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ECO-FRIENDLY APPROACHES TO SUSTAINABLE PALM OIL PRODUCTION

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ABSTRACT

There have been many innovations in mill technologies, oil palm agronomy and pest management over past decades that are increasingly meeting the certification criteria of the Roundtable on Sustainable Palm Oil (RSPO). In addition, because oil palm plantations may be functionally analogous to forests, and remain undisturbed for several decades, they can provide some essential ecosystem services to local/national stakeholders in terms of direct use-values (products, economics) and indirect use-values (carbon sequestration, biodegradation, hydrology); though the economic value of indirect services, such as maintenance of water quality, have not been recognized as national assets. On the other hand, option values (gene pools) and existence values (biodiversity) for oil palm plantations are low and loss of these values is contentious when natural systems are converted. Negative perceptions of oil palm being 'eco-friendly' also reflect the extent to which forest and peatland conversion to oil palm have resulted in off-site effects such as carbon mobilization, damage to river systems from sedimentation and loss of biodiversity. It is concluded that the industry could improve its image by adopting mitigation measures, including better landscape design and documentation of the areas under development, and by improving the visibility that some sectors of the industry are making to address these environmental issues.

Keywords: ecosystem services, carbon, peat, forest, biodiversity.

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INTRODUCTION

The oil palm industry is continuing to expand to meet the burgeoning world demand for palm oil, secondary products from the food and manufacturing industries, and more recently, by the development of biodiesel. Increases in production have been achieved by intensifying production per unit area through breeding, improved agronomy and better plantation management. There has also been substantial expansion in the area under oil palm cultivation, notably in Indonesia, involving conversion of secondary forest and peat swamps. This has generated adverse media publicity by environmentalists over the loss of biodiversity and greenhouse gas mobilization from vegetation and soils that the industry needs to counteract.

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For further growth, the sector faces major challenges to remain economically competitive by improving mill technologies, increasing average fresh fruit bunch yields of less than 20 t ha^{-1} to the 35 t ha^{-1} by the adoption of best planting materials and best-developed practices, and ensuring that palm oil production does not have 'off-site' environmental effects that compromise human well-being and livelihoods, both now and in the future. The industry has been concerned with these issues of sustainable development for a number of years, culminating in the agreement of criteria defined by the Roundtable on Sustainable Palm Oil (RSPO, 2007). Henson (2003), Chan (2005) and Corley (2005) provide useful reviews of the environmental, social and economic aspects of sustainable development from the research and development perspectives of the palm oil sector.

In this review, I will firstly considers the concept of 'eco-friendly' palm oil production from an ecosystem perspective in terms of the inputs and losses of energy and materials across the boundary of a production unit comprising the plantations and the mill, I will then discuss the ecosystem services provided by landscapes dominated by a plantation monocrop and the local and global perceptions of its values. Finally, I will assess the most critical and environmentally sensitive processes involving land use change and plantation rotation that have the greatest potential impacts on externalities and environmental concerns, and how the effects might be mitigated.

OIL PALM PLANTATIONS AS ECOSYSTEM UNITS

A simple conceptual model of an oil palm plantation system comprising oil palm and a mill is shown in *Figure 1*. The functioning of the unit can be considered in terms of the mass inputs and outputs across the system boundary of water (leachates and suspended solids), nutrients (nitrogen fixation, fertilizers, weathering products), gasses (CO_2, NOx, CH_4 and smoke aerosols) and materials (inputs of fossil fuel, pesticides) and outputs of palm oil and palm biomass. Balances between inputs and outputs are simple measure of sustainability as they are largely influenced by management practices including the recycling of materials within the plantation boundary. An 'eco-friendly' system is one that has a high use-efficiency of inputs, and outputs that have minimum (ideally zero) impacts on the external environment. Most of these flux pathways have been the subject of considerable research within the industry and best practices have been developed (Chan, 2005) that will meet most of the RSPO criteria if adopted. I will therefore only briefly consider each of these material balances to identify possible knowledge gaps for assessing sustainability criteria.

Nutrients

Any production system will ultimately fail if the sum of nutrient outputs is not balanced by inputs. However, this dynamic is buffered by the large reserve pools in vegetation and mineral soil of oil palm plantations and nutritional deficiencies may take some time to be manifested until this pools is depleted. In contrast, arable cropping systems in the tropics have a high nutrient input/output ratio because a large proportion of biomass is harvested and soil disturbance from tillage results in higher nutrient leaching. Inputs of mineral nutrients (K, Mg, Si and trace elements) are supplied by the soil and weathering of bedrock supplemented by

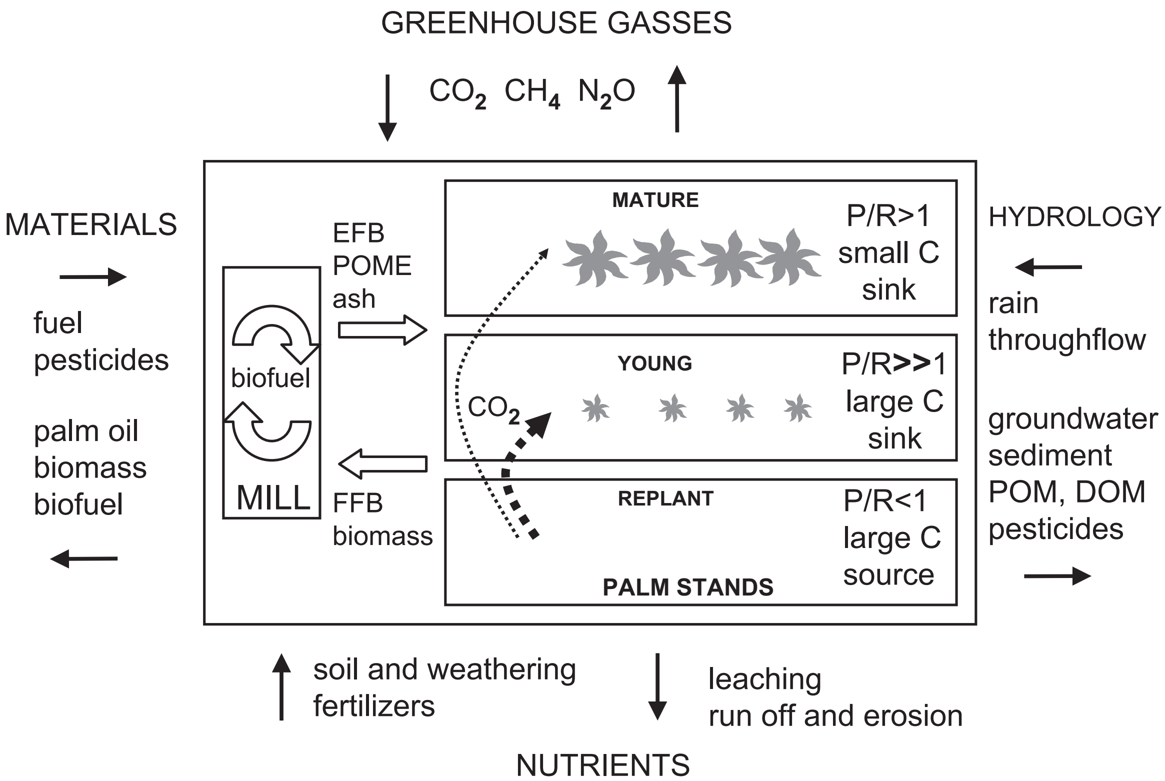

Figure 1. A schematic representation of a plantation ecosystem comprising a mill and palm stands in different stages of development from clearing to economic maturity. Ratios of plant production (P) to total respiration (R), including soil heterotrophs, are diagnostic of carbon balances at plot and system level. Inputs and output balances of materials, fuels, greenhouse gasses, nutrients and water [including particulate (POM) and dissolved organic matter (DOM)] are also diagnostic of the sustainability of the system and its impacts on the external environment.

commercial fertililzers, with K forming a major component of plantation costs. According to Teo and Chew (1987) the soil contributes 56%-75% of K demand by palms on coastal clays, but only 44% on more weathered inland soils, with the difference in demand, most of which is progressively immobilized in the trunk and fronds, supplemented by commercial fertilizer. Use-efficiency of K fertilizer on different soil series ranged from 83% on soils with low available-K to 19% on soils with high available-K where fertilizer applications in this study probably exceeded palm demand and were potentially lost as leachates. In lowland areas where the water table is at a few metres depth, palm roots may access nutrient supplies in ground water but this does not appear to be quantified. Fertilizers are spot placed, banded or broadcast, and recycling of EFB, bunch ash and palm oil mill effluent (POME) from the mill to the plantation is widely practiced to reduce the need for commercial fertilizers. However, it would appear that palm requirements are generally monitored as foliar K concentrations that provides no measure of excess supply over demand (and potential losses from the system). For example, Tarmizi and Mohd Tayeb (2006) estimated that 23% of the standard application of 3.5 kg KCl applied per palm was in excess of demand. Nutrient leaching in relation to placement of fertilizer, bunch ash or palm biomass can be simply monitored by using suction cup lysimeters at different depths in the soil profile as a management tool to monitor the temporal and/or spatial patterns of the K leaching front below the plant rooting zone. Tarmizi and Mohd Tayeb (2006) also suggest that up to 20% of applied P may be fixed in inland soils so that over 2 kg palm^{-1} yr^{-1} is required to balance the takeoff. There seems to be consensus within the plantation sector that nutrient leaching is negligible under established systems but most studies are reported in the 'grey' literature (workshops, unpublished proceedings, internal reports, *etc*.) and so can not be reviewed.

By the time that palms are felled for replanting, after about 25 years, considerable pools of nutrients have been sequestered in biomass and soils that represent a significant economic capital in terms of commercial fertilizer equivalents (*Table 1*). Much of this valuable nutrient capital is lost through leaching, denitrification and potentially through the loss of nutrient-rich, surface fines in run off that can contain a significant proportion of available soil-P. Conventional replanting methods result in an uncoupling between nutrient release from the windrows of decomposing palm biomass and the nutrient uptake by young palms (which is usually supplemented by commercial fertilizers). The spatial integration of nutrient sources and sinks in palm biomass can be facilitated by planting young palms into the windrows of palm residues (Khalid *et al.*, 1999; 2001). This can result in significant savings in fertilizer costs with no yield disadvantage. However, nutrient release from decomposing palm biomass over about 20 months still far exceeds the sink capacity of soils and young palms. For example the K pool in mature palms is c. 642 kg ha^{-1} *vs.* c. 130 kg ha^{-1} in young palms at two years after replanting (Yaacob and Sulaiman, 1992) implying that the difference of c. 500 kg ha^{-1} is leached out of the system. Budgets of these nutrient dynamics are required to assess the amount of palm biomass that could be removed from the plantation as fuel in mills, production of second generation biofuels, wood composites and other industrial processes.

TABLE 1. NUTRIENT CONTENT AND FERTILIZER EQUIVALENTS IN MATURE OIL PALM BIOMASS AT REPLANTING

Palm residues	Dry matter (t ha^{-1})	Nutrient (kg ha^{-1})			
		N	P	K	Mg
Above ground	85	577	50	1 255	141
Below ground	16	65	8	129	15
Total	**101**	**642**	**56**	**1 384**	**156**
Fertilizer		A/S	CIRP	MOP	KIES
Fertilizer equivalent		3 060	370	2 770	1 000

Source: Khalid *et al*. (2001).

Peat forests are developed under very nutrient limiting conditions on soils of low inherent fertility, such as alluvial sands. Dead plant materials in these systems have very low nutrient concentrations, high lignin and high phenolic concentrations and consequently are resistant to microbial decomposition (Anderson *et al*., 1983). Water-logging further impedes decomposition. The build up of peaty organic matter progressively uncouples the nutrient cycle from the underlying parent material so that nutrient inputs are predominantly from atmospheric deposition with accessions as low as 1.8 kg K, 6 kg N and <0.1 kg P ha^{-1} yr^{-1} (Grip *et al*.,1994). Consequently tropical peats provide negligible nutrients to meet the requirements of a productive oil palm plantation and have a small reserve pool to buffer nutrient fluxes. Potassium leaching can be very high because of the low exchange capacity of peats (Ahmad *et al*., 2006). Hence, there has to be careful management of nutrient inputs/outputs balances using commercial fertilizers, since recycling of mill products is rarely practical in these systems. Monitoring of nutrient leaching would facilitate assessment of these balances to improve nutrient use-efficiencies. Considerable research has been conducted by the Palm Oil Research Institute of

Malaysia (now Malysian Palm Oil Board) on fertilizer requirements for oil palm on peat (Mohd Tayeb *et al.,* 1997) but an updated synthesis is not available in the open literature.

In conclusion, nutrient management is a well developed practice in established plantations and is assumed to have low environmental impact off site, particularly to potable water supplies. However, there are few accessible records for leaching and ground water quality to support this assumption.

Carbon/energy, GHG Emissions and Crop Protection Chemicals

Chan (2005) reviews best-developed practices (BDPs) that can improve production efficiencies and reduce environmental impacts of the industry on soils, water and air quality. Where BDPs have been adopted by the plantation sector, many of the environmental, social and economic criteria of sustainability appear to have been met (Corley, 2005). However, documentation to address the concerns regarding GHG emissions, ground water quality (*e.g.* as affected by crop protection chemicals) and other environmental parameters are not readily available to the wider community outside the industry.

Basri *et al.* (2006) have comprehensively reviewed the oil palm industry's role in reducing GHG emissions. There are increasing opportunities for the palm oil sector to use Clean Development Mechanisms (CDMs) and generate new income from Certified Emission Reductions (CERs), *e.g.* biogas production from EFBs and methane capture from POME lagoons. Again, the extent to which these measures are being adopted by the industry in relation to Malaysia's submissions of GHG inventories to the United Nations Framework Convention on Climate Change (UNFCCC) is not widely publicised and needs promotion. This issue will be considered further below in relation to changing land use for oil palm development.

Net carbon emissions during site preparation or sequestration during stand development dominant component of GHG fluxes on plantations. The carbon dynamics of an oil palm stand can be assessed in terms of the balance between carbon fixation by plants (gross primary production: P) and the total community respiration (R) of plants and heterotrophs (including soil organisms). A P: R>1 indicates that the system is sequestering carbon in biomass and soils - *i.e.* a young stand. As a natural forest approaches maturity the P:R ratio for the vegetation approaches unity. Although many oil palms approach an asymptote for biomass increments over 25-50 years, the underlying soils can take centuries to reach equilibrium between organic matter inputs and decomposition. The eddy flux method for measuring net CO_2 balances of P and R across the canopy boundary is currently the best technique for obtaining integrated measures of plantations as carbon sinks or sources at system level. Unfortunately, the areas covered by eddy flux measurements may be difficult to define in landscapes with heterogeneous vegetation and other anthropogenic sources. Hence, inventories of carbon in biomass and soils in stands of different ages (Henson and Chang, 2008) are more practical to provide information of the net balance between carbon sinks in developing stands and carbon sources in stands felled for replanting and palm oil mills (*Figure 1*). These measurements are only an approximation of the net landscape dynamics because carbon release from the decomposing stand debris (months) is much faster than the rate (years) at which a comparable mass of carbon is sequestered in biomass as the stand develops. Hence, very extensive areas of forest conversion or replanting will represent a carbon source but could be offset elsewhere by carbon sequestration through the regrowth of forests (Hashimotio *et al.*, 2000) and oil palm plantations in contrast to the small carbon sink of areas converted to annual crops (Henson, 2005). Refinement of carbon budgets for Peninsular Malaysia, the east Malaysian states and Kalimantan is limited by primary data for soil carbon pools on major soil groups, carbon losses from soils (as particulate matter in run off on slopes and dissolved organic-C), increased mineralization rates of soil carbon as a consequence of soil disturbance and exposure after a forest stand or plantation is felled, and the carry over of soil carbon to the replant.

A recent synthesis by Houghton and Hackler (1999) suggests that, for tropical Asia as a whole, emissions of carbon from changes in land use in the 1980s accounted for approximately 75% of the region's total carbon emissions. Since 1990, overall rates of deforestation and their emissions have declined, except for Indonesia, while emissions of carbon from combustion of fossil fuels have increased. They conclude that the net effect has been a reduction in emissions of CO_2 from this region since 1990 but acknowledge that the uncertainty over recent emissions could be as much as 50%. Sampling CO_2 gradients at regional level using aircraft can considerably improve these book-keeping estimates of carbon fluxes at national/regional scales because they integrate industrial sources as well as all carbon sinks (Suntharalingam *et al.*, 2004).

It is in the economic interest of the plantation manager to reduce the interval between stand felling and replanting with ground cover legumes for N fixation, nutrient immobilization and soil surface protection. This is the most vulnerable phase of oil palm management in terms of off-site impacts of erosion, run off and leaching on river quality, particularly in sloping terrains (Henson, 1994). Soil erosion is considered to be minimal under established plantations in the sense that sediment is not transported beyond the plantation boundary (but may be redistributed internally). However, little information is available in the open literature on the degradation of river water quality due to sediment in run off, and diffuse pollution of ground and surface waters by fertilizers, crop protection chemicals and mill effluents (Sarmani *et al*., 1992). A long-term study on the effects of POME applications in plantations (Hamdan *et al*., 1997) concluded that, with correct management, there was no ground water contamination by nutrients or dissolved organic matter. However, such studies are few and site specific and ground water quality appears to be an important information gap for monitoring the general compliance of management practices to RSPO criteria, pollution legislation, upstream Life Cycle Analysis (LCA), and for assessing the indirect values of ecosystem services provided by oil palm plantations.

ECOSYSTEM FUNCTIONS AND SERVICES

Economic growth, understood as increasing production and consumption of goods and services, has altered ecosystem structure and function to a point where we are now eroding those ecosystem services on which our economy relies, and fundamentally, of these on which we depend on for life support, such as clean air and water (Howarth and Farber, 2002). The global processes of agricultural development has generally involved a transition from diverse traditional systems, often involving small areas of staple food crops and extensive usage of natural systems for most other utilities, to landscapes dominated by cereals and other arable monocrops (Anderson, 2007). Henson (2003) points out that oil palm is unique as an agricultural monocrop in the extent of its landscape cover with a vegetation type that functions as a forest but has oil yields up to five times higher than from oilseed rape (which provides few other economic benefits and many environmental problems). Here I consider the ecosystem services that oil palm provides to some stakeholders and some disservices as perceived by others.

Ecosystem functions are the physical, chemical and biological processes that maintain what an ecosystem does such as carbon and nutrient cycling, climate regulation, hydrologic functions and as a habitat for wildlife. Ecosystem functions are value-neutral to human society unless they relate to transaction costs, *i.e*. changes in function related to land use or management that provide a service of some economic value. Ecosystem services are therefore defined by values society places on provision of goods (food, fuel and fibre), services (regulation and quality of water supplies, *etc.*), bioremediation (detoxification of waste materials, carbon sequestration) and beneficial outcomes for the natural environment (*e.g*. nature conservation, tourism).

The goods and services provided by different components of oil palm ecosystems are outlined in *Table 2*. The total economic value (TEV) is the sum of the four components of ecosystem services provided by OP: direct use values (provisioning services), indirect use values (regulating services), option values (preserving services) and non-use or existence values (cultural services) (De Groot *et al.*, 2002).

Direct use values are the basis for the current economic basis of the oil palm industry not only including palm oil as the primary commodity and a precursor to industrial and pharmaceutical products, but also the use of co-products (kernal oil, palm kernel cake) and secondary products such as fibre board or furniture from trunks and fronds. By-product values include empty fruit bunches (EFB) for energy generation, bunch ash and POME to offset fertilizer costs, and biogas/bioethanol production from POME and EFBs as CDMs for carbon offset trading. Integrated livestock production and other cash crops are additional sources of smallholder income. Inter-planting of high value timber trees at low densities around plantations or in buffer /riparian zones (to avoid shading of palms) could also provide significant revenues.

Indirect use values include attributes supporting oil palm production such as healthy soil as a growth medium, biological control agents, nutrient recovery by deep-rooted plants ('nutrient pumping'), and ground cover legumes for nitrogen fixation and erosion control. At catchment level, mature oil palm plantations may have similar environmental attributes to natural forest in purifying water and air, regulating ground water and stream flows, providing a humid microclimate and sequestering significant stocks of carbon in palm biomass and soils. The total economic value of these ecosystem services to national economies is worth billions of USD (Anderson, 2007) as represented by the replacement costs of industrial technologies for reducing GHG emissions and water treatment. However, negative environment aspects of the industry, both in perception and practices, apply during the conversion of natural vegetation to plantations and during rotations when there can be severe impacts on biodiversity, water quality and GHG mobilization.

Option values involve protecting the potential of systems for future uses by safeguarding genetic and species diversity. This also includes conservation of germplasm from crop varieties that may be

TABLE 2. VALUES PLACED ON ECOSYSTEM SERVICES

Component	Direct UV (provisioning services)	Indirect UV (regulating services)	Option V (preserving services)	Existence or non-use value (cultural services)
Palms (production phase)	Food, industrial products, biodiesel	Catchment hydrology, local climate, carbon sink	Wildlife habitats: landscape design and reforestation	Low if replacing natural forest, high for rehabilitation of degraded habitats
Palm residues (trunk, frond, EFB, ash)	Industrial fibre, fertilizer, CDMs *e.g.* methane capture, new product technologies	Biofuels (methane, bioethanol), erosion control, soil fertility	Microbial gene pool, conservation of below-ground biodiversity	-
Weeds	Animal feed	Biological control, nutrient retention, erosion control	Conservation above- and below-ground BD	-
Associated crops (GC legumes, SH crops, other trees)	Animal feed, small-holder livelihood, agro-forestry with high value trees	Nutrient 'pumping' by deep-rooted plants, nitrogen fixation, erosion control	Conservation above- and below-ground BD	-
Soil/soil organic matter	-	Plant growth medium nutrient cycling, bioremediation, hydrologic functions, carbon sink	Carbon and nutrient carry-over in transitional stage	Negative perceptions of erosion, river siltation, GHG emissions
Stakeholder Values	← Local National?		National/Global? →	

uncompetitive under present environmental and economic conditions but may have eco-physiological characters, drought or pest and disease resistance mechanisms of value in an uncertain future. Oil palm plantations have a higher associated biodiversity than arable crops as a consequence of a more complex vegetation structure (tree *vs.* herbaceous plant) and longer undisturbed periods between rotations. None the less, the diversity of communities associated with oil palm stands is low compared to natural forest and hence, landscapes dominated by palms have a small fraction of the natural biodiversity of the systems they replace. Below ground diversity of bacteria, fungi and invertebrates is higher because of the legume, weed and palm residue cover and well-developed soil structure (Anderson, 2007). Overall, oil palm plantations have low preservation or option values but this can be mitigated by establishment of forest reserves and landscape planning.

Cultural services (non-use or existence values) are the social, cultural, aesthetic and ethical benefits gained from biodiversity and natural habitats. Some groups attach social and religious values to individual species, such as the hornbill in Borneo. Others gain value from simply knowing the existence of certain species (pandas, gorillas, tigers), or species-rich tropical rain forests, and are prepared to give significant funding for species and habitat protection (*e.g.* the World Wildlife Fund) even if they never actually visit these areas. Nunes and van den Burgh (2001) review examples of this willingness to pay (WTP) for profit forgone to ensure protection of natural habitats. Oil palm has low cultural or existence values since the plantations displace many traditions and beliefs that have evolved around the environment and resources of natural or community forests. This is a highly controversial issue involving conflicts between native customary land rights and government/private sector developments on 'unproductive' areas in the interests of profits and the national economy. The mixed environmental, social and economic benefits to Dayak communities in Sarawak from the *Koncep Baru* oil palm development programme are discussed by Majid Cooke (2002).

LAND CONVERSION TO OIL PALM

The internal conflicts between local and national stakeholders (*Table 2*) are a microcosm of the international tensions between the direct economic benefits to producers from palm oil and the concerns of consumers in countries with high per capita GDP over the ecological costs of this development. The focus of these concerns are not so much on the environmental impacts of established plantations and mill operations, that are subject to national legislation (*e.g.* zero burning), voluntary adoption of RSPO criteria and CDM initiatives, but on the environmental consequences of changes in land use and plantation rotations that relate to loss of biodiversity, mobilization of carbon pools, soil erosion and impacts on water quality and supply.

Biodiversity and Landscape Design

The process of agricultural development worldwide has involved the fragmentation of natural vegetation cover and development of extensive crop monocultures. Further conversion of tropical forest in Southeast Asia, Amazonia and Africa is inevitable unless international financing schemes for Reduction in Deforestation and Degradation (REDD), biodiversity conservation and carbon offset are recognized under the post-2012 agreements of the UNFCCC, are adequately funded and implemented with immediate effect. In the mean time there is urgent need for proactive land management to mitigate the effects of forest loss and fragmentation that are more effective before and during, rather than after, the deforestation process (Laurance and Gascon, 1997).

Fragmentation of natural habitats due to forest conversion, or landscape changes to enhance agriculture production, is one of the factors causing the decline in the diversity of wildlife species. Wildlife habitats have been extensively disturbed and reduced in their potential capacity to hold viable populations to, while the structure of the landscape mosaic may inhibit natural dispersal between habitats. Habitat fragmentation also alters the forest climate on a local scale (< 1 km) leading to wind disturbance and elevated desiccation near the forest margins. These changes in microclimate can alter tree mortality and gap dynamics, plant species community composition, biomass dynamics and carbon storage (Laurance, 2004). There have been extensive studies of these processes in Amazonia where rain forest are being cut at rates of up to 20 000 $km^2 yr^{-1}$ leading to isolated forest fragments of 1 to 100 ha (Stouffer *et al*., 2006). Studies of understorey birds showed that the habitat structure (secondary growth, agro-forestry or pasture) was often as important as the size of the forest fragment for bird species abundance. Some fragments surrounded by 100 m of open pasture resulted in the reduction of insectivorous bird populations by 95% even where these pastures were themselves surrounded by continuous forest and old regrowth (Stouffer *et al*., 2006). Unlike pasture and arable crops, oil palm has a more complex and durable habitat structure that can provide a buffer zone for the microclimate at forest margins and some degree of connection between neighbouring patches of forest. However, as the extent of oil palm cover increases, corridors of natural vegetation are required to enable species to disperse over longer distances. Some examples of landscape design to mitigate the effects of deforestation are given in *Table 3*. The scales of these specific recommendations may not be practical for the industry to adopt. However, the practice of not converting vegetation on slopes

TABLE 3. EXAMPLES OF LANDSCAPE-DESIGN GUIDELINES THAT COULD BE USED TO INFLUENCE PATTERNS OF DEFORESTATION (from Laurance and Gascon, 1997)

Guideline	Potential impacts on the landscape
Prohibit forest clearing within 150 m of water courses	Enhance landscape connectivity, stabilize watersheds, improve water quality.
Prohibit forest clearing on steep (>30°) slopes	Retain forest remnants in steep areas, reduce soil erosion, ameliorate downstream flooding.
Prohibit clearing of rare vegetation types	Enhance biological and landscape diversity, provide seed sources for future reforestation.
Stipulate that forest clearings can not exceed 20 ha in area	Reduce deforestation and rate of deforestation, reduce fragmentation of habitats.
Specify that individual landowners may not clear over 50% of primary forest on their properties.	Reduce deforestation rate, ensure that some forest cover is retained.
Prohibit forest clearing or hunting within 1 km of nature reserve boundaries.	Reduce edge effects for reserves, increase effective area of the reserve, ensure habitats around reserves do not function as population sinks for forest-dependant species.

of more that 25° often leaves isolated patches of forest on hill tops and ridges where a corridor connecting these areas could greatly improve the ecological integrity of the area. The preservation of wide riparian zones serves not only to provide wildlife corridors through some element of natural vegetation through the core of plantations but also provides other ecosystem services by acting as a filter for sediment, nutrients, and biodegradation of crop protection chemicals from plantations to protect aquatic biodiversity and water quality. Requirements for a 10 m buffer strip along feeder streams may provide some protection for the water-course from diffuse population once the plantation is established. However, such narrow strips may provide little protection against massive run off and sediment transfers during storm events immediately after site preparation. Natural riparian zones also have high aesthetic values; they are a learning environment for education and enhance tourist perceptions of the landscape. Similarly, replanting major road margins with wide belts of indigenous tree could significantly improve the countryside image in transit, enhance biodiversity around plantations and might be eligible as a carbon sink under future REDD negotiations.

Water, Erosion and Nutrients

One of the key ecosystem services provided by forested catchments is the filtration and purification of water and regulation of stream flows. As a consequence, the pure stream water from undisturbed catchments is low in suspended solids, nutrients and dissolved organics and often of potable quality without the cost of further treatment. An indication of the direct market valuation of this ecosystem service is given by the problem faced by New York City where water supplies from the Catskill Catchment were compromised by sewage and agricultural population. In 1997, a new water purification plant would have cost USD 6-USD 8 billion to set up with USD 300 million annual running costs. A much less expensive and sustainable solution was to raise USD 660 million in Environmental Bonds for reforestation, and compensation for land development, to restore the natural ecosystem services as well as conservation, recreational use and other values to society (Anon, 2007).

Unfortunately, a global trend in the tropics has been that on-site profits from farming, logging or plantation development accrue to the company manager while the wider community suffers the off-site costs of river siltation and dredging, flash flooding, decline in fisheries and aquatic biodiversity, population and loss of other environmental services in both fresh and coastal waters. Occasionally, lack of attention to erosion control measures during land preparation can also rebound on the developer, as when failure to retain adequate riparian reserve strips, exacerbated flooding and resulted in losses of 5000 ha of 3-year-old palms in the Lower Kinatabangan flood plain in Sabah (Teoh *et al.*, 2001). Similarly, wetland draining and channelling of Mississippi wetlands, as is happening with peat areas, reduced flood buffering and resulted in damage valued at USD 12 billion from exceptional storms in 1993 (Novitski *et al.*, 1997).

There are few studies in the accessible literature quantifying the consequences of forest conversion to oil palm on losses of soil through erosion, and sediment loading of streams and rivers. Bruijnzeel (2004) comprehensively reviews over 60 catchment studies on the hydrologic impacts of forest conversion to other land uses - none of this involved oil palm. Henson (PORIM) reviews one such study by the Drainage and Irrigation Department of Malaysia (DID, 1989) on the effects of land use change on soil and water resources in Sungai Terikam. Following clearance of the forest for oil palm, stream sediment loads increased from below 50 Mg km^{-2} yr^{-1} to 400 Mg km^{-2} yr^{-1}, then fell to 100 Mg km^{-2} yr^{-1} when the legume cover was established but did not decrease to base-line (pre-conversion) rates until the plantation was 3 years old. Such studies are important to not only to assess the effects of improving management practices on catchments but also to demonstrate the commitment of the industry to reducing the off-site impacts of oil palm development. Malmer (1996), for example showed that clear felling forest in Sabah for an *Acacia mangium* plantation did not increase surface run off on slopes if the topsoils were undisturbed but compacted tractor tracks caused extensive run off and gully formation. Bruijnzeel (2004) also concludes that as long as soil surface disturbance remains limited the bulk of the increased water yield from clear-felled catchments occurs as base flow. However, surface compaction by heavy machinery can result in reduced infiltration so that ground water reserves are not replenished resulting in strong declines of base flows during the dry season. Much hydrological damage caused through the conversion of tropical forest might be averted through better implementation of best practices or development of improved methods of site preparation and land management. Although not directly relevant to site preparation to oil palm, reduced impact logging practices (RIL) can reduce sediment yields by four to 10 times those of conventional commercial operations (Hartanto *et al.*, 2003) and conserve soil fertility. Nykvist *et al*. (1994) found that plantation regrowth was twice as fast on sites where there was no burning and soil disturbance was minimized to conserve nutrient stocks. There may be similar economic and environmental benefits for adopting components of RIL practices for site preparation involving planned access routes for heavy machinery, extracting trees by cable rather than by tractor and minimizing soil losses (Pinard and Putz, 1996). In addition, the palm residue management methods for replanting (Khalid *et al*., 2001) might be adapted for conversion sites to capitalize on the nutrient in the forest biomass.

Carbon

Tropical deforestation is a source of nearly 20% of human induced GHG emissions to the atmosphere including 1.5 billion tonnes of carbon each year. Between 1990 and 2005, more than 10 million hectares per year of forest cover was lost throughout the tropics, amounting to more than 28 million hectares in Indonesia and 1.5 million hectares in Malaysia over this period (FAO, 2005). The total area under oil palm in Indonesia and Malaysia was about 3.5 million hectares in 2005 apparently refuting the claims by Friends of the Earth that the demand for palm oil is the most primary cause of rain forest loss in this region (Corley, 2005). However, while commercial logging may be the major cause of deforestation in Southeast Asia, damaged habitats are then open for oil palm development and business linkages between the sectors are often close. The Indonesian Palm Oil Research Institute (IOPRI) estimates that only 3% of oil palm developments are in primary forest but 63% in bush and secondary forest (of undefined maturity) and 34% from other land uses.

A major cause of the contention over oil palm developments is the general lack of reference to specific data supporting either side of the argument by environmentalists and developers, on what constitutes 'rain forest'. The 'rain forest' term is broadly applied in the media to a wide spectrum of forest cover in the humid tropics that encompasses primary forest, various ages of secondary forest following commercial logging, to forest regrowth on abandoned land. For example, Proctor *et al*. (1993) found that above-ground biomass of different primary forest types within the same region of Sarawak can vary within a range of 210-650 Mg ha^{-1} (equivalent to 84-260 Mg C ha^{-1}) of which between 22% and 67% may be removed by commercial logging (Lasco, 2002). Rain forest soils can contain 110 - 190 Mg C ha^{-1} (Lashof, 1989) with losses of 100 Mg C ha^{-1} following aggressive commercial logging operations. Soil carbon under poor grassland, such as *alang-alang*, can be reduced to only 5% of initial forest levels (Caddisch *et al.*, 1996). However, secondary forest regrowth can sequester carbon at rates between 1.4 Mg C ha^{-1} yr^{-1} (Lasco *et al.*, 2006) to about 4 Mg C ha^{-1} yr^{-1} (Hashimotio *et al.*, 2000) depending on the initial level of damage to the site. Hence, considerable inaccuracies can be incorporation into carbon budgets by assuming general values for the starting point of the conversion to oil palm plantations.

The dynamics of these conversions are illustrated in *Figure 2*. Following land clearance, the carbon is mobilized from decomposing (or burnt) residues and from the labile soil organic matter in the top 30-50 cm of the profile. Carbon in soil organic matter below 50 cm depth may be thousands of years old, highly stabilized and remain relatively unaffected by changes in vegetation type for many decades. During this transition, stage replanted palms do not have sink strength comparable to the source and so there is a net system loss of carbon. The exposure of soil to high temperatures and rainfall, results in a massive loss of the forest nutrient capital which, in the case of phosphorus, may have taken a thousand years or more to accumulate from atmospheric inputs. The developing plantation system sequesters carbon and nutrients in palm biomass and soil organic matter during the economic phase of the plantation before felling for replanting. During this process, there is a further loss of carbon since there is initially little, if any, vegetation on site to act as a sink for the large carbon source in decomposing residues. Carbon may be sequestered in other areas of successional forest and young plantations within the landscape complex but forestry operations or extensive plantation developments taking place over a large area will result in a net mobilization of carbon that is nationally accountable for signatories to the UNFCCC. Similarly, nutrient losses from cleared forest or palm stands may be captured in adjacent stands down slope or by riparian zones (protecting water quality) but extensive developments will exceed these buffering processes in the landscape; particularly under poor practices for site preparation.

The utilization of peat forests for oil palm cultivation is also contentious. Tropical peats have high conservation status for many unique aspects of their biodiversity; they are important hydrologically for regulating water supply and quality. Forested peatlands in Southeast Asia store at least 42 000 megatones of soil carbon and current emissions from peats of 2000 megatones per year equals almost 8% of the global emissions from burning fossil fuel (Hooijer *et al.*, 2006). Most tropical peats brought into cultivation have large soil carbon reserves in the order of 100 to 250 Mg C ha^{-1} but can be as high as 3700 Mg C ha^{-1} (Henson, 2007). Again, the starting point for the change in land use is important to assess environmental impact of conversion. Henson (2007) observed that of the 1.7 million hectares of peat in Sarawak, much has been previously damaged by logging and drainage and so plantation development may not be on virgin forests with high conservation value. However, a major concern is the potential for carbon loss from peats as a consequence of drainage and conversion

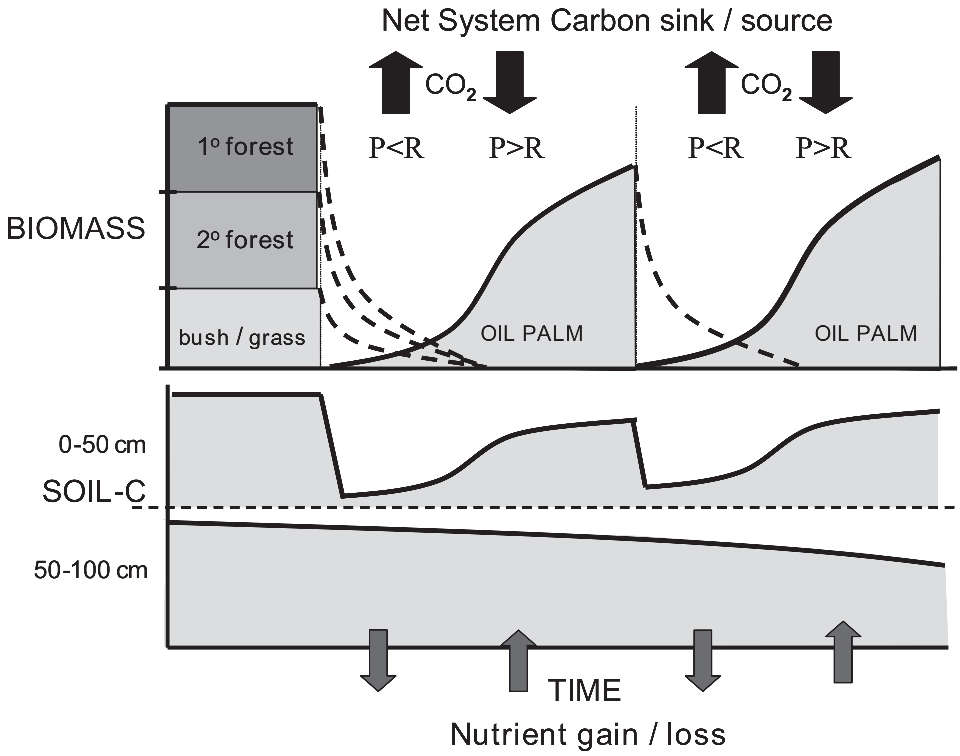

Figure 2. Dynamics of carbon and nutrients in plant and soil pools during forest conversion to oil palm and at replanting. The magnitude of carbon pools in different forest cover, relative to oil palm is suggested (see text). The decomposition of the forest or palm biomass is indicated by dashed lines. Soil carbon pools are scales relative to the primary forest. The dynamics of the surface carbon pools is significantly influenced by clearance methods and changes in litter inputs whereas stabilized carbon in subsoil may be relatively unaffected. The ratios of plant production (P) and community respiration (R), and of nutrient inputs/outputs, across the system boundary are diagnostic of whether the system is aggrading or degrading.

to other land uses. Melling *et al.* (2005) suggest that following conversion, an oil palm plantation on peat had lower CO_2 emissions than from a native swamp forest. It is difficult to equate this with the consensus of data syntheses (Henson, 2007; Hooijer *et al.*, 2006; Germer and Sauerborn, 2007), plot studies (Furukawa *et al.*, 2005), and landscape (eddy covariance) flux measurements (Hirano *et al.*, 2007) that drainage and crop management on peats results in significant mobilization of peat carbon stocks as CO_2 and methane. One possible reason for the discrepancy in the study by Melling *et al.* (2005) is that respiration by living roots can constitute 40%-60% of soil CO_2 efflux (Raich and Nadelhoffer, 1989) but roots are spatially more heterogeneously distributed under oil palm (Adachi *et al.*, 2006) and are less dense under young oil palm, and so may have been under represented in the assessment of carbon flux in this study as a consequence of spatially limited sampling.

Germer and Sauerborn (2007) have made a comprehensive synthesis of greenhouse gas balances for oil palm plantation establishment on degraded grassland, forests or peats; including different site preparation options including burning or zero burning of residues. The GHG balances for these systems are shown in *Table 4*. They estimated that rehabilitation of tropical grassland with oil palm plantations not only neutralizes emissions caused by grassland conversion (biomass decomposition and soil disturbance) but also results in net uptake of 135 Mg CO_2 ha^{-1} from the atmosphere. In contrast, they estimated that conversion of forest on mineral soils causes the net release of approximately 650 Mg ha^{-1} CO_2 equivalents (CE) while peat conversion peat mobilises over 1300 Mg CE ha^{-1} during the first 25-year cycle of oil palm growth. Depending on the peat depth, continuous decomposition augments this by 800 Mg CE ha^{-1} with each additional plantation cycle. A particular issue of note in *Table 4* is the large variation around mean values for initial carbon pools in grassland, forest or peat. This emphasizes the point, already made above, that it is important to determine the starting point of carbon stocks in vegetation and soils before conversion oil palm plantations since the history of land use can embrace a very wide range of actual and perceived environmental consequences in terms of carbon stocks and GHG emissions. In carrying out these surveys, Van Noordwjk *et al.* (2002) emphasize that using generic, rather than tree-specific, allometric equations can result in substantial (up to 100%) overestimates of above-ground biomass depending on wood density and tree shape. Similarly, soil

TABLE 4. GREENHOUSE GAS BALANCE IN CARBON DIOXIDE EQUIVALENTS (Mg ha^{-1} ± SE) FOR OIL PALM PLANTATION ESTABLISHED ON DEGRADED GRASSLAND, FOREST ON MINERAL SOIL OR ON PEAT FOREST (from Germer and Sauerborn, 2007)

	Land clearing	Change in soil carbon or peat decomposition	Fixation in oil palm plantation biomass	Carbon balance
Grassland rehabilitation (zero burning)	42 ± 27	-48 ± 24	-129 ± 40	-136 ± 37
Grassland rehabilitation (burning)	43 ± 28	-48 ± 24	-129 ± 40	-134 ± 36
Forest conversion on mineral soil (zero burning)	627 ± 326	150 ± 75	-129 ± 40	647 ± 361
Forest conversion on mineral soil (burning)	648 ± 337	150 ± 75	-129 ± 40	668 ± 372
Forest conversion on peat (zero burning)	627 ± 326	816 ± 393	-129 ± 40	1 314 ± 679
Forest conversion on peat (burning)	648 ± 337	816 ± 393	-129 ± 40	1 335 ± 690

Note: Positive values indicate carbon sources, negative values indicate carbon sinks.

carbon stocks depend on the history of land use and management (Lugo and Brown, 1993) and hence, assessments of carbon balances for particular plantation developments also require base-line data from field surveys rather than approximations from the literature.

It may be that rates of carbon losses from peats can be reduced by water-level management to reduce rates of subsidence and oxidation (Henson, 2007). However, even if deferred over a few plantation cycles, there seems to be general consensus that development of peats will inevitably result in the mobilization of these large carbon pools. If economic development of these areas is seen as unavoidable by federal or state governments, rather than challenge the environmental lobby on the issue of peats as a source or sink of carbon, considerable credit might be gained by voluntary carbon offsets. By forgoing the options of third or fourth logging cycles, resulting in highly degraded sites, allowing long-term regeneration of secondary forest not only provides a significant carbon sink but also restores other services including wildlife reserves and buffer zones.

Carbon and Land Use Post-2012

The UNFCCC has launched an initiative to assess the policies and incentives for Reducing Emissions from Deforestation and Degradation (REDD) in the post-2012 period of the Kyoto CDM Protocol when carbon offsets are likely to become a major area of international trading (Gullison *et al.*, 2007). Industrialized countries must help tropical countries to develop sustainably by providing economic incentives for the maintenance of forest cover (Stern, 2007) while avoiding the negative impacts of deforestation including reduction of rainfall, loss of biodiversity, ill effects on human heath from biomass burning, impacts on water supplies and services, and loss of option values for productive forests.

GHG emissions may have to be accounted at national levels by emergent economies to comply with the UNFCCC (*e.g.* Basri *et al.*, 2006). Hence, in a similar way to international carbon trading, the carbon costs in the oil palm sector need to be evaluated in terms of CDMs, returns *vs.* avoidance costs of developing new areas of forest or peats, carbon off-sets in forestry and landscape planning for plantations on areas, such as degraded lands, where development will result in a net increase in carbon pools as well as the restoration of other ecosystem services.

Osborne and Kiker (2005) calculated that using Guyana's forests for climate change mitigation can generate equivalent revenue to that of conventional, large-scale logging at 12% discount rate at a break-even price for carbon of USD 0.2 Mg C^{-1}; trading prices for C-offset post-2012 may be much higher (Gullison *et al.*, 2007). More recently, a pioneering initiative has been set up between the government in Guyana and a United Kingdom-based investment company, Canopy Capital (2008) will trade in ecosystem services such as rainfall generation, climate regulation, and biodiversity maintenance and water storage. Guaranteed initial payments for five years will safeguard the survival of the pristine 370 000 ha Iwokrama Reserve and 80%-90% of long-term revenue will accrue to the reserve and local communities.

Reduced impact logging practices (RIL) can significantly reduce tree mortality in the remaining forest and the regenerative potential of soil nutrient (and carbon stocks). Reducing fatal damage of the residual stand from 40% to 20% can result in a increase in mean carbon storage over 60 years by 36 mg C ha^{-1} compared to conventional logging practices (Pinard and Cropper, 2000). Healey *et al.* (2000) suggest, however, that carbon trading prices will have to be significantly higher to offset the discount rates for the additional costs of RIL operations. Re-forestation (also creating wildlife habitats and corridors) is likely to be a major area of carbon trading if REDD proposals are adopted. Paradoxically, oil palm plantations, unlike rubber and other tree plantations are not eligible for carbon offset payments. If this policies remains unchanged, they might qualify if left undisturbed to mature and not replanted. However, while the genetic life span of oil palm is about 200 years, there is little information on carbon sequestration in oil palm stands far beyond their economic life span, and the processes of natural succession involved in their eventual reversion to natural forest. In terms of island biogeography, these processes are likely to be impeded by the considerable distances of forest refugia for plant species to colonize core areas of landscapes dominated by palms. Should this become policy for carbon offset, then strategies for the ecological management of abandoned plantations will need to be developed.

Finally, Butler (2007) provides an interesting assessment of the economics of peat development for oil palm in Indonesia. He concludes that it is unlikely that future carbon trading schemes proposed could compensate for profit forgone with palm oil at present prices. However, if palm oil prices fell significantly, trading peat carbon could be economically viable but would involve unprecedented funding. If other economic values of the ecosystem services provided by peat forest are factored in the margin of this discrepancy might be reduced.

CONCLUSIONS AND RECOMMENDATIONS

The term 'eco-friendly' approach to sustainable palm oil production can have two different associations. On one hand, there is a system that fulfils the actual environmental, social and economic criteria of development to global consumers, the host nation and to the oil palm sector. The environmental costs of development and economic benefits to the nation and plantation stakeholders should be compatible ('planet, people and profit') but, if not, can require legislation and enforcement - as with the zero burning policy in Malaysia. On the other hand 'eco-friendly' can be a subjective perception of the impact of development to environmentalists and conservationists that may, or may not, map on to the real situations on the ground - *e.g.* a possible mismatch of deforestation rates and oil palm expansion noted by Corley (2005) that could be a matter of defining 'forest' and whether the plantation or forestry sectors initiated 'deforestation'. In preparing this review, it has become apparent that a contributory factor to these possible misconceptions may result from a lack of external visibility to many aspects of research, development and environmental monitoring that are more 'eco-friendly' in some sectors of the industry than are given credit. For example, *Partners for Wetlands* project, set up by the Department of Wildlife, Department of Irrigation and Drainage, and WWF Malaysia in 1998 (Teoh *et al.*, 2001) brought together a wide range of stakeholders to address economic, social, tourism and human-wildlife conflicts in an effort to gain commitment and participation in the protection of the Kinabatangan sanctuary in the Lower Kinabatangan floodplains of Sabah. This study provides useful insight into the problems that can arise if economic development from upstream to downstream does not give adequate consideration to the need for conservation and protection of the environment. Such initiatives deserve much greater publicity in the international press.

As a starting point for this review, I assumed that established estates, managed under best practices, can achieve many of the environmental criteria of the RSPO. I have therefore emphasized the most sensitive phases of management during the rotation of plantations and forest conversion that have the greatest off-site impacts and hence external perceptions of the 'eco-friendliness' of the palm oil sector. Areas that appear to need promotion, research and development are:

- improving the transparency and visibility of significant achievements by national, state or private sectors of the industry towards more sustainable, 'environmental-friendly' palm oil production.
- monitoring ground water quality in lowland areas for nutrients, crop protection chemicals and dissolved organic carbon (and required for LCAs). Concentrations alone may be insufficient environmental assessment unless through flow of groundwater, *i.e.* diluting surface is more or less static. Leachate monitoring at depths in the soil profile could be more widely adopted as a tool for assessing

the nutrient and DOC 'tightness' of surface treatments such as fertilizer and bunch ash placement, EFB mulching and replanting into plantation biomass.

- on sloping terrains, enforce the conservation of slopes greater than 25°, establish gauged catchments to monitor drainage water quality in relation to management practices including sediment and nutrient losses associated with forest conversion, terracing and plantation rotations. Base-line monitoring is required for at least two years before conversion.
- carry out geo-referenced surveys to estimate the carbon pools of biomass, soils and peats before conversion to oil palm. In degraded areas, surveying biodiversity indicators (birds, mammals, butterflies) compared to natural vegetation cover could justify some changes in land use from 'forest' cover.
- implement landscape planning to conserve areas of undisturbed or secondary forest and corridors to connect fragmented areas such as isolated hills and ridge tops. Wider protection zones for riparian areas to maintain ecosystem services including conservation and amenity values and adequately buffer surface run off and sediment loading of rivers immediately after site preparation.
- where commercial logging continues, adopt RIL practices to offset carbon emissions caused by other changes in land use, such as peatland conversion.
- make a transparent assessment of the economic benefits of peatland conversion to oil palm including peat depth, accessibility and possible environmental payments for carbon offset post-2012.
- national assessments of the total economic values of ecosystem services, particularly the impacts of changes in land use for oil palm on water supplies, water quality, increased flood risks and on other stakeholder livelihoods.
- enable the adoption of best practices in order to improve yields in the processing and plantation sectors. Eco-friendly systems are essentially those that make efficient and sustainable use of existing land resources rather than increasing production through extensive developments.
- finally, to publish more research in international, peer reviewed journals. I am aware that there are internal reports, workshop documents and unpublished conference proceedings that address some of the gaps in information I have identified above. However, this 'grey' literature is not accessible to the wider scientific community for peer assessment and can not be cited.

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