult start-up period industrial producers are likely to dominate oil palm production, and could set the conditions for smallholder participation, unless there is political intervention and appropriate smallholder incentives. The shift from state-led to neoliberal governance systems in Indonesia has generated policies that facilitate smallholders to increase their share of the market, but successive changes in policy, coupled with regional differences in the manner and effectiveness with which they are implemented, has affected local outcomes (McCarthy and Cramb, 2009; McCarthy, 2010). In many of these areas government institutions are weak, traditional land rights are difficult to defend and spatial planning rules, if they exist, are rarely applied (Colchester and Jiwan, 2006; Colchester et al., 2006).

Fewer than 40% of all land holdings in Indonesia are formally titled, the rest being held under informal or customary tenure (World Bank study quoted by Colchester 2011). Land acquisition in East Malaysia (Sabah and Sarawak) and Indonesia by some companies has been criticised for not recognising the traditional land rights of local people (Colchester and Jiwan, 2006). Oil palm expansion in West Kalimantan, funded by the International Finance Corporation, has been suspended because companies were judged to be violating the IFC's own guidelines on land acquisition by failing to obtain the free, prior and informed consent of local people. As land becomes increasingly scarce conflicts over land acquisition between companies and

smallholders are likely to increase. The past few years have seen a great expansion of negotiations for land conversion agreements in Papua New Guinea, Indonesian West Papua, some Pacific Islands, many Congo basin countries, and Latin America. These negotiations are often asymmetrical, with local people lacking access to information, or to legal recourse when their rights are infringed (Colchester et al., 2006; Colchester, 2011; Cramb et al., 2009; Cramb, 2012). In cases where companies are seeking accreditation by the Round Table on Sustainable Palm Oil (RSPO, 2006) adherence to its Principles should counter these problems. These principles concern the provision of adequate information to other stakeholders (Principle 1), compliance to local, national and international laws (Principle 2), and responsibility towards employees and communities affected by oil palm development (Principle 6) (RSPO, 2006).

In the long term it is clearly in the interests of the oil palm industry to increase yields. However in the short term it appears to be a higher priority for many companies to increase land holdings in anticipation of future rising demands, particularly when land is becoming increasingly scarce. Expansion onto forested land is attractive as income from timber can be used to offset development costs, although laws governing timber extraction vary from country to country. Expansion of corporations into Africa offers opportunities to improve African oil palm yields, which are currently very low. Yields in Nigeria, Africa's major oil palm producing country, are around one eighth of Malaysia's 21.2 t ha^{-1} of fresh fruit bunches (2010 data sourced from FAOSTAT, 2012). This is partly due to unfavourable environmental factors such as a long dry season and heavy cloud cover, but also because of inefficient plantations management, poor quality plants and low input use, issues that can be resolved with appropriate investments. Hence protection of remaining forest lands in Asia may result in displacement of land clearance activities to Africa, which might facilitate and accelerate the intensification of African production systems.

5. Carbon: oil palm is no substitute for natural forests, but is better than the alternatives

The standing carbon stock of an oil palm estate is variously reported at 50 to 100 t ha^{-1} (MPOC, 2007; Morel et al., 2011). This is not as high as that of logged natural forests where carbon stocks range from 90 to 180 t ha^{-1} subject to logging intensity and recovery time, or unlogged rainforest where values range from 175 to 215 t ha^{-1} (MPOC, 2007; Morel et al., 2011). It is, however, significantly more than other vegetable oil crops: the standing biomass of soybean at the end of a 120-day crop period is approximately 6 t ha^{-1} (Lawn and James, 2011). Where oil palm replaces natural forest, the carbon gain of producing palm oil compensates for the carbon loss from forest conversion after 75–93 years (Fargione et al., 2008; Danielsen et al., 2009). For conversion from grassland the corresponding period is only 10 years or less, although when peat forests are converted to oil palm it may be up to 600 years (Fargione et al., 2008; Gibbs et al., 2008; Danielsen et al., 2009). Nevertheless, carbon balance within oil palm systems established on degraded lands can become positive within less time than for those replacing forest. Companies should be seeking to minimise carbon emissions from expanded oil palm production, and the most effective way to do this might be through intensifying production or limiting expansion to degraded grasslands (Fairhurst and McLaughlin, 2009). It is possible that financial incentives through REDD+ schemes might be used to encourage such practices, but the transfer of REDD+ funds to oil palm companies is likely to be met, perhaps justifiably, by an environmentalist outcry. In any case, opportunities for expansion onto degraded grasslands are limited by the availability of such land as compared to forested lands. Other than land use change, one of the most significant practices affecting greenhouse gas emissions in the oil palm industry is the capture of methane from palm oil mill effluent ponds. Such methane capture is currently eligible for payments from the 'clean development mechanism' under the Kyoto Protocol.

Aside from carbon balance, oil palm also outperforms many other crops (including soybean, maize, colza, wheat and sugar cane) in terms of maintenance of soil quality, net energy production and greenhouse gas emissions (other than carbon), water use, nitrogen and energy use efficiency, while pesticide inputs are very low in relation to the net energy production (de Vries et al., 2010).

6. Global versus local values: biodiversity

It is undoubtedly the case that large scale biodiversity loss accompanies the conversion of natural forest to oil palm (Koh and Ghazoul, 2008; Bruhl and Eltz, 2010; Fayle et al., 2010; Foster et al., 2011; Edwards et al., 2012; Jambari et al., 2012). Industrial oil palm estates can be established in ways that make allowances for biodiversity (Koh et al., 2009), particularly by retaining forests in riverine areas and on steep slopes, or by setting aside areas of High Conservation Value Forest. Regrettably, there are few examples where this potential has been realised.

Smallholder systems provide some opportunity to retain a more diverse landscape matrix that has the potential of supporting a greater fraction of the original biodiversity, and also of providing a less hostile matrix across which animals might move. The diversity of crops and density of uncultivated boundaries between smallholdings might contribute in supporting some biodiversity. Furthermore, some charismatic animals that have been the focus of environmentalist concerns, such as orangutans, may be less sensitive to smallholder farming systems than conservation campaigns might suggest (Meijaard et al., 2010), although they remain vulnerable where industrial oil palm preponderates (Campbell-Smith et al., 2011). Increasing the structural heterogeneity of an agricultural system is thought to increase species diversity. Understory vegetation in oil palm plantations increases the abundance and richness of beetles in Sabah (Chung et al., 2000) and bird communities in Guatemala (Najera and Simonetti, 2010), and might also support natural pest control services (Wood, 1969). Wildlife-friendly agricultural approaches favour planting oil palm within a more diverse agroforestry system (Bhagwat and Willis, 2008; Foster et al., 2011), although this would substantially reduce oil palm yields (Koh et al., 2009; Phalan et al., 2009).

Few extensive areas of Asian lowland tropical rainforest remain, and many of those that do are fragmented and degraded. The biological cost of rainforest loss is incalculable. Consumers are as much part of the problem as are the producers. Many other agricultural commodities have contributed to substantial losses of forest and biodiversity, and some of these commodities have fewer essential uses than oil palm. The impact of oil palm on biodiversity is undoubted, but it should be set in the context of other less productive crops. Set against this is the undoubted reality that oil palm cultivation has contributed to improving the livelihoods of large numbers of poor people; their prosperity has brought some stability to the forest frontier and has enabled people to attain a level of development where environmental objectives may be higher priorities.

7. A way forward

The first of the ecosystem principles adopted by the Convention on Biological Diversity is that conservation is a matter of

societal choice (Sayer and Maginnis, 2005). As such, many tropical countries with large populations of poor rural dwellers will opt for oil palm rather than natural forest. The overwhelming desire to escape poverty and pursue economic advancement, coupled with continuing consumption of palm oil globally, suggests a future with more oil palm and less forest. The challenge is not to stop oil palm expansion, but to shape its development to minimise impacts on biodiversity, carbon, local peoples' welfare and other priorities.

There are clear options for bringing degraded lands into production, improving yields, and providing incentives to stimulate smallholder innovations. Yet, much of the future expansion of oil palm will take place in regions where regional and local governance is relatively weak, spatial planning ineffective, and land tenure uncertain (Feintrenie et al., 2010a). We suggest that these institutional failures will be the main obstacle to protecting environmental values and achieving more equitable social outcomes as palm oil production expands. Thus there are three principle recommendations that would make the largest contribution to sustainably oil palm production: (1) promotion of yield intensification to reduce the requirement for area expansion; (2) good governance relating to smallholder tenure security and forest conservation; and (3) promotion of smallholder organisations to redress the balance of power in negotiated agreements with commercial estates and milling companies.

Oil palm expansion is ultimately driven by the consumer. Consumer behaviour can, and has, shaped the emergence of a more socially and environmentally aware industry. While there is still a long way to go, and many improvements to be made, the rate at which goals of equity and sustainability will be achieved is ultimately a function of consumer behaviour and, as the Convention on Biological Diversity has acknowledged, a societal choice.

References

Arif, S., Tengku Mohd Ariff, T.A., 2001. The case study on the Malaysian palm oil. UNCTAD/ESCAP Regional Workshop on Commodity Export Diversification and Poverty Reduction in South and Southe-East Asia, Bangkok.

Balint, P.J., Stewart, R.E., Desai, A., Walters, L.C., 2011. Wicked Environmental Problems. Managing Uncertainty and Conflict Island Press, Washington, DC.

Barr, C.M., Sayer, J.A., 2012. The political economy of reforestation and forest restoration in Asia–Pacific: critical issues for REDD+. Biological Conservation 154, 9–19.

Bhagwat, S.A., Willis, K.J., 2008. Agroforestry as a solution to the oil-palm debate. Conservation Biology 22, 1368–1369.

Breure, K., 2003. The search for yield in oil palm: basic principles. In: Fairhurst, T.H., Härdter, R. (Eds.), The Oil Palm. Management for Large and Sustainable Yields. Potash and Phosphate Institute/Potash Institute of Canada and International Potash Institute, Singapore, pp. 59–98.

Bruhl, C.A., Eltz, T., 2010. Fuelling the biodiversity crisis: species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo). Biodiversity and Conservation 19, 519–529.

Butler, R.A., Koh, L.P., Ghazoul, J., 2009. REDD in the red: palm oil could undermine carbon payment schemes. Conservation Letters.

Campbell-Smith, G., Campbell-Smith, M., Singleton, I., Linkie, M., 2011. Apes in space: saving an imperilled orangutan population in Sumatra. PLoS ONE, 6.

Carlson, K.M., Curran, L.M., Ratnasari, D., Pittman, A.M., Soares, B.S., Asner, G.P., Trigg, S.N., Gaveau, D.A., Lawrence, D., Rodrigues, H.O., 2012. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. Proceedings of the National Academy of Sciences of the United States of America 109, 7559–7564.

Chung, A.Y.C., Eggleton, P., Speight, M.R., Hammond, P.M., Chey, V.K., 2000. The diversity of beetle assemblages in different habitat types in Sabah, Malaysia. Bulletin of Entomological Research 90, 475–496.

Colchester, M., 2011. Palm oil and indigenous peoples in South East Asia. International Land Coalition, Rome, p. 36.

Colchester, M., Jiwan, N., 2006. Ghosts on our Own Land: Indonesian Oil Palm Smallholders and the Roundtable on Sustainable Palm Oil. Forest Peoples Programme and Perkumpulan Sawit Watch. Moreton-in-Marsh, England and Bogor, Indonesia, p. 24.

Colchester, M., Jiwan, N., Andiko, Sirait M., Firdaus, A.Y., Surambo, A., Pane, H., 2006. Promised Land: Palm Oil and Land Acquisition in Indonesia: Implications for Local Communities and Indigenous Peoples. Forest Peoples Programme, Perkumpulan Sawit Watch, HuMA and the World Agroforestry Centre. Moreton-in-Marsh, UK and Bogor, Indonesia.

Corley, R.H.V., 2009. How much palm oil do we need? Environmental Science and Policy 12, 134–139.

Corley, R.H.V., Tinker, P.B., 2003. The Oil Palm. Blackwell Science, Oxford.

Cramb, R., Sujang, P.S., 2011. 'Shifting ground': Renegotiating land rights and rural livelihoods in Sarawak, Malaysia. Asia Pacific Viewpoint 52, 136–147.

Cramb, R.A., 2010. Agrarian angst and rural resistance in contemporary Southeast Asia. Asia Pacific Viewpoint 51, 226–228.

Cramb, R.A., 2011. Re-inventing dualism: policy narratives and modes of oil palm expansion in Sarawak, Malaysia. Journal of Development Studies 47, 274–293.

Cramb, R.A., 2012. Palmed off: incentive problems with joint-venture schemes for oil palm development on customary land.

Cramb, R.A., Colfer, C.J.P., Dressler, W., Laungaramsri, P., Le, Q.T., Mulyoutami, E., Peluso, N.L., Wadley, R.L., 2009. Swidden transformations and rural livelihoods in Southeast Asia. Human Ecology 37, 323–346.

Danielsen, F., Beukema, H., Burgess, N.D., Parish, F., Bruhl, C.A., Donald, P.F., Murdiyarso, D., Phalan, B., Reijnders, L., Struebig, M., Fitzherbert, E.B., 2009. Biofuel plantations on forested lands: double jeopardy for biodiversity and climate. Conservation Biology 23, 348–358.

Dayang Norwana, A.A.B., Kunjappan, R., Chin, M., Schoneveld, G., Potter, L., Andriani, R., 2011. The Local Impacts of Oil Palm Expansion in Malaysia: An Assessment Based on a Case Study in Sabah State. Working Paper. CIFOR, Bogor, Indonesia, p. 17.

de Vries, S.C., van de Ven, G.W.J., van Ittersum, M.K., Giller, K.E., 2010. Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. Biomass and Bioenergy 34, 588–601.

Edwards, D.P., Fisher, B., Wilcove, D.S., 2012. High conservation value or high confusion value? Sustainable agriculture and biodiversity conservation in the tropics. Conservation Letters 5, 20–27.

Fairhurst, T.H., McLaughlin, D., 2009. Sustainable oil palm development on degraded land in Kalimantan. WWF.

FAOSTAT, 2012. FAOSTAT Statistics Database. UN Food and Agriculture Organisation, Rome.

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. Science 319, 1235–1238.

Fayle, T.M., Turner, E.C., Snaddon, J.L., Chey, V.K., Chung, A.Y.C., Eggleton, P., Foster, W.A., 2010. Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. Basic and Applied Ecology 11, 337–345.

Feintrenie, L., Chong, W.K., Levang, P., 2010a. Why do farmers prefer oil palm? lessons learnt from Bungo District, Indonesia. Small-Scale Forestry 9, 379–396.

Feintrenie, L., Schwarze, S., Levang, P., 2010b. Are local people conservationists? Analysis of transition dynamics from agroforests to monoculture plantations in Indonesia. Ecology and Society, 15(4), 37.

Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, D.B., Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H., 2008. Should agricultural policies encourage land sparing or wildlife-friendly farming? Frontiers in Ecology and the Environment 6, 380–385.

Foster, W.A., Snaddon, J.L., Turner, E.C., Fayle, T.M., Cockerill, T.D., Ellwood, M.D.F., Broad, G.R., Chung, A.Y.C., Eggleton, P., Khen, C.V., Yusah, K.M., 2011. Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. Philosophical Transactions of the Royal Society—Biological Sciences 366, 3277–3291.

Garcia-Ulloa, J., Sloan, S., Pacheco, P., Ghazoul, J., Koh, L.P., 2012. Lowering environmental costs of oil palm in Colombia. Conservation Letters 5, 366–375.

Ghazoul, J., Butler, R.A., Mateo-Vega, J., Koh, L.P., 2010. REDD: a reckoning of environment and development implications. Trends in Ecology and Evolution 25, 396–402.

Gibbs, H.K., Johnston, M., Foley, J.A., Holloway, T., Monfreda, C., Ramankutty, N., Zaks, D., 2008. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. Environmental Research Letters, 10.

Griffiths, W., Fairhurst, T., 2003. Implementation of best management practices in an oil palm rehabilitation project. Better Crops International 17, 16–19.

Gutierrez-Velez, V.H., DeFries, R., Pinedo-Vasquez, M., Uriarte, M., Padoch, C., Baethgen, W., Fernandes, K., Lim, Y.L., 2011. High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon. Environmental Research Letters, 6.

Hunt, C., 2010. The costs of reducing deforestation in Indonesia. Bulletin of Indonesian Economic Studies 46, 187–192.

Jambari, A., Azhar, B., Ibrahim, N.L., Jamian, S., Hussin, A., Puan, C.L., Noor, H.M., Yusof, E., Zakaria, M., 2012. Avian biodiversity and Conservation in Malaysian oil palm production areas. Journal of Oil Palm Research 24, 1277–1286.

Jelsma, I., Giller, K., Fairhurst, T., 2009. Smallholder oil palm produciton systems in Indonesia: lessons from the NESP Ophir Project. Wageningen University, Wageningen.

Koh, L.P., Ghazoul, J., 2008. Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. Biological Conservation 141, 2450–2460.

Koh, L.P., Ghazoul, J., 2010. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. In: Proceedings of the National Academy of Sciences of the United States of America, vol. 107, pp. 11140–11144.

Koh, L.P., Ghazoul, J., Butler, R.A., Laurance, W.F., Sodhi, N.S., Mateo-Vega, J., Bradshaw, C.J.A., 2010. Wash and spin cycle threats to tropical biodiversity. Biotropica 42, 67–71.

Koh, L.P., Levang, P., Ghazoul, J., 2009. Designer landscapes for sustainable biofuels. Trends in Ecology and Evolution 24, 431–438.
Lawn, R.J., James, A.T., 2011. Application of physiological understanding in soybean improvement. I. Understanding phenological constraints to adaptation and yield potential. Crop and Pasture Science 62, 1–11.
Lee, J.S.H., Ghazoul, J., Obidzinski, K., Koh, L.P. Understanding variations in smallholder oil palm yields and incomes in Sumatra, Indonesia, in preparation.
McCarthy, J.F., 2010. Processes of inclusion and adverse incorporation: oil palm and agrarian change in Sumatra, Indonesia. Journal of Peasant Studies 37, 821–850.
McCarthy, J.F., Cramb, R.A., 2009. Policy narratives, landholder engagement, and oil palm expansion on the Malaysian and Indonesian frontiers. Geographical Journal 175, 112–123.
McCarthy, J.F., Gillespie, P., Zen, Z., 2012. Swimming upstream: local Indonesian production networks in "Globalized" palm oil production. World Development 40, 555–569.
Meijaard, E., Albar, G., Nardiyono, Rayadin Y., Ancrenaz, M., Spehar, S., 2010. Unexpected ecological resilience in Bornean orangutans and implications for pulp and paper plantation management. Plos One 5, e12813.
Mielke, 2012. Global supply, demand and price outlook for vegetable oils—especially palm oil. Oil World. ISTA Mielke GmbH, Hamburg.
Morel, A.C., Saatchi, S.S., Malhi, Y., Berry, N.J., Banin, L., Burslem, D., Nilus, R., Ong, R.C., 2011. Estimating aboveground biomass in forest and oil palm plantation in Sabah, Malaysian Borneo using ALOS PALSAR data. Forest Ecology and Management 262, 1786–1798.
MPOC, 2007. Palm Oil: Tree of Life. Official Report. Malaysian Palm Oil Council, Kuala Lumpur, p. 20.
Najera, A., Simonetti, J.A., 2010. Can oil palm plantations become bird friendly? Agrofor. Syst. 80, 203–209.
Naylor, R.L., Liska, A.J., Burke, M.B., Falcon, W.P., Gaskell, J.C., Rozelle, S.D., Cassman, K.G., 2007. The ripple effect: biofuels, food security, and the environment. Environment 49, 30–43.
Nelson, P.N., Webb, M.J., Orrell, I., van Rees, H., Banabas, M., Berthelsen, S., Sheaves, M., Bakani, F., Pukam, O., Hoare, M., Griffiths, W., King, G., Carberry, P., Pipai, R., McNeill, A., Meekers, P., Lord, S., Butler, J., Pattison, T., Armour, J., Dewhurst, C., 2010. Environmental sustainability of oil palm cultivation in Papua New Guinea. ACIAR Technical Report. The Australian Centre for International Agricultural Research, Canberra.
Obidzinski, K., Andriani, R., Komarudin, H., Andrianto, A., 2012. Environmental and social impacts of oil palm plantations and their implications for biofuel production in Indonesia. Ecology and Society, 17.
Phalan, B., Fitzherbert, E.B., Rafflegeau, S., Struebig, M.J., Verwilghen, A., 2009. Conservation in oil palm landscapes. Conservation Biology 23, 244–245.
Rist, L., Feintrenie, L., Levang, P., 2010. The livelihood impacts of oil palm: smallholders in Indonesia. Biodiversity and Conservation 19, 1009–1024.
RSPO, 2006. RSPO principles and criteria for sustainable palm oil production. Round Table on Sustainable Palm Oil, 53.
Sayer, J.A., Collins, M., 2012. Forest governance in a changing world: reconciling local and global values. The Round Table: The Commonwealth Journal of International Affairs 101, 137–149.
Sayer, J.A., Maginnis, S. (Eds.), 2005. Forests in Landscapes: Ecosystem Approaches to Sustainability. Earthscan, London, 257pp.
Sheil, D., Casson, A., Meijaard, E., van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., Wertz, K., Kanninen, M., 2009. The Impacts and Opportunities of Oil Palm in Southeast Asia: What Do We Know and What Do We Need to Know? Occasional Paper. Center for International Forestry Research, Bogor, Indonesia.
Smith, N.J.H., Williams, J.T., Plucknett, D., Talbot, J.P., 1992. Tropical Forests and their Crops. Cornell University Press, Ithaca.
Vermeulen, S., Goad, N., 2006. Towards better practice in smallholder palm oil production. IIED.
White, J., White, B., 2012. Gendered experiences of dispossession: oil palm expansion in a Dayak Hibun community in West Kalimantan. Journal of Peasant Studies 39, 995–1016.
Wicke, B., Sikkema, R., Dornburg, V., Faaij, A., 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28, 193–206.
Wood, B.J., 1969. Studies on effects of ground vegetation on infestations of *Oryctes rhinoceros* (L) (Col, Dynastidae) in young oil palm replantings in Malaysia. Bulletin of Entomological Research 59, 85–96.
World Bank, 2010. Improving the Livelihoods of Palm Oil Smallholders: The Role of the Private Sector. International Finance Corporation, World Bank Group, Washington DC, USA, p. 32.
Zeven, A.C., 1972. Partial and complete domestication of oil palm (*Elaeis guineensis*). Economic Botany 26, 274–279.