UN-REDD
PROGRAMME

Ecosystem services and biodiversity from new and restored forests: tool development

UN-REDD PROGRAMME

1 October 2010

Multiple Benefits Series **5**

The UN-REDD Programme, a collaborative partnership between FAO, UNDP and UNEP, was created in response to, and in support of, the UNFCCC decision on REDD at COP 13 and the Bali Action Plan. The Programme supports countries to develop capacity to reduce emissions from deforestation and forest degradation and to implement a future REDD mechanism in a post-2012 climate regime. It builds on the convening power of its participating UN agencies, their diverse expertise and vast networks, and "delivers as One UN".

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the biodiversity assessment and policy implementation arm of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. The centre has been in operation since 1989, combining scientific research with practical policy advice.

The United Nations has proclaimed 2010 to be the International Year of Biodiversity. People all over the world are working to safeguard this irreplaceable natural wealth and reduce biodiversity loss. This is vital for current and future human wellbeing. We need to do more. Now is the time to act.

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Citation: Miles, L., Kapos, V., Dunning, E. 2010. Ecosystem services from new and restored forests: tool development. *Multiple Benefits Series* **5**. Prepared on behalf of the UN-REDD Programme. UNEP World Conservation Monitoring Centre, Cambridge, UK.

Acknowledgements With thanks for comments and input to Dr Pham Manh Cuong, Dr Barney Dickson, Dr Nathalie Doswald, Cordula Epple and Matea Osti

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1 Purpose and approach

1.1 Background

Viet Nam is in the process of reforestation, being on track to plant 5 million hectares before 2010, with 3 million hectares planned subsequently. Most original forest cover is lost or degraded, with only a small fraction of primary forest remaining. The reforestation programme includes afforestation, reforestation and forest restoration. A range of practices are used: plantation of native and non-native species, assisted natural regeneration, and natural regeneration. During the 1990s, forest cover increased in equal measure due to natural forest regeneration and to planted forests (Meyfroidt & Lambin 2008).

Since the forest reforms of the 1990s, national forestry policy has aimed to protect critical watersheds and conserve nature in addition to supplying timber. Reforestation in Viet Nam therefore shares these multiple aims. Mangrove forests are also recognised as providing coastal protection services. Forests are classified as Special Use (mainly for conservation), Protection (for watershed maintenance), or Production (for timber production) areas, although in practice there is a high degree of overlap between these functions. The 5 million hectare programme's funds are almost exclusively directed to establishment and conservation of state-managed protection and special-use forest.

Mangrove forests are a special case, in that their area is a tiny proportion of Viet Nam's total forest cover, but their value for coastal protection, fisheries, biodiversity (including breeding birds) and local livelihoods is high (Tri *et al*. 1998, Wikramanayake *et al*. 2001, Meyfroidt & Lambin 2009).

This document, and the related *Multiple Benefits Series* **6** on *Methods for assessing and monitoring change in the ecosystem-derived benefits of afforestation, reforestation and forest restoration* have been produced to support Viet Nam in its goals of attaining multiple benefits from forest. This document provides a basis for estimating the probable impacts of different forest cover creation approaches on the ecosystem-derived benefits of biodiversity, water provision, soil conservation and non-timber forest products. The companion paper provides guidance on designing a monitoring system and selecting to provide direct evidence of impacts.

1.2 Introduction

The simple tool presented here has been developed for rapid assessment of the likely speed and extent of ecosystem service delivery resulting from forest cover creation, to assist in:

- selecting appropriate approaches for new reforestation and forest restoration efforts, with the aim of providing specific ecosystem services and / or biodiversity.
- identifying the extent to which biodiversity and ecosystem services may be provided by specific reforested and restored areas
- estimating the overall area of low or high provision of biodiversity and ecosystem services by a set of existing reforested areas

Restoration of degraded forest, as opposed to restoration of deforested areas, is not addressed.

We consider the following approaches to forest cover creation:

- Natural regeneration
- Assisted natural regeneration
- Planting native species
- Planting non-native species

… and the following ecosystem-derived benefits of REDD+, which are those non-carbon services provided by forest, for which most information is available:

- Biodiversity conservation
- Water regulation and quality
- Soil conservation and quality
- Non-timber forest product (NTFP) availability for local benefit

The tool takes the form of a graphical score card for multiple benefits delivery, backed up by supporting tables that offer detailed explanations of the rationale behind the summary. The score card grades the approaches for each potential benefit in terms of the end result and the speed of delivery of that result. The tables detail the impact on the four benefits of the different practices that may be employed within the four broad different approaches to forest cover creation. These draw upon a combination of peer-reviewed evidence and expert knowledge.

1.3 Definitions

For consistency, we distinguish REDD+ *activities* (e.g. enhancement of forest carbon stocks, reducing forest degradation) from *approaches* (e.g. assisted natural regeneration, planting non-native species) (Figure 1). Each approach may be carried out using different *practices* (e.g. intensive monoculture, planting of perch trees) and each practice may employ different *techniques* (e.g. planting to a certain depth; use of herbicides to create fire breaks). We recognise that this choice of terms is fairly arbitrary.

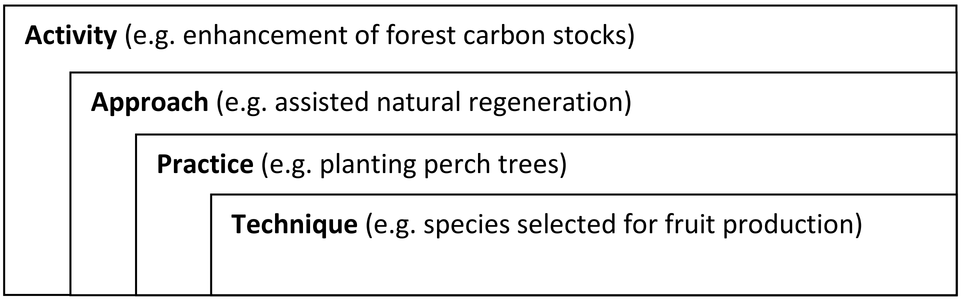


Figure 1: Hierarchy of terms used to describe REDD+ implementation

In the score card, we focus on the activity of enhancement of forest carbon stocks, through the approaches of natural regeneration, assisted natural regeneration, planting native species and planting non-native species. More detailed information on the impacts of different practices on the four ecosystem-derived benefits is found in the Annex.

1.3.1 Approaches to forest cover creation

Natural regeneration is defined as the use of minimal interventions to allow a natural process of forest colonisation and succession. The only practices considered to belong to natural regeneration are the management of threats such as grazing, fire, extractive use or invasive species. Degraded sites may not be good candidates for natural regeneration, and the availability of propagules from nearby sites is essential to its success.

Assisted natural regeneration is the use of additional interventions to speed the process of regeneration of a natural forest, and to enable it where conditions for natural regeneration are lacking. Practices employed may include the planting of perch trees to attract birds that disperse seeds, nurse trees to provide shade for regenerating species of mature forest and stabilise soils, soil restoration through the use of green manure or legumes, ongoing threat removal, landscape modification such as terracing, the addition/removal of drainage, or bunding, or clearing competing vegetation.

Planting native species creates a planted native forest, and practices may include the planting of single species (monoculture), mixed species, or analogue species (with species planted to fulfil particular ecological functions e.g. soil enrichment, successional role); the intensive use of agrochemicals or other methods to clear competing vegetation, manage pests and encourage rapid growth; the use of nurse trees or groundcover crops.

Planting non-native species creates a non-native plantation. The range of practices followed is very similar to those employed for native species, but the outcomes may differ radically.

The four approaches to forest creation are neither mutually exclusive nor completely discrete, but form a continuum of intensity of intervention from natural regeneration, to assisted natural regeneration, through planting native species to planting non-native species.

1.3.2 Afforestation and reforestation

Our tool does not distinguish afforestation from reforestation, although afforestation may result in the loss of existing valuable ecosystem services. During afforestation, it is likely that ecosystem-derived benefits arising from the existing vegetation cover of the area would be lost, to be replaced at a later date by different benefits from the new forest. These trade-offs may be substantial, and are not addressed by the present tool.

If forest is created in areas that have not borne forest for over fifty years, but which were originally forested, an ecologist would see this as forest restoration, but the IPCC definition would see this as afforestation. However, if for reasons such as topography, soil cover or climatic conditions the area has not been forested *in known history*, both define this as afforestation. The trade-offs are likely to be greater in the second case.

2 Score card

This tool summarises the likely effects of the choice of forest creation approach on the delivery of the multiple benefits of biodiversity conservation, water regulation and quality, soil conservation and non-timber forest product availability.

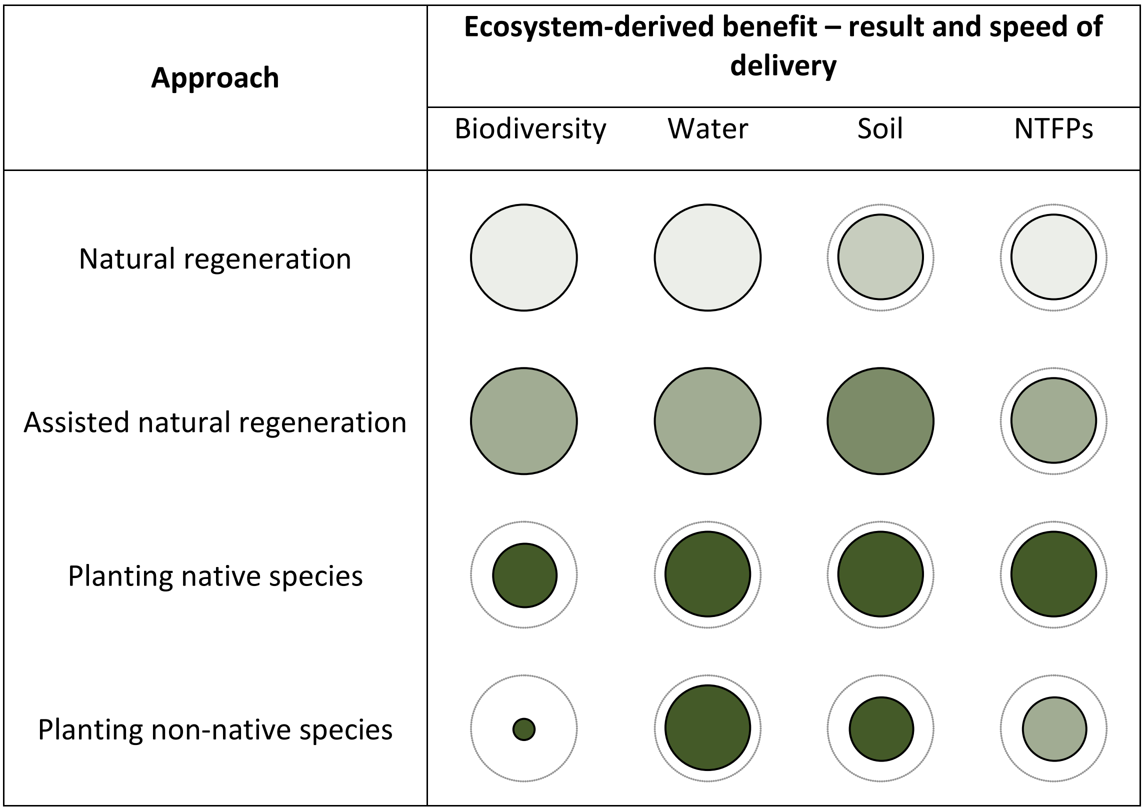
The score card illustrates the quality and rapidity of benefits resulting from each forest creation approach, if common practice is followed with successful results. The success at delivery of these multiple benefits is shown in the form of circles of increasing size (representing the final result) and deepening shade (representing speed of delivery). These values are qualitative and comparable between forest creation approaches, but not strictly comparable between ecosystem services.

It is immediately noticeable that assisted natural regeneration produces the best results over the set of multiple benefits considered, but that planting native species produces the fastest results. Unassisted natural regeneration produces generally slower but good results for multiple benefits, whilst planting non-native species produces generally rapid but poorer results (especially for biodiversity). The most appropriate approach at any given location will depend upon the benefits that are most desired, the required speed of outcome, the site condition and context, and the financial and human resources available.

Approaches to creating functional forest ecosystems depend not only on the initial state of the land and the desired outcome, but also the time frame and financial constraints (Chazdon 2008). The ecosystem services outcomes of any forest creation at any given site depend on and the choice and implementation of practices employed and their success. A badly-executed natural regeneration project can yield significantly fewer multiple benefits than a well-executed non-native species plantation.

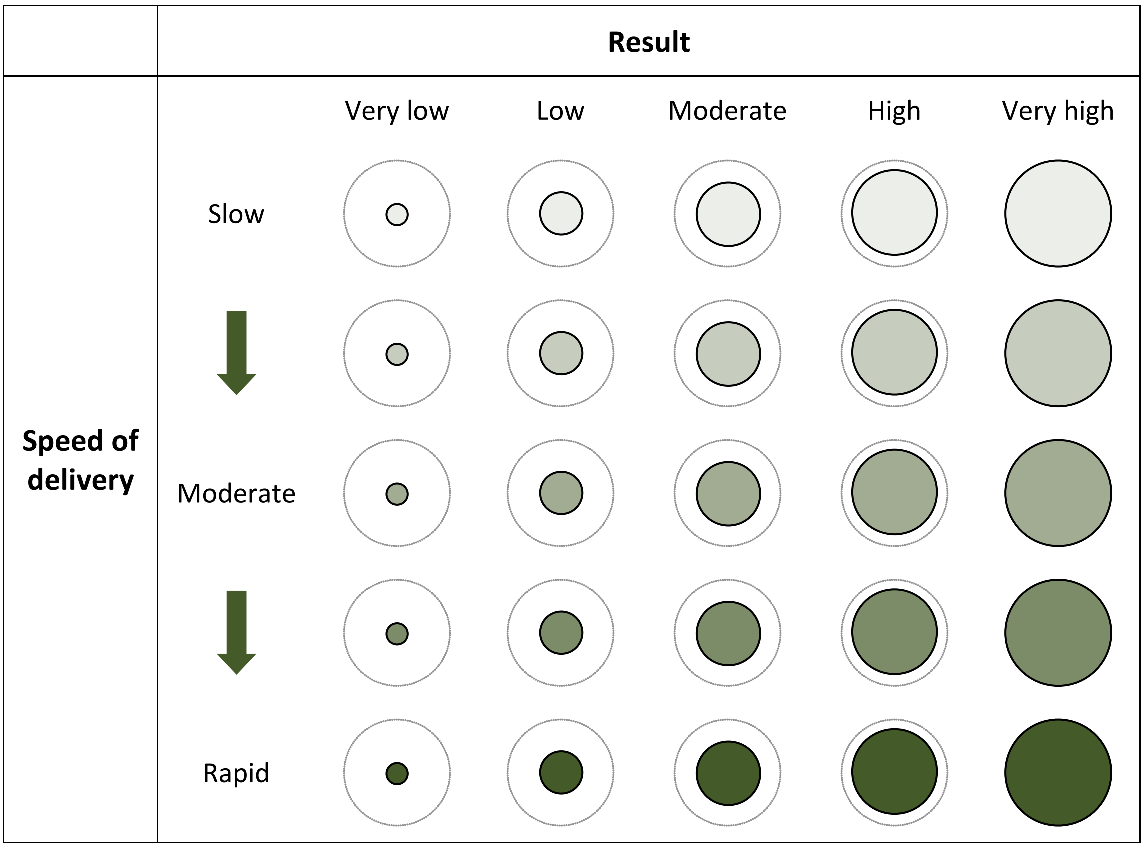
The results shown in the score card are based on an extensive literature search, combined with our own ecological knowledge. The Annex contains a summary review of the general impacts of each approach, and supporting tables detailing the specific impacts of individual practices. We hope that this is useful in understanding the rationale behind each score and identifying the likely impacts of the choice of practice employed within each approach.

Score card:



Larger circles indicate greater delivery of service; darker circles represent faster speed of delivery. See key for detail.

Key:



2.1 How to use the score card

The overall aim of the score card is to facilitate rapid assessment of the likely effects of different forest creation approaches. The values represent probable rather than certain outcomes for ecosystem services, and so should not be relied upon to give accurate results for any particular site.

The score card may be useful for a number of purposes:

2.1.1 National to regional scale: estimating the overall provision of benefits by existing reforested areas

There is scope to use the score card to examine to what extent individual ecosystem-derived benefits occur in the country's reforested area overall. If the area created using different approaches is known, and the score card is used to identify the potential for benefits, a simple sum will yield an estimate of the area likely to be on a trajectory towards very high, high (etc.) provision of each of the four services. A more refined analysis would include information about the potential for delivery of the different services in the different areas (e.g. is there a local population likely to use non-timber forest products; is the new forest close to an existing area of conservation value that could supply colonising species?).

If maps of reforested areas are available, this analysis can be carried out using a Geographic Information System to produce maps of the potential for delivery of ecosystem-derived benefits by existing new and restored forests.

2.1.2 National to regional scale: selecting approaches and practices for new forest cover creation at a landscape scale

The primary objective of any new forest will determine the choice of approach and practices, which in turn will largely determine the outcomes for ecosystem-derived benefits. However, the location of the forest in the wider landscape, and the condition of the site, sets the upper boundary for potential benefits as well as influencing the potential success of the approach.

The score card could contribute to spatial priority-setting, identifying the likely benefits resulting from different approaches, and matching these up to the desired benefits in particular areas. At a minimum, this map-based analysis would also require information on the objectives of extending the area of forest, maps of the potential for delivery of the different services, and maps of land available for forest creation. The results will inform a decision on the appropriate approaches and locations for new forest cover.

Additional information needed for final decision-making will include the results of stakeholder consultations, the costs of applying different approaches and the financial & personnel resources available.

2.1.3 Site scale: identifying possible benefits provided by specific reforested and restored areas

Site-based assessment is required to obtain a definitive answer about ecosystem service provision.

However, the score card can be used to identify the services likely to be offered by individual sites that have already been restored using particular practices or are planned. This could be a useful follow-up exercise to a spatial priority-setting analysis. Referring to detailed tables in the Annex of this document, it is possible to gain a better idea of the influence of specific practices on ecosystem-derived benefits, and to identify references providing evidence to support their use. This understanding may be used to identify possible change in practices to increase the benefits that result from existing or planned new forest areas.

3 References

Chazdon, R.L. 2008. Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Land. *Science* 320: 1458-1460.

Meyfroidt, P., Lambin, E.F. 2008. Forest transition in Vietnam and its environmental impacts. *Global Change Biology* 14(6): 1319-1336.

Tri, N. H., Adger, W.N., Kelly, P M. 1998. Natural resource management in mitigating climate impacts: the example of mangrove restoration in Vietnam. *Global Environmental Change* 8(1): 49-61.

Wikramanayake, E., Dinerstein, E., Loucks, C. J., Olson, D. M., Morrison, J., Lamoreux, J., McKnight, M., Hedao, P. (eds.) 2001. *Terrestrial Ecoregions of the Indo-Pacific: A Conservation Assessment*. Island Press. Island Press, Washington, DC.

Annex: Supporting evidence

A1.Score card numbers

These tables present the values shown in the score cards in numerical form. The ecosystem service result is ranked from 1 (very low) to 5 (very high); the speed is ranked from 1 (slow) to 5 (fast).

Table 1: Numerical values for score card: result

Approach	Ecosystem service – result			
	Biodiversity	Water	Soil	NTFPs
Natural regeneration	5	5	4	4
Assisted natural	5	5	5	4
Planting native species	3	4	4	4
Planting non-native species	1	4	3	3

Table 2: Numerical values for score card: speed of delivery

Approach	Ecosystem service – speed of delivery			
	Biodiversity	Water	Soil	NTFPs
Natural regeneration	1	1	2	1
Assisted natural	3	3	4	3
Planting native species	5	5	5	5
Planting non-native species	5	5	5	3

A2. Natural regeneration

The speed and effectiveness of natural succession depends on the availability of propagules (73) and dispersers (108, 124) and the capacity of species for (re-)sprouting, on the condition of the site and on the intensity of threats (80). Where sources of seed are distant and/or dispersers are absent, colonisation may be very slow. Where land has been used intensively or the site is otherwise degraded, or where threats such as fire and grazing exert an influence, the establishment and growth of native species are likely to be limited and can be enhanced through management. However, the costs of such management (e.g. constructing fire breaks, fencing or patrolling) can be high and need to be balanced against the advantages in terms of more rapid regeneration. A further important consideration is the impact that such interventions may have on local communities, their access to resources and their attitudes to the regenerating forest.

A2.1 Biodiversity

Overall, successful natural regeneration delivers very high biodiversity, but it develops relatively slowly. Where site conditions are favourable, adequate supplies of seed and dispersers exist and threats are not severe, natural regeneration can lead to the development of structural complexity (48, 112) and compositional diversity (78) similar to mature forests, with a full range of natural ecological processes. The resultant high biodiversity (67) is thought to increase the resilience, productivity and carbon storage of the forest (37, 87). Since forests hold greater biodiversity as they age, the site will harbour greater biodiversity the longer natural regeneration and succession has proceeded (37). In some cases, only a subset of the original forest species will be present (59). This is largely dependent on the availability of seed and the type and abundance of seed dispersers present (16, 80).

Natural regeneration can be slow compared to other approaches, but where nearby forest patches provide a high availability of propagules and seed dispersers, natural regeneration can be both the fastest and least costly approach to restoring natural forest (93).

Natural regeneration can affect the biodiversity in the surrounding landscape positively or negatively, depending on the context. Where there are active threats and little threat management, these threats could potentially be displaced to the surrounding areas (110), and, like other approaches, natural regeneration may cause changes to species composition in adjacent mature forest fragments (107), given that species compositions in secondary forests differ from undisturbed sites (16, 112). On the other hand, these forests can play an especially important role as a stepping stone for wildlife (87), provide a source of species or services for other sites (89) or alleviate stresses on adjacent forests by minimising edge effects (90). There are likely to be fewer risks of detrimental impacts on the surrounding landscape compared to planting forests, particularly non-native ones.

A2.2 Water regulation and quality

The long-term effect of naturally regenerated forest on water regulation and quality is likely to be very similar to that of mature native forest. It may reduce water yields relative to other (non-forest) land uses (8), but by limiting erosion it helps to maintain water quality (73) and the development of tree canopy and root systems will help to regulate extreme flows (13), preventing some types of flooding. These services develop as the trees and canopy cover are established, but this may be slower than in some other approaches.

A2.3 Soil conservation and quality

Successful natural regeneration can help to conserve soil and its quality, but these effects may be realised relatively slowly compared to other reforestation approaches. Regenerated forests have been found to have significantly higher surface soil organic matter content, total nitrogen and microbial populations than in plantations (122, 123), as well as greater porosity, lower bulk density, higher concentrations and proportions of soil organic carbon, more microfungal biomass and higher substrate utilisation efficiency of soil microorganisms than do monoculture plantations (123). These sites are less subject to soil compaction than those undergoing reforestation via other approaches. As succession proceeds, soil organic matter will increase, improving soil quality and enhancing soil moisture content and retention (24).

A2.4 Non-timber forest product availability for local use

Eventually, NTFP availability for local use will be high in forests resulting from natural regeneration, since successful regeneration with limited human disturbance will result in a more structurally and compositionally diverse natural ecosystem (48, 93), which is more likely to provide a diversity of NTFPs (80). However, development of a full species complement and associated NTFP availability may be slow, particularly where the site is severely degraded (80). The greater long-term resilience provided by the higher biodiversity in natural regeneration (87), may help to ensure the long-term availability of NTFPs (107).

The NTFPs available from naturally regenerated forests often have a greater history of local use than products from planted stands, making uptake and use by local people more likely. However, many naturally regenerated sites, where the approach has been chosen because of their proximity to wild seed sources or the difficulty of access for management, are remote and afford limited access to local people. On the other hand, there may be fewer restrictions on use by local people than in many plantations (88).

Practice (natural regeneration)	Specific outcomes			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Natural succession, no threat management	This is usually the cheapest option, and in many cases can deliver biodiversity benefits more effectively than other methods (93). The 'end result' can range from a fully developed secondary forest that resembles mature native forest in both its structure (including a fully developed understory and associated microhabitats) and composition (16, 48, 112, 82) to a stunted and depauperate system.	Forest regeneration has positive effects on water quality and regulation of extreme flows. Capacity for water storage increases during succession (16). Slower canopy development may slow attainment of the reduced flows characteristic of mature forest (8). Where erosion is a problem, slow canopy development may lead to greater sedimentation than for some other approaches . Successful development of tree canopy and root systems helps to regulate extreme flows (13) and deliver water over longer periods.	Successful forest regeneration helps to establish high rates of litter production and organic enrichment of soils relatively quickly (73), but information on the patterns of litter accumulation during succession is scarce (30). Reforestation can successfully restore many aspects of the nitrogen cycle (70), but slower regeneration on severely degraded sites may cause further erosion and nutrient leaching (16) . Successful regeneration also limits export of litter and nutrients to other sites.	Successful natural regeneration should yield a diversity of NTFPs throughout succession (e.g. some bamboo and cardamom species flourish in the more open environment of disturbed and regenerating forests - 60). Such products may have a greater history of local use than those from introduced planted species, making uptake more likely. However, natural regeneration may be too slow to meet the needs of growing local populations for forest products (80).
Threat management: fire	Controlling fire may permit more rapid regeneration (94) and development of mature forest structure and composition (112). Managing fire may also reduce likelihood of invasion by non-native species (98). In fire-adapted ecosystems, such management may limit recruitment of some native species. Management techniques such as construction of fire breaks may increase access to regenerating forest and extraction pressures on it.	As 'no threat management'; but ground cover development and canopy closure likely to be more rapid and therefore limit erosion and its adverse effects on water quality (8, 81). Erosion caused by soil exposure and/or root damage resulting from fire also limited, but some management techniques (bull-dozed fire breaks) may increase erosion. Regulation functions are also likely to develop more rapidly and be similar to mature forest sooner because of avoided damage to root systems.	Canopy closure and increase in ground cover and litter due to fire suppression (8) are likely to limit erosion and sediment delivery to other sites. Harmful effects of fire on physical, chemical, and biological properties of soils are also reduced, including: reduction in water holding capacity; soil compaction; soil erosion; loss of mineral nutrients by volatilisation; convection, and leaching (80).	NTFP supply likely increased, especially from fire-sensitive species (94). Fire management may increase the accessibility of NTFPs. It may also involve removal of accumulated fuels (80), which can then be made available for use.

Practice (natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Threat management: grazing	Intensive grazing can prevent regeneration altogether (96). Effective control of grazing is likely to permit more rapid regeneration and development of structural complexity, and especially to promote development of the understory and ground layer (96). Where management limits access by native species (e.g. large vertebrates) full development of ecosystem processes and some biodiversity benefits may be limited.	As 'no threat management'; but canopy closure and development of understory and ground layer are likely to be more rapid and therefore limit erosion (96) and its adverse effects on water quality. Erosion caused by trampling will also be limited (97) as will nitrate leaching from animal wastes (126). Regulation functions are likely to develop more rapidly because of avoided grazing damage and reduced soil compaction (96).	Effects on erosion as 'no threat management'. Reduced compaction will improve soil quality, but this recovery may be slow. Grazing can cause chemical impoverishment of forest soils (97); as a result of grazing management soil nutrient status is likely to improve slowly (97), following a possible initial decline due to reduced inputs from dung (126).	NTFP supply likely increased, and herbaceous products (some fodder, fibre and medicinals) more available at early stages. However, understory development and lower frequency of paths may reduce accessibility in addition to any restrictions imposed by managers to allow regeneration (84)
Threat management: invasives	Invasive species frequently colonise sites rapidly and may inhibit the regeneration of native forest species, thereby limiting both carbon and biodiversity benefits. Controlling invasives reduces this competition and thereby permits more rapid regeneration of diversity (107) and structural complexity (70). However, some invasive control measures may cause serious damage to native species when applied very intensively (100).	As 'no threat management'; However, some invasives may form effective ground cover that limits erosion (8) and its adverse effects on water quality. Some management techniques (use of herbicides) may cause pollution. Others may compact soils, adversely affecting regulation functions.	Effects on erosion 'no threat management', but some interventions can cause erosion. In some cases, controlling invasives may reduce litter inputs temporarily and slow decomposition rates (107). Invasive species can affect the soil microbe community (118), and removing them can reduce accumulations of soil pathogens such as *Chromolaena odorata* (119).	Likely to increase supply of traditionally used NTFPs, especially early on. Invasive removal can itself generate NTFPs.

Practice (natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Threat management: extractive use	Extractive use can remove species from regenerating ecosystems and may have profound effects on key regeneration processes (e.g. hunted species often maintain biodiversity through seed dispersal -107). Reducing this pressure will increase the abundance of both exploited species (107) and those that depend on them, and may promote more rapid development of mature forest structure.	As 'no threat management'; Regulation functions likely to develop more rapidly and be similar to mature forest sooner because of avoided damage, including soil compaction, during extraction. The strength of this positive effect will vary depending on the intensity of extractive use.	Effects on erosion as 'no threat management'. Some extractive activities cause compaction and others (fodder harvest) may represent significant export of nutrients and organic matter. Limiting extractive activities should reduce these effects on soils and promote recovery from them.	The supply of NTFPs is likely to be greater in the long-term. While there is a potential conflict between limiting extractive use (to avoid damage to structure & regeneration) and use of NTFPs, limitations may help to ensure use is sustainable and reduce risk of local extinction of NTFP species (107). Controlling extractive use can cause problems for local communities by limiting their access to important resources.

Practice (natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Location and design in relation to wider landscape	Location (position with respect to existing natural forest and the characteristics of the surrounding matrix) will affect identity and diversity of plant propagules, and animal species arriving at the regeneration site (89), and therefore will affect both the speed and composition of natural regeneration (107, 108). Species richness is likely to be lower in smaller and more isolated fragments (105, 106). Recruitment of animal-dispersed plant species is affected much more strongly by location and patch size than is recruitment of wind-dispersed species (80, 105). Location also determines the role of the site in metapopulation function (106) and as a stepping stone for movement of species between forest remnants (87), and will dictate its role as a source of species and services (e.g. pollination) for other sites and agricultural ecosystems (89).	While most forests may be no better at delivering water than some alternative land uses in headwater catchments (8), cloud forests can strip water from mist, thereby increasing net precipitation (1). Floodplain forests can contribute to groundwater recharge and provide pollution control (25). Reforestation on floodplains may also help to regulate flooding (8, 15, 25). Sometimes forests on slopes will also reduce flood risk downstream (3). Regeneration in sites, such as steep slopes, that are particularly prone to erosion reduces sedimentation problems from exposed soils and management actvities (8).	Soil protection services of forests depend on the spatial distribution of forests over landscapes (1). Effects of forest regeneration on soil stabilisation are especially valuable on steep slopes (8). Steep slope sites will export leaf litter, nutrients including fertilisers and sediment, but also receive these from up-slope. Neighbouring low-nutrient ecosystems may be adversely affected by nutrient transfer. Agricultural soils may be vulnerable to transport of agrochemicals used for vegetation clearance.	Location affects access and therefore NTFP availability. Proximity to markets has a strong influence on the potential for commercialisation.

A3. Assisted natural regeneration (ANR)

Various methods of assisting natural regeneration can increase the speed and effectiveness of succession. These include enhancing the availability of propagules and dispersers, which are critical determinants of succession (73, 108, 124), improving site condition through the use of green manures and cover crops, and managing competing vegetation and other threats. More rapidly regenerated sites regain their ecological functions more rapidly, including important roles in metapopulation function and as stepping stones for dispersers and other species.

A3.1 Biodiversity

Assisted natural regeneration can deliver high gains for biodiversity conservation at moderate speed, and more rapidly than natural regeneration. Where biodiversity outcomes are a key priority, ANR practices can be very effective at helping to develop structural complexity and compositional diversity through, for example, enrichment planting (76), nurse trees (58) and threat management (e.g. removing invasives reduces competition, 107). Even where biodiversity is not a key priority, providing perches to attract animal seed dispersers (108) will inevitably increase biodiversity, through their presence and the resulting higher abundance of seedlings (109).

The practices used in ANR can have diverse effects on biodiversity depending on the specific context so it is important to understand the ecology of a given site. Like natural regenerating forests, ANR practices can have beneficial impacts the surrounding landscape, but also pose some risks.

A3.2 Water regulation and quality

Assisted natural regeneration can lead to very positive outcomes for water regulation and quality, at a moderate speed of delivery (faster than natural regeneration but slower than plantations). Different ANR practices and management activities affect water quality and regulation differently (81). For example, clearance of competing vegetation may expose soil and lead to erosion and sedimentation, or use of herbicides in threat management could pollute downstream watercourses. However, due to the likely faster establishment of ground cover compared to natural regeneration (74), and higher quality forest cover compared to planted forests (81), overall, ANR can minimise erosion and adverse effects on water quality (23).

As for natural regeneration, the development of tree canopy in ANR may reduce flows (13) and soil moisture because of forests' higher transpiration and water use than other vegetation types (8, 50). However, water use will be less than in many non-native planted forests (121). As soil moisture holding capacity increases during succession (16) through the development of root systems and soil organic matter, ANR approaches can quickly develop an effective water regulation function.

A3.3 Soil conservation and quality

Compared to other reforestation approaches, assisted natural regeneration is likely to have the most positive results for soil conservation, dependent upon the management practices undertaken. This approach delivers results faster than natural regeneration, since colonisation and forest structural development occur more rapidly (74). Structural development in particular may be slower than in plantations, but these nonetheless have more limited value for soil conservation. ANR generally minimises soil disturbance and maintains soil integrity (74), increases soil organic matter (24) and protects the soil faster than other approaches, through rapid development of a ground layer (5), especially where legumes, green manure, or ground cover crops are planted). Additionally, since it is forest quality rather than canopy cover which ensures low erosion rates (81), ANR approaches are often more successful at reducing erosion than structurally homogenous plantations.

A3.4 Non-timber forest product availability for local use

Typically, ANR will result in high NTFP availability for local use, as does natural regeneration (88). The practices employed in ANR mean that NTFPs can often be harvested sooner than in the case of natural regeneration – yielding a moderate speed of delivery – particularly where plants are chosen both for facilitating natural regeneration and for their NTFP value (56, 59).

NTFP availability will vary greatly depending on the practices used in ANR, and local preferences for NTFP species. Where seedlings planted for enrichment purposes are chosen in the light of NTFP demands, outcomes may be especially positive (56).

Local people's access to these NTFPs by may be limited by both physical accessibility and restrictive conditions put on forest resources (e.g. some Forest Protection Contracts in Vietnam, 52). Since ANR often involves greater management intensity than for natural regeneration, and often occurs in fairly degraded sites where natural regeneration is not possible (80), site accessibility may already be relatively high. This can enhance NTFP use (79, 91), and commercialisation where there is greater proximity to local settlements and transport routes (86).

Practice **(assisted natural regeneration)**	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Facilitate dispersal (e.g. Perches; propagule transfer; limited enrichment planting with native species)	More rapid and more reliable development of structure expected, compared to unassisted regeneration. Development of diversity likely to be more rapid and possibly greater in total than unassisted natural regeneration (93). Perches and structural complexity help to attract animal seed dispersers (108), accelerate plant colonisation (74) and improve species richness and abundance of seedlings (109). Additional animal species are likely to arrive more rapidly, attracted by the dispersers or by the developing forest cover & composition (108). A full range of ecological processes is also likely to develop more rapidly as a result.	Development of tree canopy and root systems as a result of successful regeneration helps to regulate extreme flows (13) and deliver water over longer periods. Capacity for water storage increases during succession (16). Canopy closure, ground cover and quality of forest cover develop more rapidly, and therefore limit erosion (8, 81) and its adverse effects on water quality more rapidly, than for unassisted regeneration. Regulation functions are also likely to develop more rapidly and be similar to mature forest sooner than for unassisted regeneration.	Rapid canopy closure and development of ground layer relative to natural regeneration (74) leads to soil protection, and likely less soil loss than some other reforestation approaches. They are also likely to lead to rapid accumulation of soil organic matter. Successful forest regeneration helps to establish high rates of litter production and organic enrichment of soils relatively quickly (73), but information on the patterns of litter accumulation during succession is scarce (30). Reforestation can successfully restore many aspects of the nitrogen cycle (70), and also limits export of litter and nutrients to other sites.	The availability of NTFPs varies among sites depending on factors affecting structure and diversity. Successful assisted natural regeneration should yield a diversity of NTFPs throughout succession. These products may have a greater history of local use, making uptake more likely than for products from planted non-native or non-local species. Plants chosen for perches or enrichment purposes may be picked specifically for their NTFP value (56) (59).

Practice (assisted natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Clearing competing vegetation	Clearing may be necessary for regeneration to take place. It should lead to more rapid development of mature structure and composition, but the understorey may be impoverished and associated species less abundant. The development of processes dependent on understorey is likely to be slowed and any stepping stone function develops more slowly for understorey species.	As for 'facilitate dispersal', but repeated clearance may expose soil and lead to erosion (13) with adverse effects on water quality (23).	As for 'facilitate dispersal', but if the understorey vegetation or forest litter layer is removed, there will be increased erosion rates (5, 8, 13). Repeated clearance is more likely to cause erosion. Reduced litter inputs from ground layer and understorey may slow organic matter and nutrient accumulation (17, 24).	Development of full structure and diversity is likely to increase NTFP supply, but NTFPs from early successional and understorey species may be less abundant.
Green manure/legume cover crops	These practices should speed canopy development and succession and development of mature forest composition Canopy closure may subsequently limit understory development (48) and eliminate some stress-tolerant species. More herbaceous cover in the short term will support herbivores and may affect soil fauna through likely more rapid accumulation of organic matter (24, 66)	As for 'facilitate dispersal'. Rapid coverage of soil should reduce erosion (8) and its adverse effects on water quality (23) considerably	Rapid coverage of soil surface should reduce erosion considerably (5). Cover crop litter, especially from leguminous species (66), is often nutrient-rich and rapidly decomposing, so soil quality (nutrient and organic matter content) is likely to be improved (24).	Development of full structure and diversity is likely to increase NTFP supply, especially from species associated with manure or cover crops. NTFPs from some early successional species may be less abundant.

Practice (assisted natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Nurse trees	Full three-dimensional forest structure develops more rapidly so that ground layer may be suppressed sooner by canopy closure (48). Mature forest composition may develop more rapidly and additional species associated with nurse trees may be present (58) and further facilitate colonisation (28). Generalist pollinators and herbivores attracted by nurse trees may colonise more rapidly. Site likely to play a role in metapopulation function and also to serve as a stepping stone from a relatively early stage (87).	As for 'facilitate dispersal'	As for 'facilitate dispersal'. Some nurse trees have high leaves with nutrient content that decompose rapidly. These may enhance soil quality, providing local pockets of enriched soil (80).	Nurse trees may themselves provide NTFPs and/or facilitate the growth of other species (36) that provide NTFPs.
Landscape engineering - terracing, bunding, drainage addition or removal etc	While such techniques should speed canopy development and closure they may in some cases actually slow regeneration (93). These techniques may favour particular species (intentionally or indirectly). Where engineering creates a more variable environment, diversity may be greater (and vice versa) (48). Surface manipulation may slow establishment of litter layer and associated fauna. Some engineering may affect down-slope dispersal.	Poor practice in surface modification risks increased erosion in the short term, but many methods help to limit it. These will have longer term positive effects on water quality as above. Some methods (e.g. drainage or bunding) are specifically designed to affect water flows. Regulation functions likely to develop more rapidly and be similar to mature forest sooner than for unassisted regeneration.	Poor practice in surface modification risks increased erosion in the short term, but many methods help to limit it. These will have longer term positive effects on soil conservation as above and on soil quality (59). Engineering may limit export of both sediment and nutrients to other sites.	Supply of some specific NTFPs may be intentionally favoured by this approach

Practice (assisted natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Threat management: ongoing management of fire, grazing, invasives	Where appropriate techniques are used, controlling threats may permit more rapid regeneration (70) of structural complexity and composition and ecological function, except where management limits access by native species. Removing invasives reduces competition that can slow succession (107), but complete removal of species such as vines may cause serious damage to native vegetation (100). Controlling fire will increase presence of species whose establishment is fire-limited and thus overall species numbers (114), but prescribed burning can control insects and diseases, prepare seedbeds, and release seeds from serotinous cones (80). Management may displace threats to other areas/sites (110) and may effectively limit dispersal and stepping stone effects(87).	As for 'facilitate dispersal', but some interventions may cause erosion and consequent adverse effects on water quality.	As for 'facilitate dispersal', but fire suppression (and grazing management) may reduce inputs of rapidly available nutrients (ash and dung). However, fire suppression will reduce potentially harmful effects of fire on physical, chemical, and biological properties of soils, including: reduction in water holding capacity; soil compaction; soil erosion; loss of mineral nutrients by volatilisation; convection, and leaching (80)	Development of full structure and diversity likely to increase NTFP supply. Invasive management can itself be a source of products, as can fire management, which may involve removal of accumulated fuels (80) that can then be used by local people

Practice (assisted natural regeneration)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Location and design in relation to wider landscape	Location (position with respect to existing natural forest and the characteristics of the surrounding matrix) will affect identity and diversity of plant propagules, and animal species arriving at the regeneration site (89), and therefore will affect both the speed and composition of natural regeneration (107, 108). Species richness is likely to be lower in smaller and more isolated fragments (105, 106). Recruitment of animal-dispersed plant species is affected much more strongly by location and patch size than is recruitment of wind-dispersed species (80, 105). Location also determines the role of the site in metapopulation function (106) and as a stepping stone for movement of species between forest remnants (87), and will dictate its role as a source of species and services (e.g. pollination) for other sites and agricultural ecosystems (89).	While most forests may not be better at delivering water than some alternative land uses in headwater catchments (8), cloud forests play an important role in stripping water from mist, thereby increasing net precipitation (1). Floodplain forests can contribute to groundwater recharge and provide pollution control (25). Reforestation on flood plains and may also help to regulate flooding (8, 15, 25). Sometimes forests on slopes will also reduce flood risk downstream (3). Regeneration in sites, such as steep slopes, that are particularly prone to erosion reduces sedimentation problems from exposed soils and management activities (8).	Soil protection services of forests depend on their spatial distribution over landscapes (1). Effects of forest regeneration on soil stabilisation are especially valuable on steep slopes (8). Steep slope sites will export leaf litter, nutrients including fertilisers and sediment, but also receive these from up-slope. Neighbouring low-nutrient ecosystems may be adversely affected by nutrient transfer. Agricultural soils may be vulnerable to transport of agrochemicals used for vegetation clearance.	Location affects access and therefore NTFP availability

A4.Planting native species

Plantations of native species tend to develop a closed canopy and accumulate biomass more rapidly than in natural regeneration (112), but more slowly than some non-native plantations. Competition for light and water by a well-developed canopy layer may reduce opportunities for colonisation and succession (80). The understory is usually less developed than in naturally regenerated forests (48). Practices involving less disturbance in site preparation and in management (e.g. limited site clearance, longer rotational cycles) are more common in native than in non-native plantations and can promote understory development (37, 59) and colonisation by mature forest species.

In some cases, planted native species may have low survival rates (28, 29, 98), and ultimately, management practices will determine the outcome. In one instance in Viet Nam, for example, low survival was due to low quality soil, uncontrolled grazing and lack of care by planters (52).

Short rotational cycles involving more frequent access by forest workers can increase hunting frequency and decrease density and diversity of vertebrates. Varying harvest timing within a parcel can ensure greater structural heterogeneity, provide refugia from disturbance and so reduce effects on native species. As species characteristic of mature native forest are likely to be less abundant in short-rotation forests, related ecological processes such as dispersal and pollination may be less developed. Harvest practice can also have important impacts on forest dynamics; many forest management plans in Vietnam have reduced the quality and quantity of tropical secondary forests because of the damage caused to forest dynamics (127).

Mixed plantation forest is more likely than monoculture to have a sustained effect on ecosystem-derived benefits, due to its greater resilience in the face of climate change (87).

A4.1 Biodiversity

Planting native species can deliver moderate gains for biodiversity conservation quite rapidly and may have more substantial biodiversity outcomes in the very long term. Forest structure (112), composition (93), and ecological processes (108) can develop more quickly than for forest regeneration approaches, and this can in turn help natural successional processes to recover (58, 78), if management practices allow. For example, in north-eastern Viet Nam, native plantations have been successfully transformed into near-natural forest stands (78). Using native rather than non-native species will generally have better biodiversity outcomes (37, 58) because they generate more niches for other native species. Even monocultures can enhance species richness where regeneration is not possible, by matching planted species to a site, creating canopy cover and altering the microclimate and conditions to attract wildlife (125). Planting mixtures of native species usually promotes colonisation by further native species (36, 58, 108). Analogue species may be selected specifically to provide food or habitat for wildlife (47).

Generally, practices involving less disturbance in site preparation and in management (e.g. longer rotational cycles, which are more usual in native plantations than in non-native plantations, 59) and those which prioritise biodiversity will have the most beneficial results. In addition to the conservation value of these results, higher biodiversity may increase productivity and carbon storage and is likely to improve the plantation’s resilience to climate change and some other pressures (87).

Impacts of native species plantations on biodiversity in the surrounding area will vary according to the species used, management practices and the surrounding land use. For example, plantations prevent the movement of non-forest species and some specialists (42), or may increase pollinator activity (111). Native species plantations may also involve less risk of invasive species.

A4.2 Water regulation and quality

High water regulation functions and water quality gains can be delivered rapidly through planting native species. These results will be affected significantly by site condition, the specific practices used, the species included and management activities undertaken (4, 13, 17, 81). Monocultures are more likely to require agrochemical inputs that can reduce water quality (82, 83). Mixed species are more likely to have a sustained effect on the service, due to greater resilience to climate change and some other pressures (87). Managing for structural diversity will help a litter layer to develop more quickly, minimising erosion (8, 81), sedimentation and resultant adverse effects on water quality.

Native plantations, where harvested, usually have longer rotations than non-native ones (59). Harvesting disrupts watershed protection and can substantially increases sediment concentrations in streams (59, 83) so longer rotations offer better outcomes for water regulation and quality.

A4.3 Soil conservation and quality

Overall, native plantations rapidly deliver high soil conservation outcomes, especially where the practices used specifically promote them. Native plantations typically cause fewer changes to soil biogeochemistry than non-native species (29). More diverse plantations with lower levels of disturbance can quickly improve soil quality (59, 66) through increases in soil organic matter (58) and fertility (93). On degraded sites, monocultures of particular species can be used to protect against soil erosion via their abundant production of leaf litter (36; though non-native species are more commonly used for this purpose, due to a better understanding of which species are able to establish on degraded sites, 98). However, surface soil organic carbon, total nitrogen and microbial populations may be significantly lower than in assisted or natural regeneration (e.g. 122).

Site condition and the species used influence the effects of native species plantations on soil erosion, as do the practices chosen (e.g. through their effects on understory and ground cover, which reduce erosion when they are better developed - 5, 8, 29, 81). The different practices also have variable off-site effects on soil depending on the use of agrochemical inputs, whether and how frequently trees are harvested (5) and position in the wider landscape (1, 8).

A4.4 Non-timber forest product availability for local use

Plantations of native species have the potential to deliver rapidly a high availability of NTFPs for local use, if their production is prioritised and local people are not prevented from using these products by limited access or management regime (52, 88, 94). Where native species with multiple uses are planted, diverse and abundant NTFPs can be obtained (e.g. 49, 94), and may be available more rapidly than following natural regeneration of similar species (112).

If the production of NTFPs is not a priority, the effect of planting native species on NTFP availability will be determined by the management practices used. For example, planting a monoculture will result in fewer NTFPs than managing for structural variation or diversity, or using analogue species to mimic natural ecosystem functions (e.g. many edible insects preferentially feed on tree legumes, 94). Native plantations may affect the availability of NTFPs in the adjacent landscape through reducing stresses such as wind disturbance and desiccation on surrounding forests (42, 90), or increasing invasion by weedy species (42, 107). Depending on the previous land use, NTFPs obtained from the site prior to planting may no longer be available (e.g. in Vietnam, 'bare hills' which have since been replaced by forest plantations supplied a range of NTFPs that are no longer available, 77).

Practice (planting native species)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Even-aged monoculture following intensive high input site preparation	Resulting forest is a simple system with few native plant species and lower animal diversity than natural forest (50). It is structurally homogeneous (37, 42), providing few microhabitats (51, 82) or opportunities for additional native plant species to colonise (51, 80). However animal species are more likely to colonise or use forest than in non-native plantation and may thus provide better seed dispersal. Site preparation and management may eliminate some existing species (52). Agrochemical inputs (fertiliser, herbicides, pesticides) and sedimentation from site preparation may adversely affect aquatic ecosystems and others (43, 67, 83). Fertilisation may promote dominance of weedy species (26)	Effects on water supply depend on species selection (4, 13, 17) - ''thirsty' species such as Eucalyptus especially reduce supply (17, 71). Agrochemical inputs may adversely affect water quality, but evidence from tropical forests is lacking (83). Elimination of ground layer can add to erosion and sedimentation (8, 126). Rapid growth and root development may make this one of the most rapid ways to attain water regulation function (e.g. 71).	After initial soil disturbance during site preparation, rapid canopy closure and root growth may contribute to soil protection. However, if management inhibits development of understory and ground layers there will be greater soil loss (8, 81). Often forest will improve soil quality through increase in soil organic matter (58) and fertility (93), but these effects will depend on the species planted. Because their litter is better matched to the decomposer community native species are less likely to have adverse effects on soil quality (40, 123). Run-off containing sediment and high levels of agrochemical inputs may affect soil chemistry in neighbouring ecosystems (83).	As a result of structural simplicity and low biodiversity, NTFP availability is likely to be limited, unless the planted species itself provides NTFPs (e.g. 62). NTFP availability in monoculture plantation may be lower than for other land uses (77). However, some important NTFP species may thrive in large scale plantations (69), for example cinnamon in Viet Nam (49). Management can promote production and harvest of some NTFPs, such as edible insects (94) fuel, fodder (98) and/or fungi. Some plantation species may support local honey production (e.g. 94) and/or produce fruits attractive to hunted species

Practice **(planting native species)**	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Match species to site (monoculture)	More rapid development of mature plantation may lead to development of greater microhabitat diversity (48) and attract wildlife (125), though never to the extent found in the mature stage of natural forest succession (82). Lower requirement for intensive management and agrochemical inputs may reduce adverse impacts described for ‘even-aged monoculture’ and lead to higher overall biodiversity.	As for ‘even-aged monoculture’, but there may be a reduced need for agrochemical inputs, limiting adverse impacts on water quality. More rapid growth will provide more rapid attainment of water regulation function.	As for ‘even-aged monoculture’, but effects related to agrochemical inputs are likely to be reduced. The choice of species can affect the extent to which soils experience leaching loss (45).	As for ‘even aged monoculture’

Practice (planting native species)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Mixed species and functional types	Supports higher biodiversity than monoculture (58) because greater diversity of the plantation can lead to development of structural complexity more similar to native forest (37) and a greater range of niches and resources for native species (59), including ecological specialists (58). Understory biodiversity has recovered well in some mixed-species plantations (36). Genetic diversity of planted species means the plantation is likely to be less susceptible to serious fungal, insect, or animal damage than are plantation monocultures (58).	Effects on water supply depend on species selection; use of ‘thirsty' species will cause greater reductions in supply (4, 13, 17). More variable species requirements may reduce need for agrochemical inputs (116) and thus limit adverse impacts on water quality. Where growth is rapid there will be more rapid attainment of water regulation function.	As for even-aged monoculture, but species related effects will be moderated by the mixture. Litter decay and nutrient cycling are enhanced with increased diversity, (59), even by mixing as few as two tree species (66). Agrochemical inputs and related impacts are likely lower than for monoculture.	Planted species themselves are more likely to include some useful for NTFPs (possibly. planted specifically for generating income, 56); overall availability is potentially greater than in monoculture (58). For example, pollarded oak forests in China are also managed for production of Chinese oak caterpillar for silk and food (94), and harvesting cinnamon within plantations in Viet Nam (49) can add significantly to local household income. Plantations are most likely to provide fuel, fodder and/or fungi. Some plantation species may support local honey production (e.g. mulberry, 94) and/or produce fruits attractive to hunted species.
Manage for structural variation or diversity, e.g. **Staged planting, limited thinning, adequate spacing, allowing understory development**	The structural complexity of these systems, which may in some cases be nearly as great as in native forest (82), may promote more use by native wildlife (58) including seed dispersers (108) that may facilitate colonisation by native tree species (28, 39).	As for ‘mixed species’; forest structure can also influence water use (15). Management may generate ongoing episodes of substrate disturbance and sedimentation leading to adverse effects on water quality. Structural variation may enhance resilience (37, 87)	As for ‘mixed species’, but may include ongoing episodes of substrate disturbance. Understory development reduces the risk of erosion (5, 58, 81). Understory development may also enhance accumulation and cycling of organic matter and nutrients (39, 58)	As for ‘mixed species’. Greater diversity of colonising native species also increases likely availability of a wider range of NTFPs. More frequent access by forest workers can increase hunting activity and decrease supply of bushmeat. Allowing understory development may add to NTFP availability (58, 59)

Practice (planting native species)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Use of nurse crops and ground cover crops	These systems may be more used by native wildlife, including seed dispersers, because of structural complexity (58, 108). Ground cover crops provide shelter for animals and potentially greater resources for native herbivores, but may limit colonisation opportunities for additional native tree species (48). There is a reduced need for agrochemical inputs, so the related adverse effects described above may be eliminated.	Effects on water supply as for 'mixed species', but water use may be greater because of more rapid development of leaf area. The need for agrochemical inputs will be reduced (42) and soil will be more protected (8, 81), so effects on water quality will be less adverse, or even positive. Development of root systems and soil organic matter by these crops should contribute to regulation function (16).	Enhanced ground cover and litter layer protects soil from erosion (5, 8, 23, 29, 81) and enhances soil organic matter (24). Many nurse and ground crops are leguminous and enhance soil nitrogen (66, 126) and nurse trees provide sites of locally enriched soil (80).Agrochemical inputs and related adverse effects are likely to be lower.	As for 'manage for structural variation or diversity'.
Analogue species /ecological roles to mimic natural ecosystem functions	These systems may be more used by native wildlife, including seed dispersers, because of structural complexity (58) and specific inclusion of wildlife food plants (108) and other species providing nest space and shelter. This may facilitate colonisation by native tree species (108). By providing a greater resource for native frugivores and pollinators it may also increase biodiversity-related services off site.	As for 'mixed species' with the potential additional benefit of selecting species based on their water use or potential to contribute to phytoremediation and erosion control. Resilience effects also likely to be greater.	As for 'mixed species'. Analogue species may be selected with soil conservation in mind (36), including for decomposable litter and / or nitrogen fixation (28, 29, 58).	Planted species themselves may be chosen to include some useful for NTFPs (56, 94), and greater diversity of colonising native species also increases the likely availability of a wider range of NTFPs.

Practice	**Specific outcomes**			
(planting native species)	**Biodiversity**	**Water**	**Soil**	**NTFPs**
Location and design in relation to wider landscape	Large patch sizes and adjacency to other forest areas may reduce edge effects on stature, wind damage and stratification, and fire (42, 59, 90, 107, 108) as well as increase opportunities for colonisation by native species and promote understory development (58). Where reforestation occurs in an increasingly fragmented landscape, as in the subtropical forests of north-western Viet Nam (51), biodiversity may continue to decrease due to edge effects on birds and mammals. Patches of reforestation in a fragmented landscape can facilitate dispersal, migration and pollination (28) and help to conserve fauna by acting as 'stepping stones' and connecting populations between native forest patches (37, 87, 93). Proximity of plantations to native forest may enhance risks of invasion (107), fire damage and other structural impacts, and adverse effects of pests in native forests (42), but may also reduce the frequency of non-forest invasive species within the plantation itself and increase pollination and yield of any crop species such as coffee included within the plantation (111). Plantations around remaining forest patches may act as buffer zones, helping to alleviate stresses caused by edge effects (90) and potentially diverting other pressures on forest biodiversity by meeting some needs for forest products.			

A5.Planting non-native species

Plantations of non-native species generally develop a closed canopy and accumulate biomass more rapidly than in natural regeneration (112). Competition for light and water by the well-developed canopy layer may reduce opportunities for colonisation and succession (80). The understory is usually less developed than in naturally regenerated forests (48). Generally, non-native plantations are intensively managed, and less likely to be colonised by native forest species than are native plantations.

Short rotational cycles involving more frequent access by forest workers can increase hunting activity and decrease density and diversity of vertebrates. Varying harvest timing within a parcel can ensure greater structural heterogeneity, provide refugia and reduce effects on native species. As species characteristic of mature native forest are likely to be less abundant in short-rotation forests, related ecological processes such as dispersal and pollination may be less developed.

Mixed plantation forest is more likely than monoculture to have a sustained effect on ecosystem-derived benefits, due to its greater resilience in the face of climate change (87).

A5.1 Biodiversity

Non-native plantations are likely to have the lowest biodiversity conservation value of the approaches reviewed here; plantations, especially even-aged monocultures, rarely provide suitable habitats for many species (1, 29). However, what useful habitat they do offer develops relatively quickly. Their contribution to conservation must be considered in light of the previous land use at the site (25, 37, 41).

Non-native plantations are likely to be characterised by greater structural homogeneity (37, 42), a more limited range of resources available for native species (42) and lower resilience in the face of environmental stresses (87). However, these characteristics are strongly dependent on the management practices used. Non-native plantations can provide surrogate resources where restoration using native species is not feasible (28, 29) - particularly in severely degraded areas and grasslands (98) - as long as species are matched to the site (125). Depending on the selection of species and management practices, they can also alter the microclimate and conditions of degraded sites to allow colonisation by native species, accelerating natural regeneration (37, 58, 108, 125). They may therefore facilitate natural succession if the planted species are suppressed after a time (70, 80).

As part of the wider landscape, non-native plantations can reduce edge effects, such as wind damage, on adjacent mature forest fragments (42, 90). They may also alter species composition in such forests, including through the spread of insect pests and diseases (80, 107) and increasing the abundance of generalist predators (in response to food supply; e.g. 32). They may act as barriers for some species (42) or facilitate dispersal, migration and pollination for others (28).

A5.2 Water regulation and quality

Planting non-native species can rapidly deliver significant gains in water regulation and quality. These effects are very dependent on the species planted (which can affect water supply, 2, 7), as well as on the practices used (8, 15, 81). Where they are long-established, the water use of both native and non-native plantations can resemble that of old-growth forests (17).

If agrochemical inputs are used, water quality *may* be reduced (83), though there is limited information available to verify this (82, 83). The use of are mixed species and functional types, and of nurse or ground-cover crops can help to protect the soil and limit erosion (8), as well as minimise the need for inputs (42), so that adverse impacts on water quality are limited.

The development of canopy and root systems plays an important role in water regulation, moderating heavy flows. The effect depends on location in the landscape (13, 1) and acts primarily at local level (5, 15, 81).

A5.3 Soil conservation and quality

The typical result of non-native plantation development on soil conservation and quality is only moderately good, but with a rapid rate of delivery. The long-term outcome for soils is the poorest out of the approaches reviewed here, reflecting the findings that nutrient availability is lower in plantation soils than equivalent natural forest (40), non-native plant species can create very different soil conditions to native species (29), and some non-native species such as *Eucalyptus* produce toxic litter (67, 123) which inhibits other species' growth. Effects on erosion are also species dependent, varying with leaf shape, canopy structure and root density and depth (81, 126).

In severely degraded areas, certain non-native species are often more successful than native species (98, 120), and as they develop can alter the microclimate and increase topsoil organic matter and nitrogen levels (58). This can help to rehabilitate a site and allow subsequent natural colonisation or native plantings. Practices which enhance structural diversity and promote a ground layer of vegetation will reduce soil erosion (5, 58, 81) and can help to quickly improve nutrient cycling (39, 58). The choice of species planted has a strong effect on the outcome, especially in monocultures.

A5.4 Non-timber forest product availability for local use

Planting non-native species is likely to result in moderate NTFP availability for local use, depending on the choice of species and the management practices undertaken. In general, they deliver these NTFPs moderately quickly. Non-native plantations may not have the structural complexity (48) and compositional diversity (82) necessary to harbour a diversity of NTFPs (80), particularly in the case of monocultures (1, 29). Some planted tree species can provide NTFPs, with uptake varying between contexts. For example, the legume *Leucaena leucocephala* in Indonesia is described by one author as a 'wonder tree,' because of its multiplicity of uses for timber and NTFPs (98) but the same species is described as 'toxic' in Madagascar by another author (99), because it has strong invasive tendencies and poisons threatened lemurs.

Local access to NTFPs will depend on the wider socioeconomic and institutional context, and the management regime. As plantations are often created with commercial intent, restrictions on use may be greater than for regenerating forest (88, 94). Physical access and access to markets, however, may be easier, as plantations, with their higher management intensity, are more likely to be located near to infrastructure and populated areas (79, 91).

Planting non-native species may positively affect the availability of NTFPs in the adjacent landscape through reducing stresses such as wind disturbance and desiccation on surrounding forests (42, 90). Negative impacts may result if the plantation acts as a source for invasive weedy species (42, 107).

The previous land use and state of degradation will affect whether the supply of NTFPs increases (e.g. 69) or decreases (e.g. 77).

Practice (planting non-native species)	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Even-aged monoculture following intensive high input site preparation	Resulting forest is structurally homogeneous (37, 42), providing few microhabitats (51, 82) and is therefore poor in native species (oil palm plantations provide an extreme example - 31, 53, 54, 55). Some generalist native species may benefit (32). Competition for light and water limits the potential for succession (80). Site preparation and management including agrochemical inputs, may have negative effects on soil fauna, stimulate growth of weeds and invasives and inhibit the establishment of native forest species (10, 87, 93). They may also directly eliminate some existing species (52), increase occurrence of pathogens and pests (10, 93, 94) and have adverse effects on other ecosystems off site. Low genetic diversity increases plantation susceptibility to pests and pathogens (58, 87)	Effects on water supply depend on species selection (4, 13, 17) - ''thirsty' species such as *Eucalyptus* spp. especially reduce supply (17, 71). In some cases, non-native species have a lower water use efficiency than native species (121). High agrochemical inputs may adversely affect water quality, but evidence from tropical forests is lacking (83). Elimination of ground layer can add to erosion and sedimentation (8, 126). Rapid growth and root development may make this the most rapid way to attain water regulation function (e.g. 71).)	After initial soil disturbance and protection during site preparation, rapid canopy closure and root growth may contribute to soil protection. However, if management inhibits development of understory and ground layers there will be greater soil loss (8, 81). Often forest will improve soil quality through increase in soil organic matter (58) and can improve soil fertility (93), but these effects depend on the species planted. Some may have adverse effects on organic matter and nutrient availability (40, 123) and may accumulate toxic secondary compounds (67). Adverse impacts of these changes on soil fauna will also reduce soil quality. Run-off containing sediment and high levels of agrochemical inputs may affect soil chemistry in neighbouring ecosystems (83).	As a result of structural simplicity and low biodiversity, NTFP availability is likely to be limited, unless the planted species itself provides NTFPs for local benefit (e.g. 62, 98). NTFP availability in monoculture plantation may be lower than for other land uses; for example in Vietnam 'bare hills' that formerly provided many NTFPs for poorer households have been replaced by non-native monoculture plantations, with negative economic consequences (77). However, some important NTFP species may thrive in large scale plantations (69) and management can promote production and harvest of e.g. edible insects (94), fuel, fodder (98) and/or fungi.

Practice **(planting non-native species)**	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Match species to site (monoculture)	More rapid development of mature plantation may lead to development of greater microhabitat diversity (48) and attract wildlife (125), though never to the extent found a mature natural forest (82). Lower requirement for intensive management and agrochemical inputs may reduce adverse impacts described above and lead to higher overall biodiversity.	As for even-aged monoculture, but there may be a reduced need for agrochemical inputs, limiting adverse impacts on water quality. More rapid growth leads to more rapid attainment of water regulation function.	As for 'even-aged monoculture', but effects related to agrochemical inputs are likely to be reduced. The choice of species can affect the extent to which soils experience leaching loss (45).	As for 'even-aged monoculture'.
Mixed species and functional types	Supports higher biodiversity than monoculture (58) because greater diversity of the plantation can lead to development of structural complexity more similar to native forest (37) and a greater range of niches and resources for native species (59). Genetic diversity means the plantation itself is likely less susceptible to serious fungal, insect, or animal damage than plantation monocultures (58)	Effects on water supply depend on species selection; use of 'thirsty' species will cause greater reductions in supply (4, 13, 17). More variable species requirements may reduce need for agrochemical inputs (116) and limits adverse impacts on water quality. Where growth is rapid there will be more rapid attainment of water regulation function.	As for 'even-aged monoculture', but species related effects will be moderated by the mixture. Litter decay and nutrient cycling are enhanced with increased diversity, (59); even by mixing as few as two tree species (66). Agrochemical inputs and related impacts are likely lower than for monoculture.	Planted species themselves are more likely to include some useful for NTFPs (possibly. planted specifically for this purpose, 56), and therefore overall availability is potentially greater (58); most likely to provide fuel, fodder and/or fungi.

Practice **(planting non-native species)**	**Specific outcomes**			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Manage for structural variation or diversity, **e.g. Staged planting, limited thinning, adequate spacing, allowing understory development**	The structural complexity of these systems, which may in some cases be nearly as great as in native forest (82), may promote more use by native wildlife (58) including seed dispersers (108) that may facilitate colonisation by native tree species (28) (39).	As for 'mixed species' ; forest structure can also influence water use (15). Management may generate ongoing episodes of substrate disturbance and sedimentation leading to adverse effects on water quality. Structural variation may enhance resilience, including to climate change (37, 87)	As for 'mixed species', but may include ongoing episodes of substrate disturbance. Understory development reduces the risk of erosion (5, 58, 81). Understory development may also enhance accumulation and cycling of organic matter and nutrients (39, 58)	As for 'mixed species and functional types'. Greater diversity of colonising native species also increases likely availability of a wider range of NTFPs. More frequent access by forest workers can increase hunting activity and decrease supply of bushmeat. Allowing understory development may add to NTFP availability (58, 59)
Use of nurse crops and ground cover crops	These systems may be more used by native wildlife, including seed dispersers, because of structural complexity (58, 108). Ground cover crops provide shelter for animals and potentially greater resources for native herbivores, but limit colonisation opportunities for native tree species (48). There is a reduced need for agrochemical inputs, so the adverse effects described above may be reduced.	Effects on water supply as for mixed species, but water use may be greater because of more rapid development of leaf area. The need for agrochemical inputs will be reduced (42) and soil will be more protected (8, 81), so effects on water quality will be less adverse or even positive. Development of root systems and soil organic matter should contribute to regulation function (16).	Enhanced ground cover and litter layer protects soil from erosion (5, 8, 23, 29, 81) and enhances soil organic matter (24). Many nurse and ground crops are leguminous and enhance soil nitrogen (66, 126) and nurse trees provide locally enriched soil (80). Agrochemical inputs and related adverse effects are likely to be lower.	As for 'manage for structural variation or diversity'.

Practice (planting non-native species)	Specific outcomes			
	Biodiversity	**Water**	**Soil**	**NTFPs**
Analogue species /ecological roles	These systems may be more used by native wildlife, including seed dispersers, because of structural complexity (58) and specific inclusion of wildlife food plants (108) and other species providing nest space and shelter. This may facilitate colonisation by native tree species (108). By providing a greater resource for native frugivores and pollinators it may also increase biodiversity-related services off site	As for 'mixed species' with the potential for additional benefits through selecting species based on their water use or potential to contribute to phytoremediation and erosion control. Resilience effects also likely to be greater.	As for 'mixed species'. Analogue species may be selected with soil conservation in mind (36), including for decomposable litter and / or nitrogen fixation (28, 29, 58). Certain non-native species can be used for phytoremediation to restore soils negatively affected by agrochemicals or other toxins (28).	Planted species themselves may be chosen to include some useful for NTFPs (56, 94), and greater diversity of colonising native species also increases the likely availability of a wider range of NTFPs.
Location and design in relation to wider landscape	Large patch sizes and adjacency to other forest areas may reduce edge effects on stature, wind damage and stratification, and fire (42, 59, 90, 107, 108) as well as increase opportunities for colonisation by native species and promote understory development (58). Where reforestation occurs in an increasingly fragmented landscape, as in the sub-tropical forests of north-western Viet Nam (51), biodiversity may continue to decrease due to edge effects on birds and mammals. Patches of reforestation in a fragmented landscape can facilitate dispersal, migration and pollination (28) and help to conserve fauna by acting as 'stepping stones' and connecting populations between native forest patches (37, 87, 93). Proximity of plantations to native forest may also enhance risks of invasion (107), fire damage and other structural impacts, and adverse effects of pests in native forests (42). Plantations around remaining forest patches may act as buffer zones, helping to alleviate stresses caused by edge effects (90) and potentially diverting other pressures on forest biodiversity by meeting some needs for forest products			

A6. References cited in the Annex tables

(1) MEA 2005 Chapter 21: Forest and Woodland Systems. In: MEA 2005. Ecosystems and human well-being: current state and trends: findings of the Condition and Trends Working Group. Edited by R. Hassan, R. Scholes, N. Ash. Island Press, Washington, DC

(2) MEA 2005 Chapter 7: Freshwater Ecosystem Services. In: MEA 2005. Ecosystems and human well-being: current state and trends : findings of the Condition and Trends Working Group. Edited by R. Hassan, R. Scholes, N. Ash. Island Press, Washington, DC

(3) Laurance, W.F. 2007. Forests and floods. Nature 449: 409-410.

(4) Fallas, J. 1999. Net Precipitation Patterns in Undisturbed and Fragmented Costa Rican Cloud Forest. In: IHP 1999 Hydrology and water management in the humid tropics: Proceedings of the Second International Colloquium 22-26 March 1999, Panama, Republic of Panama. pp389-398.

(5) Nik, A.R., Yusop, Z. 2004. Hydrological impacts of forestry and land-use activities: Malaysian and regional exerpience. In: UNESCO/IHP, Water: Forestry and Land Use Perspectives, IHP-VI Technical Document in Hydrology No. 70. pp89-105.

(6) Bonell, M. 2004. Selected issues in mountain hydrology of the humid tropics. In: UNESCO/IHP, Water: Forestry and Land Use Perspectives, IHP-VI Technical Document in Hydrology No. 70. pp34-56.

(7) SCBD 2010. In-depth review of the programme of work on the biological diversity of inland water ecosystems: Summary of background information and key messages. SBSTA 14th Meeting. UNEP/CBD/SBSTTA/14/INF/3 11 April 2010.

(8) FAO-CIFOR 2005. Forests and floods: Drowning in fiction or thriving on facts? RAP Publication 2005/03 Forest Perspectives 2. Indonesia: CIFOR and FAO.

(9) Bruijnzeel, L.A., van Dijk, A.I.J.M., van Noordwijk, M., Chappell, N.A., Schellekens, J. 2007. Tropical deforestation, people and flooding. (Response to Bradshaw et al. 2007) CIFOR. http://www.worldagroforestry.org/water/downloads/bca_bruijnzeel.pdf. Accessed 25/06/10.

(10) Bradshaw, C.J.A., Sodhi, N.S., Peh, K.S.H., Brook, B.W. 2007. Global evidence that deforestation amplifies flood risk and severity in the developing world. Global Change Biology 13: 2379-2395.

(11) Betts, R.A., Boucher, O., Collins, M., Cox, P.M., Falloon, P.D., Gedney, N., Hemming, D.L., Huntingford, C., Jones, C.D., Sexton, D.M.H., Webb, M.J. 2007. Projected increase in continental runoff due to plant responses to increasing carbon dioxide. Nature 448: 1037-1041.

(12) Holwerda, F., Bruijnzeel, L.A., Muñoz-Villers, L.E., Equihua, M., Asbjornsen, H. 2010. Rainfall and cloud water interception in mature and secondary lower montane cloud forests of central Veracruz, Mexico. Journal of Hydrology 384: 84-96.

(13) Bruijnzeel, L.A. 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? Agriculture, Ecosystems and Environment 104: 185-228

(14) Bruijnzeel, L.A. 1999. Hydrology of Tropical Montane Cloud Forests: A Reassessment. In: IHP 1999 Hydrology and water management in the humid tropics: Proceedings of the Second International Colloquium 22-26 March 1999, Panama, Republic of Panama. pp353-388.

(15) Blumenfeld, S., Lu, C., Christophersen, T. and Coates, D. (2009). Water, Wetlands and Forests. A Review of Ecological, Economic and Policy Linkages. Secretariat of the Convention on Biological Diversity and Secretariat of the Ramsar Convention on Wetlands, Montreal and Gland. CBD Technical Series No. 47.

(16) Holscher, D., Mackensen, J., Roberts, J.M. 2005. Forest recovery in the humid tropics: changes in vegetation structure, nutrient pools and the hydrological cycle. In: Bonell, M., Bruijnzeel, L.A. (eds) Forests, Water and People in the Humid Tropics: Past Present and Future hydrological research for integrated land and water management. Cambridge: Cambridge University Press. pp598-621.

(17) Scott, D.F., Bruijnzeel, L.A., Mackensen, J. 2005. The hydrological and soil impacts of forestation in the tropics. In: Bonell, M., Bruijnzeel, L.A. (eds) Forests, Water and People in the Humid Tropics: Past Present and Future hydrological research for integrated land and water management. Cambridge: Cambridge University Press. pp622-651.

(18) Grip, H., Fritsch, J.M., Bruijnzeel, L.A. 2005. Soil and water impacts during forest conversion and stabilisation to new land use. In: Bonell, M., Bruijnzeel, L.A. (eds) Forests, Water and People in the Humid Tropics: Past Present and Future hydrological research for integrated land and water management. Cambridge:

Cambridge University Press. pp561-589.
(19) FAO 2007. Proceedings of the regional workshop “Towards Sustainable Management of Planted Forests". Planted Forests and Tree Working Paper 41E.
(20) Nambiar, E.K.S. 2008. Site management and productivity in tropical plantation forests. Proceedings of Workshops in Piracicaba (Brazil) 2004 and Bogor (Indonesia) 2006. Bogor, Indonesia: CIFOR.
(21) Kobayashi, S., Turnbull, J.W., Cossalter, C. 2001. Rehabilitation of Degraded Tropical Forest Ecosystems Project. In: Kobayashi, S., Turnbull, J.W., Toma, T., Mori, T., Majid, N.M.N.A. (eds.) Rehabilitation of Degraded Tropical Forest Ecosystems: Workshop Proceedings 2-4 November 1999, Bogor, Indonesia. CIFOR. pp1-16.
(22) Mori, T. 2001. Rehabilitation of Degraded Forests in Lowland Kutai, East Kalimantan, Indonesia. In: Kobayashi, S., Turnbull, J.W., Toma, T., Mori, T., Majid, N.M.N.A. (eds.) Rehabilitation of Degraded Tropical Forest Ecosystems: Workshop Proceedings 2-4 November 1999, Bogor, Indonesia. CIFOR. pp17-26.
(23) Yusoff, M.K., Heng, S.S., Majid, N.M., Mokhtaruddin, A.M., Hanum, I.F., Alias, M.A., Kobayashi, S. 2001. Effects of different land use patterns on the stream water quality in Pasoh, Negeri Sembilan, Malaysia. In: Kobayashi, S., Turnbull, J.W., Toma, T., Mori, T., Majid, N.M.N.A. (eds.) Rehabilitation of Degraded Tropical Forest Ecosystems: Workshop Proceedings 2-4 November 1999, Bogor, Indonesia. CIFOR. pp87-98.
(24) Yarwudhi, C., Kobayashi, S., Tanaka, N., Suksawang, S. 2001. Soil conditions under natural, logged-over and secondary stands of tropical seasonal forest in Thailand. In: Kobayashi, S., Turnbull, J.W., Toma, T., Mori, T., Majid, N.M.N.A. (eds.) Rehabilitation of Degraded Tropical Forest Ecosystems: Workshop Proceedings 2-4 November 1999, Bogor, Indonesia. CIFOR. pp99-106.
(25) Hughes, F.M.R. (ed.) 2003. The Flooded Forest: Guidance for policy makers and river managers in Europe on the restoration of floodplain forests. FLOBAR2, Department of Geography, University of Cambridge, UK. 96pp.
(26) Hashim, N.R., Hughes, F.M.R. 2010. The responses of secondary forest tree seedlings to soil enrichment in Peninsular Malaysia: an experimental approach. Tropical Ecology 51(2): 173-182.
(27) FAO 2001. Soil carbon sequestration for improved land management. World Soil Resources Reports 96. FAO: Rome.
(28) Ewel, J.J., Putz, F.E. 2004. A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment 2(7): 354-360.
(29) D'Antonio, C., Meyerson, L.A. 2002. Exotic plant species as problems and solutions in ecological restoration: A synthesis. Restoration Ecology 10(4): 703-713.
(30) Bautista-Cruz, A., del Castillo, R.F. 2005. Soil changes during secondary succession in a tropical montane cloud forest area. Soil Science Society of America Journal 69: 906-914.
(31) Aratrakorn, S., S. Thunhikorn, P.F. Donald 2006. Changes in bird communities following conversion of lowland forest to oil palm and rubber plantations in southern Thailand. Bird Conservation International 16(1): 71-82.
(32) Rajaratnam, R., Sunquist, M., Rajaratnam,, L., Ambu, L. 2007. Diet and habitat selection of the leopard cat (Prionailurus bengalensis borneoensis) in an agricultural landscape in Sabah, Malaysian Borneo. Journal of Tropical Ecology 23: 209-217.
(33) Bigelow, S.W., Ewel, J.J., Haggar, J.P. 2004. Enhancing nutrient retention in tropical tree plantations: No short cuts. Ecological Applications 14(1): 28-46.
(34) Scales, B.R., Marsden, S.J. 2008. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. Environmental Conservation 35(2): 160-172.
(35) Lawton, J.H., Bignell, D.E., Bolton, B., Bloemers, G.F., Eggleton, P., Hammond, P.M., Hodda, M., Holt, D., Larsen, T.B., Mawdsley, N.A., Stork, N.E., Srivastava, D.S., Watt, A.D. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. Nature 391: 72-76.
(36) Petit, B., Montagnini, F. 2006. Growth in pure and mixed plantations of tree species used in reforesting rural areas of the humid region of Costa Rica, Central America. Forest Ecology and Management 233: 338-343.
(37) Paquette, A., Messier, C. 2010. The role of plantations in managing the world's forests in the Anthropocene, Frontiers in Ecology and the Environment 8(1): 27-34.
(38) Nadrowski, K., Wirth, C., Scherer-Lorenzen, M. 2010. Is forest diversity driving ecosystem function and

service? Current Opinion in Environmental Sustainability 2: 75-79.
(39) Lugo, A.E. 1992. Comparison of tropical tree plantations with secondary forests of similar age. Ecological Monographs 62(1): 1-41.
(40) Liao C, Luo Y, Fang C, Li B (2010) Ecosystem Carbon Stock Influenced by Plantation Practice: Implications for Planting Forests as a Measure of Climate Change Mitigation. PLoS ONE 5(5): e10867.
(41) Koh, L.P., Wilcove, D.S. 2007. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters 1: 60-64.
(42) Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Bruhl, C.A., Donald, P.F., Phalan, B. 2008. How will oil palm expansion affect biodiversity? Trends in Ecology and Evolution 23(10): 538-545.
(43) Fitzherbert, E.B., Struebig, M.J., Phalan, B., More, A. 2007. Biodiversity and Oil Palm: an objective review. Biodiversity and Oil Palm Network.
(44) Fayle T.M., Turner E.C., Snaddon J.L., Chey V.K., Chung A.Y., Eggleton P.E., 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.
(45) Ewel, J.J. 2006. Species and rotation frequency influence soil nitrogen in simplified tropical plant communities. Ecological Applications. 16(2): 490-502.
(46) 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. 2008. Biofuel Plantations on Forested Lands: Double Jeopardy for Biodiversity and Climate. Conservation Biology 23(2): 348-358.
(47) Butterfield, R.P. 1995. Promoting biodiversity: advances in evaluating native species for reforestation. Forest Ecology and Management 75: 111-121.
(48) Aubin, I., Messier, C., Bouchard, A. 2008. Can plantations develop understory biological and physical attributes of naturally regenerated forests? Biological Conservation 141: 2461-2476.
(49) Quang, N.V., Sato, N. 2008. The role of forest in people's livelihood: A case study in north-eastern Vietnam. Journal of the Faculty of Agriculture 53(1): 357-362.
(50) Clement, F., Amezaga, J.M. 2008. Linking reforestation policies with land use change in northern Vietnam: Why local factors matter. Geoforum 39(1): 265-277.
(51) Meyfroidt, P., Lambin, E.F. 2010. Forest Transition in Vietnam and Bhutan: Causes and Environmental Impacts. In: Nagendra, H., Southworth, J. (eds.) Reforesting Landscapes: Linking Pattern and Process. Landscape Series 10. Springer: London.
(52) Sunderlin, W., Huynh, T. 2005. Poverty alleviation and forests in Vietnam. CIFOR: Bogor, Indonesia. 73pp.
(53) Danielsen, F., Heegaard, M. 1995. Impact of logging and plantation development on species diversity: a case study from Sumatra. In: Sandbukt, Ø. (ed.) Management of tropical forests: towards an integrated perspective. Centre for Development and the Environment, University of Oslo: Oslo, Norway.
(54) Donald, P.F. 2004. Biodiversity impacts of some agricultural commodity production systems. Conservation Biology 18(1): 17-37.
(55) Hassall, M., Jones, D.T., Taiti, S., Latipi, Z., Sutton, S.L., Mohammed, M. 2006. Biodiversity and abundance of terrestrial isopods along a gradient of disturbance in Sabah, East Malaysia. European Journal of Soil Biology 42: S197-S207.
(56) Kilroy, H.A. 2008. Enrichment planting of an understory palm: Effect of microenvironmental factors on seedling establishment, growth, and survival. A Thesis submitted to The Miami University Honors and Scholars Program and Department of Botany. Oxford, OH.
(57) Ashton, M.S., Mendelsohn, R., Singhakumara, B.M.P., Gunatilleke, C.V.S., Gunatilleke, I.A.U.N., Evans, A. 2001. A financial analysis of rain forest silviculture in southwestern Sri Lanka. Forest Ecology and Management 154: 431-441.
(58) Lamb, D. 1998. Restoration of Degraded Tropical Forest Lands: The Potential Role of Timber Plantations. Restoration Ecology 6(3): 271-279.
(59) Lamb, D., Erskine, P.D., Parrotta, J.A. 2005. Restoration of Degraded Tropical Forest Landscapes. Science 310: 1628-1632.
(60) Belcher, B., Kusters, K. 2004. Non-timber forest product commercialisation: development and conservation lessons. In: Kusters, K., Belcher, B. (eds.) Forest Products, Livelihoods and Conservation: Case Studies of

Non-Timber Forest Product Systems. Volume 1 - Asia. Indonesia: CIFOR.
(61) Belcher, B., Ruiz-Perez, M., Achdiawan, R. 2005. Global Patterns and Trends in the Use and Management of Commercial NTFPs: Implications for Livelihoods and Conservation. World Development 33(9): 1435-1452.
(62) Sah, S.P., Dutta, I.C. 1996. Inventory and future management strategies of multipurpose tree and herb species for non-timber forest products in Nepal. In: Leakey, R.R.B., Temu, A.B., Melnyk, M., Vantomme, P. (eds.) Domestication and commercialization of non-timber forest products in agroforestry systems. pp123-130.
(63) Michon, G., de Foresta, H. 1996. Agroforests as an alternative to pure plantations for the domestication and commercialization of NTFPs. In: Leakey, R.R.B., Temu, A.B., Melnyk, M., Vantomme, P. (eds.) Domestication and commercialization of non-timber forest products in agroforestry systems. pp160-175.
(64) Belcher, B. 2003. What isn't an NTFP? International Forestry Review 5(2): 161-168.
(65) Ros-Tonen, M.A.F. 1999. Refining concepts, objectives and research questions for NTFP research. In: NTFP research in the Tropenbos programme: Results and persepctives. The Tropenbos Foundation. pp179-186.
(66) Nichols, J.D., Rosemeyer, M.E., Carpenter, F.L., Kettler, J. 2001. Intercropping legume trees with native timber trees rapidly restores cover to eroded tropical pasture without fertilization. Forest Ecology and Management 152: 195-209.
(67) Stork, N.E., Boyle, T.J.B., Dale, V., Eeley, H., Finegan, B., Lawes, M., Manokaran, N., Prabhu, R., Soberon, J. 1997. Criteria and Indicators for Assessing the Sustainability of Forest Management: Conservation of Biodiversity. CIFOR Working Paper No. 17.
(68) Vietnam Environment Monitor 2005. Biodiversity. MoNRE, World Bank and Sida.
(69) Yaron, G. 2001. Forest, Plantation Crops or Small-scale Agriculture? An Economic Analysis of Alternative Land Use Options in the Mount Cameroon Area. Journal of Environmental Planning and Management 44(1): 85-108.
(70) Paul, M., Catterall, C.P., Pollard, P.C., Kanowski, J. 2010. Does soil variation between rainforest, pasture and different reforestation pathways affect the early growth of rainforest pioneer species? Forest Ecology and Management 260: 370-377.
(71) Fahey, B., Jackson, R. 1997. Hydrological impacts of converting native forests and grasslands to pine plantations, South Island, New Zealand. Agricultural and Forest Meteorology 84(1-2): 69-82.
(72) Engel, V., Jobbágy, E.G., Stieglitz, M., Williams, M., Jackson, R.B. 2005. Hydrological consequences of Eucalyptus afforestation in the Argentine Pampas, Water Resources Research 41: W10409.
(73) Brown, S., Lugo, A.E. 1990. Tropical Secondary Forests. Journal of Tropical Ecology 6(1): 1-32.
(74) Sajise, P. 2003. Working with nature: technical and social dimensions of assisted natural regeneration. In: Dugan, P.C., Durst, P.B., Ganz, D.J., McKenzie, P.J. (eds.) Advancing assisted natural regeneration in Asia and the Pacific. Bangkok: FAO. pp5-16.
(75) Thongvichit, B., Sommun, S. 2003. Assisted natural regeneration in Thailand. In: Dugan, P.C., Durst, P.B., Ganz, D.J., McKenzie, P.J. (eds.) Advancing assisted natural regeneration in Asia and the Pacific. Bangkok: FAO. pp37-39.
(76) Shono, K., Cadaweng, E.A., Durst, P.B. 2007. Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands. Restoration Ecology 15(4): 620-626.
(77) McElwee, P. 2009. Reforesting "Bare Hills" in Vietnam: Social and Environmental Consequences of the 5 Million Hectare Reforestation Program. AMBIO: A Journal of the Human Environment 38(6): 325-333.
(78) Sturm, L., Apel, U. 2006. Forest restoration through nature-oriented reforestation practices in North Eastern Vietnam. International Forestry Review 8(3): 350-360.
(79) Quang, D.V., Anh, T.N. 2006. Commercial collection of NTFPs and households living in or near the forests: Case study in Que, Con Cuong and Ma, Tuong Duong, Nghe An, Vietnam. Ecological Economics 60(1): 65-74.
(80) Kozlowski, T.T. 2002. Physiological ecology of natural regeneration of harvested and disturbed forest stands: implications for forest management. Forest Ecology and Management 158(1-3): 195-221.
(81) Calder, I.R. 2000. Land Use Impacts on Water Resources. Land Use and Water Resources Research 1: 1.1-1.14.
(82) Cannell, M.G.R. 1999. Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. New Forests 17: 239-262.

(83) Shiva, M.P. 1998. Inventory of forest resources for sustainable management and biodiversity conservation with lists of multipurpose tree species yielding both timber and non-timber forest products (NTFPs), and shrub and herb species of NTFP importance. Indus Publishing. 704pp.

(84) Smith, J., Scherr, S.J. 2003. Capturing the Value of Forest Carbon for Local Livelihoods. World Development 31(12): 2143-2160.

(85) Evans, J., Turnbull, J.W. 2004. Plantation forestry in the tropics: the role, silviculture, and use of planted forests for industrial, social, environmental, and agroforestry purposes. Oxford University Press. 467pp.

(86) Wetterwald, O., Zingerli, C., Sorg, J. 2004. Non-timber Forest Products in Nam Dong Distric, Central Vietnam: Ecological and Economic Prospects. Schweiz Z. Forstwes 155(2): 45-52.

(87) Thompson, I., Mackey, B., McNulty, S., Mosseler, A. 2009. Forest Resilience, Biodiversity, and Climate Change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series No. 43. 67pp.

(88) Scherr, S.J., White, A., Kaimowitz, D. 2002. Making markets work for forest communities. Forest Trends Policy Brief. 22pp.

(89) Prugh, L.R., Hodges, K.E., Sinclair, A.R.E., Brashares, J.S. 2008. Effect of habitat area and isolation on fragmented animal populations. PNAS 105(52): 20770-20775.

(90) Laurance, W.F., Nascimento, H.E.M., Laurance, S.G., Andrade, A., Ewers, R.M., Harms, K.E., Luizao, R.C.C., Ribeiro, J.E. 2007. Habitat Fragmentation, Variable Edge Effects, and the Landscape-Divergence Hypothesis. PLoS ONE 2(10): e1017.

(91) Marshall, E., Schreckenberg, K., Newton, A.C. (eds) 2006. Commercialization of Non-timber Forest Products: Factors Influencing Success. Lessons Learned from Mexico and Bolivia and Policy Implications for Decision-makers. UNEP World Conservation Monitoring Centre: Cambridge, UK.

(92) Cottray, O., Miles, L., Newton, A. 2006. Non-timber forest products in Uganda. Spatial tools supporting sustainable development. UNEP-WCMC: Cambridge, UK.

(93) Chazdon, R.L. 2008. Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Land. Science 320: 1458-1460.

(94) Schabel, H.G. 2010. Forests insects as food: a global review. In: Durst, P.B., Johnson, D.V., Leslie, R.N., Shono, K. (eds.) Forest insects as food: humans bite back: Proceedings of a workshop on Asia-Pacific resources and their potential for development, 19-21 February 2008, Chiang Mai, Thailand. FAO: Bangkok, Thailand.

(95) Brodie, J.F., Gibbs, H.K. 2009. Bushmeat hunting as climate threat. Science 326: 364-365.

(96) Smith, R.L., Flake, L.D. 1983. The Effects of Grazing on Forest Regeneration Along a Prairie River. The Prairie Naturalist 15(1): 41-44.

(97) Adams, S.N. 1975. Sheep and Cattle Grazing in Forests: A Review. Journal of Applied Ecology 12(1): 143-152.

(98) Sandlund, O.T., Schei, P.J., Viken, A. 2001. Invasive Species and Biodiversity Management. Dordrecht, The Netherlands: Springer. 448pp.

(99) Jolly, A., Sussman, R.W., Koyama, N., Rasamimana, H. (ed.) Ringtailed lemur biology: Lemur catta in Madagascar. Springer: New York.

(100) Binggeli, P. 2003. Introduced and invasive plants. In: Goodman, S.M., Benstead, J.P. (eds.) The natural history of Madagascar. University of Chicago Press: Chicago. Pp257-268.

(101) Sweeney, B.W., Czapka, S.J., Yerkes, T. 2002. Riparian Forest Restoration: Increasing Success by Reducing Plant Competition and Herbivory. Restoration Ecology 10(2): 392-400.

(102) Kappelle, M., Geuze, T., Leal, M.E., Cleef, A.M. 1996. Successional age and forest structure in a Costa Rican upper montane Quercus forest. Journal of Tropical Ecology 12: 681-698.

(103) Wrangham, R. W., Chapman, C. A., Chapman, L. J. 1994. Seed dispersal by forest chimpanzees in Uganda. Journal of Tropical Ecology 10, 355-368.

(104) Yumoto, T., Maruhashi, T. 1995. Seed-dispersal by elephants in a tropical rain forest in Kahuzi-Biega National Park, Zaire. Biotropica 27(4): 526-530.

(105) Cordeiro, N. J., Howe, H. F. 2001. Low recruitment of trees dispersed by animals in African forest fragments. Conservation Biology 15(6): 1733-1741.

(106) Gaston, K. J., 2000. Global patterns in biodiversity. Nature 405(6783): 220-227.

(107) Phillips, O.L. 1997. The changing ecology of tropical forests. Biodiversity and Conservation 6: 291-311.
(108) Wunderle Jr., J.M. 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. Forest Ecology and Management 99: 223-235.
(109) Zanini, L., Ganade, G. 2005. Restoration of Araucaria Forest: The Role of Perches, Pioneer Vegetation, and Soil Fertility. Restoration Ecology 13(3): 507-514.
(110) Miles, L., Kapos, V. 2008. Reducing Greenhouse Gas Emissions from Deforestation and Forest Degradation: Global Land-Use Implications. Science 320(5882): 1454-1455.
(111) Ricketts, T.H. 2004. Tropical Forest Fragments Enhance Pollinator Activity in Nearby Coffee Crops. Conservation Biology 18(5): 1262-1271.
(112) Aide, T.M., Zimmerman, J.K., Pascarella, J.B., Rivera, L., Marcano-Vega, H. 2001. Forest Regeneration in a Chronosequence of Tropical Abandoned Pastures: Implications for Restoration Ecology. Restoration Ecology 8(4): 328-338.
(113) Zarin, D.J., Davidson, E.A., Brondizio, E., Viera, I.C.G., Sa, T., Feldpausch, T., Schuur, E.A.G., Mesquita, R., Moran, E., Delamonica, P., Ducey, M.J., Hurtt, G.C., Salimon, C., Denich, M. 2005. Legacy of fire slows carbon accumulation in Amazonian forest regrowth. Frontiers in Ecology and the Environment 3(7): 365-369.
(114) Hooper, E., Legendre, P., Condit, R. 2005. Barriers to forest regeneration of deforested and abandoned land in Panama. Journal of Applied Ecology 42(6): 1165-1174.
(115) Sangha, K.K., Jalota, R.K. 2005. Value of Ecological Services of Exotic *Eucalyptus tereticornis* and Native *Dalbergia sissoo* Tree Plantations of North-Western India. Conservation and Society 3(1): 92-109.
(116) Hartley, M.J. 2002. Rationale and methods for conserving biodiversity in plantation forests. Forest ecology and management 155: 81-95.
(117) Ehrenfeld, J.G. 2003. Effects of Exotic Plant Invasions on Soil Nutrient Cycling Processes. Ecosystems 6(6): 503-523.
(118) Kourtev, P.S., Ehrenfeld, J.G., Haggblom, M. 2002. Exotic plant species alter the microbial community structure and function in the soil. Ecology 83(11): 3152-3166.
(119) Mangla, S., Inderjit, Callaway, R.M. 2007. Exotic invasive plant accumulates native soil pathogens which inhibit native plants. Journal of Ecology 96(1): 58-67.
(120) Chacon, G., Gagnon, D., Pare, D. 2009. Comparison of soil properties of native forests, Pinus patula plantations and adjacent pastures in the Andean highlands of southern Ecuador: land use history or recent vegetation effects? Soil Use and Management 25: 427-433.
(121) Kagawa, A., Sack, L., Duarte, K., James, S. 2009. Hawaiian native forest conserves water relative to timber plantation: Species and stand traits influence water use. Ecological Applications 19(6): 1429-1443.
(122) Shi, F.C., Li, J.J., Wang, S.Q. 2008. Soil organic carbon, nitrogen and microbial properties in contrasting forest ecosystems of north-east China under different regeneration scenarios. ACTA Agriculturae Scandinavica Section B - Soil and Plant Science 58(1): 1-10.
(123) Behera, N., Sahani, U. 2003. Soil microbial biomass and activity in response to Eucalyptus plantation and natural regeneration on tropical soil. Forest Ecology and Management 174(1-3): 1-11.
(124) Holl, K.D. 1997. Factors limiting tropical rain forest regeneration in abandoned pasture: Seed rain, seed germination, microclimate and soil. Biotropica 31(2): 229-242.
(125) Lugo, A.E. 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. Forest Ecology and Management 99: 9-19.
(126) Quinn, J.M., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Williamson, R.B. 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. New Zealand Journal of Marine and Freshwater Research 31: 579-597.
(127) Tran, H., Shigeru, I., Susumu, I. 2005. Species Composition, Diversity and Structure of Secondary Tropical Forests Following Selective Logging in Huong Son, Ha Tlnh Province, Vietnam. Journal of the Faculty of Agriculture, Kyushu University 50(2): 551-571.