

ASB Lecture Note 5

Biodiversity: issues relevant to integrated natural resource management in the humid tropics

Sandy E Williams, Andy Gillison and Meine van Noordwijk

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Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns

Meine van Noordwijk, Sandy Williams and Bruno Verbist (Editors)

Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can - in a global partnership for sustainable development. (Preamble to the United Nations' Agenda21 on Sustainable Development; <http://www.un.org/esa/sustdev/agenda21chapter1.htm>).

Background to this series of lecture notes

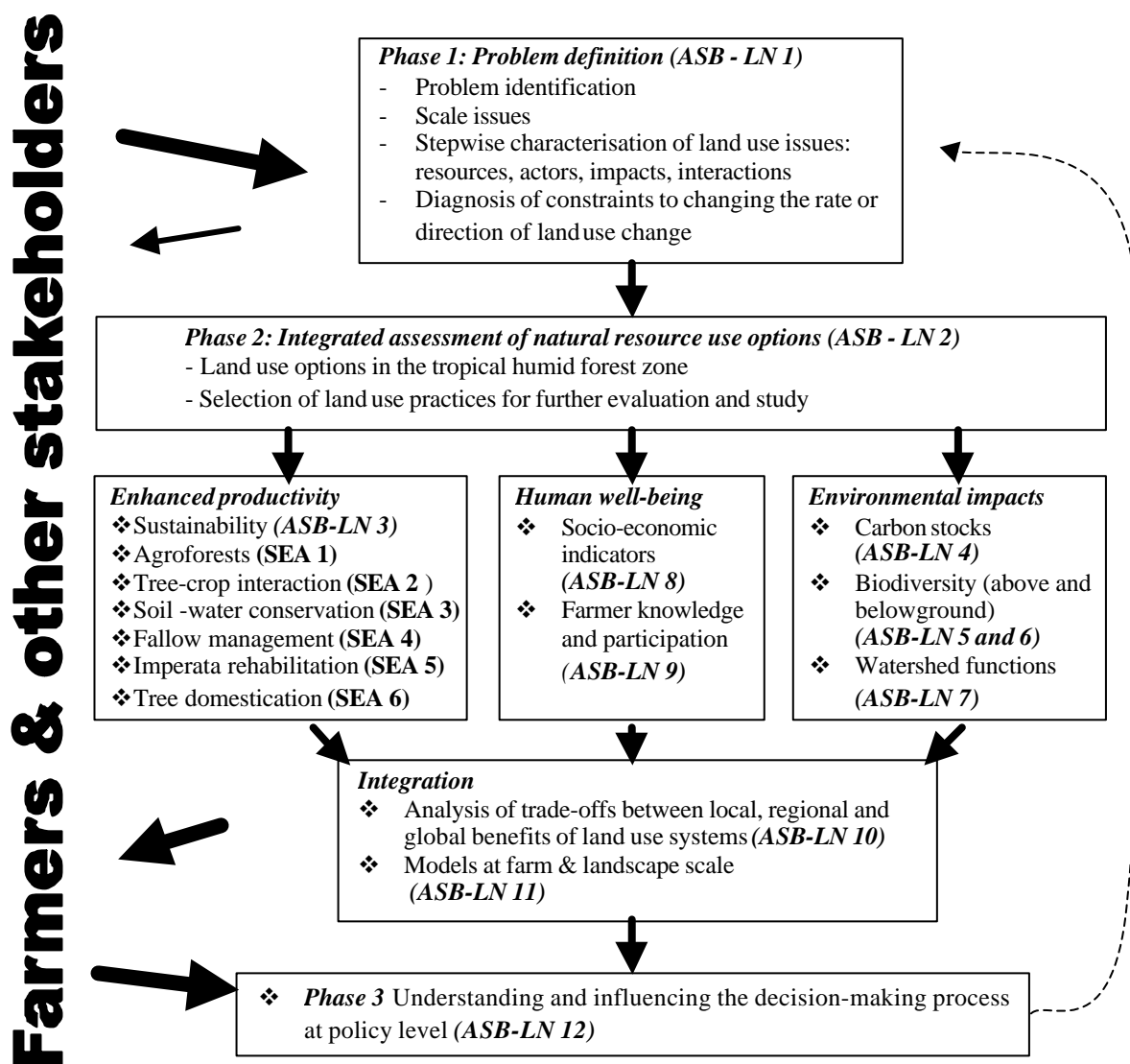
Much of the international debate on natural resource management in the humid tropics revolves around forests, deforestation or forest conversion, the consequences it has and the way the process of change can be managed. These issues involve many actors and aspects, and thus can benefit from many disciplinary perspectives. Yet, no single discipline can provide all the insights necessary to fully understand the problem as a first step towards finding solutions that can work in the real world. Professional and academic education is still largely based on disciplines – and a solid background in the intellectual capital accumulated in any of the disciplines is of great value. If one wants to make a real contribution to natural resource management issues, however, one should at least have some basic understanding of the contributions other disciplines can make as well. Increasingly, universities are recognising the need for the next generation of scientists and policymakers to be prepared for interdisciplinary approaches. Thus, this series of lecture notes on integrated natural resource management in the humid tropics was developed.

The lecture notes were developed on the basis of the experiences of the Alternatives to Slash and Burn (ASB) consortium. This consortium was set up to gain a better understanding of the current land use decisions that lead to *rapid* conversion of tropical forests, shifting the forest margin, and of the *slow* process of rehabilitation and development of sustainable land use practices on lands deforested in the past. The consortium aims to relate local activities as they currently exist to the global concerns that they raise, and to explore ways by which these global concerns can be more effectively reflected in attempts to modify local activities that stabilise forest margins.

The Rio de Janeiro Environment Conference of 1992 identified deforestation, desertification, ozone depletion, atmospheric CO₂ emissions and biodiversity as the major global environmental issues of concern. In response to these concerns, the ASB consortium was formed as a system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR), involving national and international research institutes. ASB's objectives are the development of improved land-use systems and policy recommendations capable of alleviating the pressures on forest resources that are associated with slash-and-burn agricultural techniques. Research has been mainly concentrated on the western Amazon (Brazil and Peru), the humid dipterocarp forests of Sumatra in Indonesia, the drier dipterocarp forests of northern Thailand in mainland

Southeast Asia, the formerly forested island of Mindanao (the Philippines) and the Atlantic Congolese forests of southern Cameroon.

The general structure of this series is



This latest series of ASB Lecture Notes (**ASB-LN 1 to 12**) enlarges the scope and embeds the earlier developed ICRAF-SEA lecture notes (**SEA 1-6**) in a larger framework. These lecture notes are already accessible on the website of ICRAF in Southeast Asia: <http://www.icraf.cgiar.org/sea>

In this series of lecture notes we want to help young researchers and students, via the lecturers and professors that facilitate their education and training, to grasp natural resource management issues as complex as that of land use change in the margins of tropical forests. We believe that the issues, approaches, concepts and methods of the ASB program will be relevant to a wider audience. We have tried to repackage our research results in the form of these lecture notes, including non-ASB material where we thought this might be relevant. The series of lecture notes can be used as a basis for a full course, but the various parts can also 'stand alone' in the context of more specialised courses.

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ASB-consortium members

Details of the ASB consortium members and partner organisations can be found at:
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Lecture Note 5

BIODIVERSITY: ISSUES RELEVANT TO INTEGRATED NATURAL RESOURCE MANAGEMENT IN THE HUMID TROPICS

By Sandy E. Williams, Andy Gillison and Meine van Noordwijk

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I. Objectives

1. To provide a critical framework for
 - Assessing the importance of biodiversity (above and below ground)
 - Quantifying various indicators of biodiversity
 - Considering issues of scale for biodiversity conservation and research
2. To describe the effects of forest conversion on biodiversity
3. To assess the biodiversity status of the various land cover types, before and after forest conversion

II. Lecture

1. Introduction: what is biodiversity and why is it important?

1.1 Definitions

Biological diversity (often shortened to "biodiversity") refers simply to the variety of life on Earth, including all animals, plants and micro-organisms, the genes they contain and the complex ecosystems they help form. It is the collective term for the plants, animals and micro-organisms, evolved over hundreds of millions of years, that make our planet fit for the forms of life we know today (McNeely and Scherr, 2001). The term biodiversity has gained popular use in the last decade, especially since the declaration of Agenda 21 at the Earth Summit in Rio de Janeiro, Brazil, in 1992. Biodiversity is actually a **subject**. It is not a value, nor a measure of any one specific 'quantity'.

In the Convention on Biological Diversity, governments agreed on an "official" definition of biological diversity as:

"the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

Biological diversity can be measured in terms of different components (landscapes, ecosystems, communities, species/populations and genes), each of which has structural, compositional and functional attributes. These are summarised, for reference, in Box 1. Which aspects of biodiversity we actually choose to study and measure (e.g. the number of species, its economic/conservation value or its structure) really depends on the type of question we want to answer.

1.2 What is the issue- is biodiversity under threat?

There is firm evidence (McNeely and Scherr, 2001) that:

1. Extinction rates are increasing, and are now between two and three orders of magnitude greater than the 'background' rates of extinction that have been seen over geological time in the fossil record.

2. Although humans have been the cause of two major extinction episodes in the past (i.e. the prehistoric hunting of large mammals, and elimination of bird species on oceanic islands) this time there are effects across the board, affecting species of all evolutionary forms and sizes, from all regions and habitats.

Box 1. Biodiversity at different levels: components, examples and attributes (after Putz <i>et al.</i> , 2000)				
Component	Diversity	Attributes		
		Structure (the physical organisation or pattern of elements)	Composition (the identity or variety of elements)	Function (ecological and evolutionary processes acting among the elements)
Landscape	Regional mosaics of land uses, land forms, ecosystem types	Areas of different habitat patches, perimeter-area relations, inter-patch linkages	Identity, distribution and proportions of different habitat types	Patch persistence (or turnover), inter-patch flows of energy, species and other resources
Ecosystem	Interactions between members of a biotic community and their environment	Vegetative biomass, soil structural properties	Biogeochemical standing stocks	Processes, including biogeochemical and hydrological cycling
Community	Guilds, functional groups and patch types occurring in the same area and strongly interacting through biotic relationships	Vegetation structure and trophic structure	Relative abundance of species and guilds	Flows between patch types, disturbance regimes (such as fires and floods), successional processes, species interactions
Species/ population	Variety of living species and their component populations at the local, regional or global scale	Population age structure or species abundance distributions	Particular species that are present	Demographic processes such as recruitment and death.
Gene	Variability within a species, as measured by the variation in genes within a particular species, subspecies or population	Heterozygosity or genetic distances between populations in different patches (i.e. metapopulation genetic structure)	Alleles that are present and their proportions	Gene flow, genetic drift or loss of allelic diversity in small isolated pockets.

3. Extinctions can be caused by:
 - natural processes (e.g. fires, hurricanes, droughts);
 - excessive harvesting of particular species of economic value;
 - impacts of alien invasive species including diseases;
 - the impacts of various environmental pollutants;
 - changes in climate;
 - knock-on effects from extinction of essential companion species (e.g. pollinators, fruit or seed dispersers, obligate parasites or symbionts);

However, current the rapid rate of species loss is due especially to the alteration or conversion of natural habitats into agricultural lands. Land use change is widely agreed

to be the strongest catalyst for changes in biodiversity. Furthermore, nearly half of the areas currently protected for biodiversity are themselves heavily used for agriculture, and many of them are located in regions where agriculture is a major land use (Figure 1). Neither fencing off wildlife nor restricting farming is likely to save the world's threatened species from extinction.

4. The humid tropics are an area where biodiversity levels are extremely high (Figure 3), but also where forest conversion is increasing in response to the rapidly increasing population levels there. For example, 1.1 billion people live in the areas of the 25 'global biodiversity hotspots', and in 19 of the 25, population growth rates are higher than the global average (Figure 2). Given that around two-thirds of all terrestrial species occur in tropical forests, then conversion of these has serious repercussions for global biodiversity. In the last 400 years, approximately half of the 14-18 million square kilometers of tropical forest has been cleared, and at least one million square kilometers are cleared each decade, with several times that amount being severely damaged by burning and selective logging.

1.3 Arguments for biodiversity conservation

Many people think biodiversity should be conserved. For example:

- The Convention on Biological Diversity has been ratified by over 175 countries.
- The Global Environment Facility is now spending over \$100 million per year on biodiversity conservation.
- The World Bank, GEF and Conservation International recently designated \$150 million for a new partnership fund for "critical ecosystems."
- Other international investment institutions, bilateral development agencies and NGOs have also increased biodiversity initiatives (McNeely and Scherr, 2001).

Why do people think this?

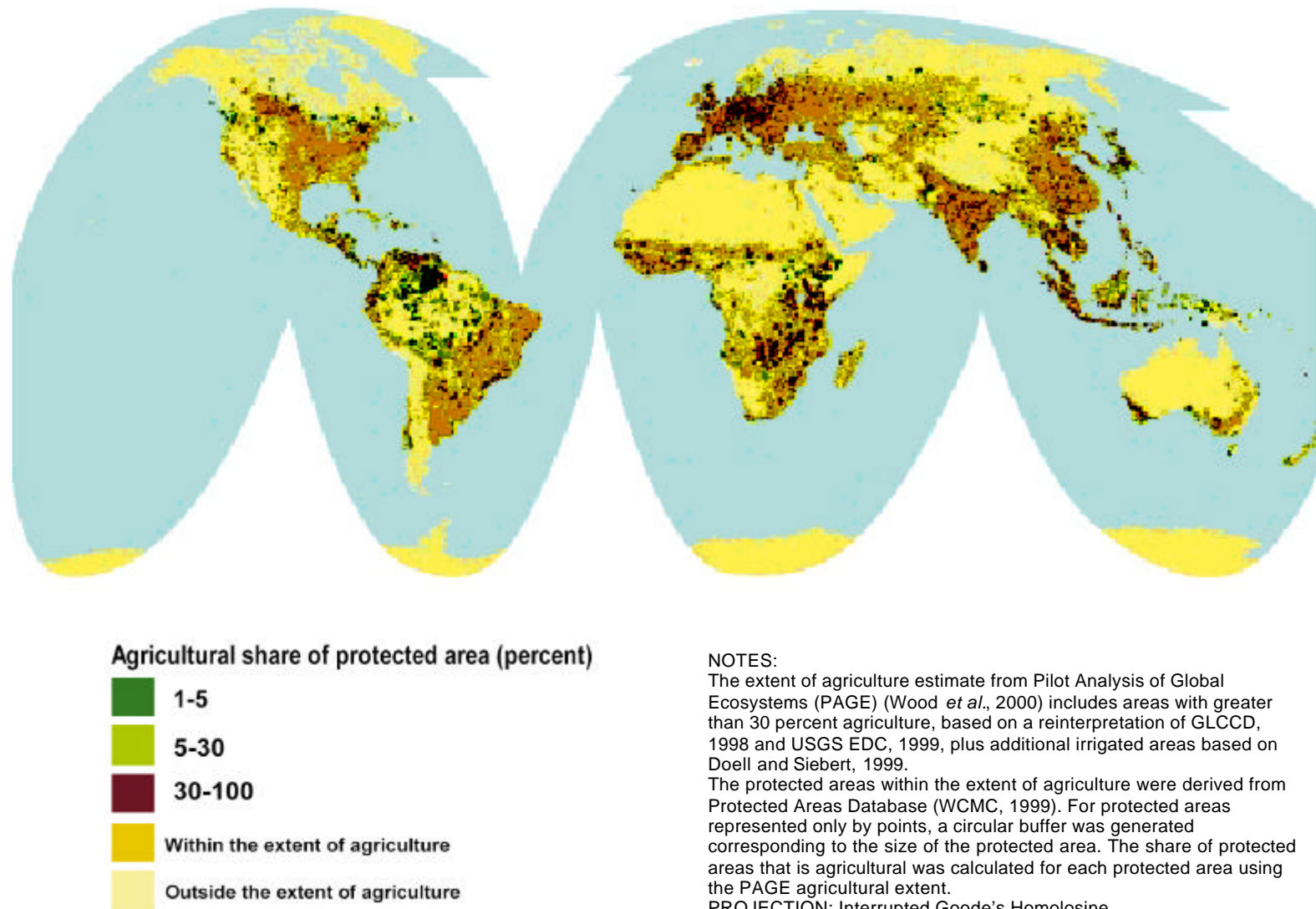
There are various arguments:

- Current value: people rely on a wide range of forest resources for food, raw materials
- Future value: genetic diversity for future crop breeding, or future products that we might one day need, for example as medicine
- Ecosystem functioning: providing environmental goods and services, maintaining ecosystem stability
- Aesthetic/cultural/spiritual: e.g. wilderness value, inspirational value
- Ethical: all species have intrinsic value, and have a right to exist

YES, BUT...The other side of the coin

- Even among people who strongly advocate biodiversity conservation, there are many different agendas, and inconsistencies regarding the 'importance' of biodiversity (above), dependent on particular perceptions/perspectives. "The person-on-the-street values species which are large, furry, fun-to-kill, cuddly, or fearsome. Conservation biologists value endangered and threatened species. Evolutionary biologists value species assemblages containing large phylogenetic differences. Protected area biologists value species not well-represented in existing reserves. Drug companies value those species containing new and valuable chemical compounds. Those of us working on sustainable development place higher values on naturally-occurring species which are most heavily impacted by development or have keystone ecological roles" (Shank, 1999).

Figure 1. Geographic relation between protected areas and agricultural land. (Source: Wood, Stanley, Kate Sebastian, and Sara J. Scherr. 2000. *Pilot Analysis of Global Ecosystems: Agroecosystems*. Washington: International Food Policy Research Institute and the World Resources Institute; reproduced in McNeely and Scherr, 2001).



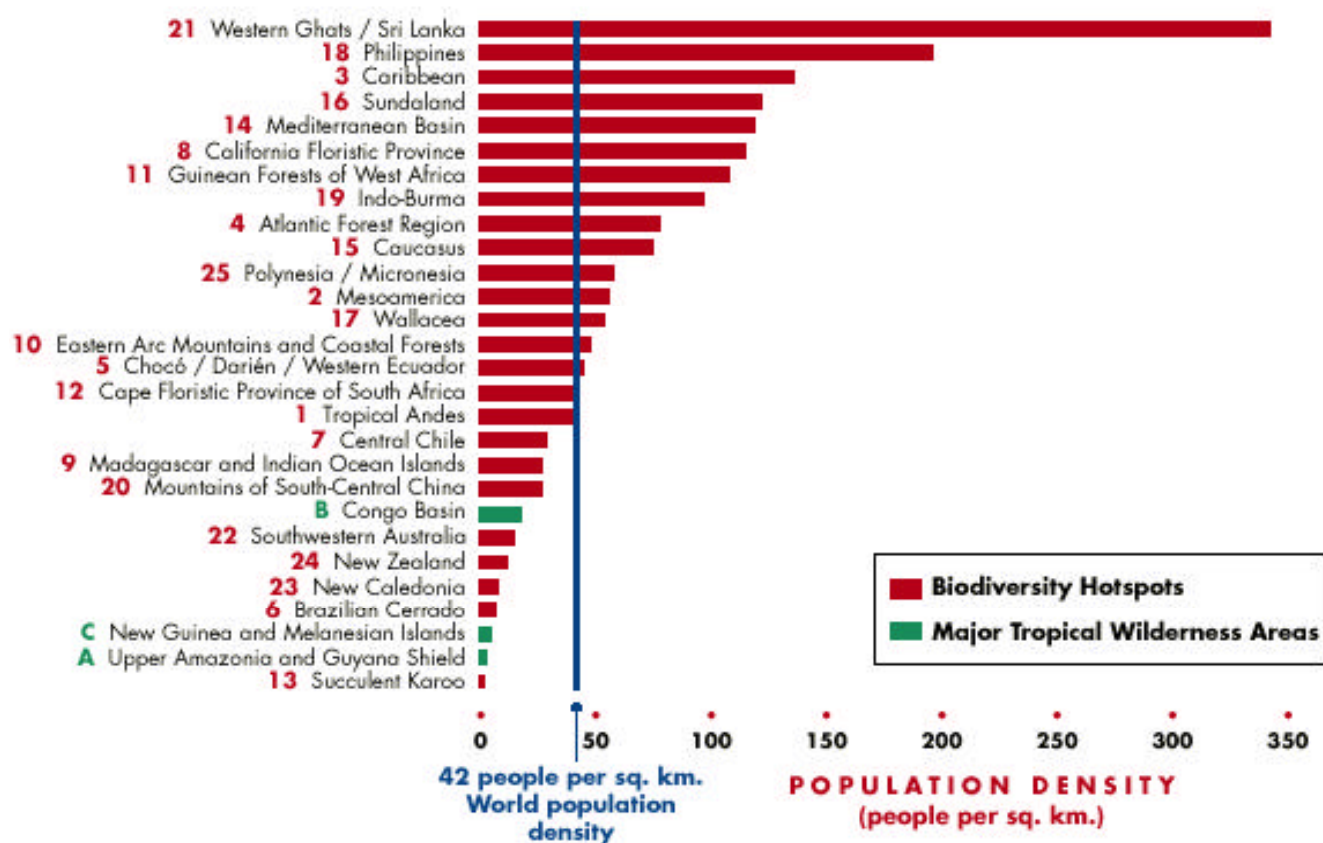
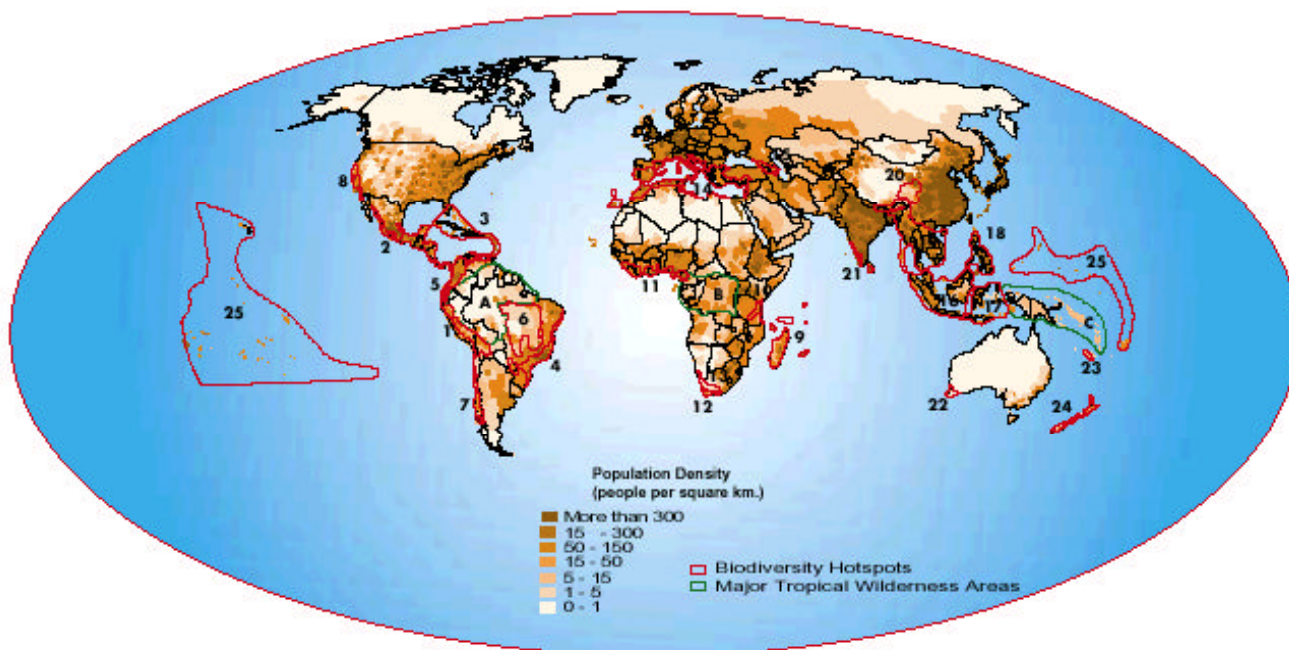


Figure 2. Global biodiversity hotspots and population densities. (Source: Cincotta, R.P. and R. Engelman. 2000. *Nature's Place: Human Population and the Future of Biological Diversity*. Washington: Courtesy of Population Action International; reproduced in McNeely and Scherr, 2001).

GLOBAL BIODIVERSITY: SPECIES NUMBERS OF VASCULAR PLANTS

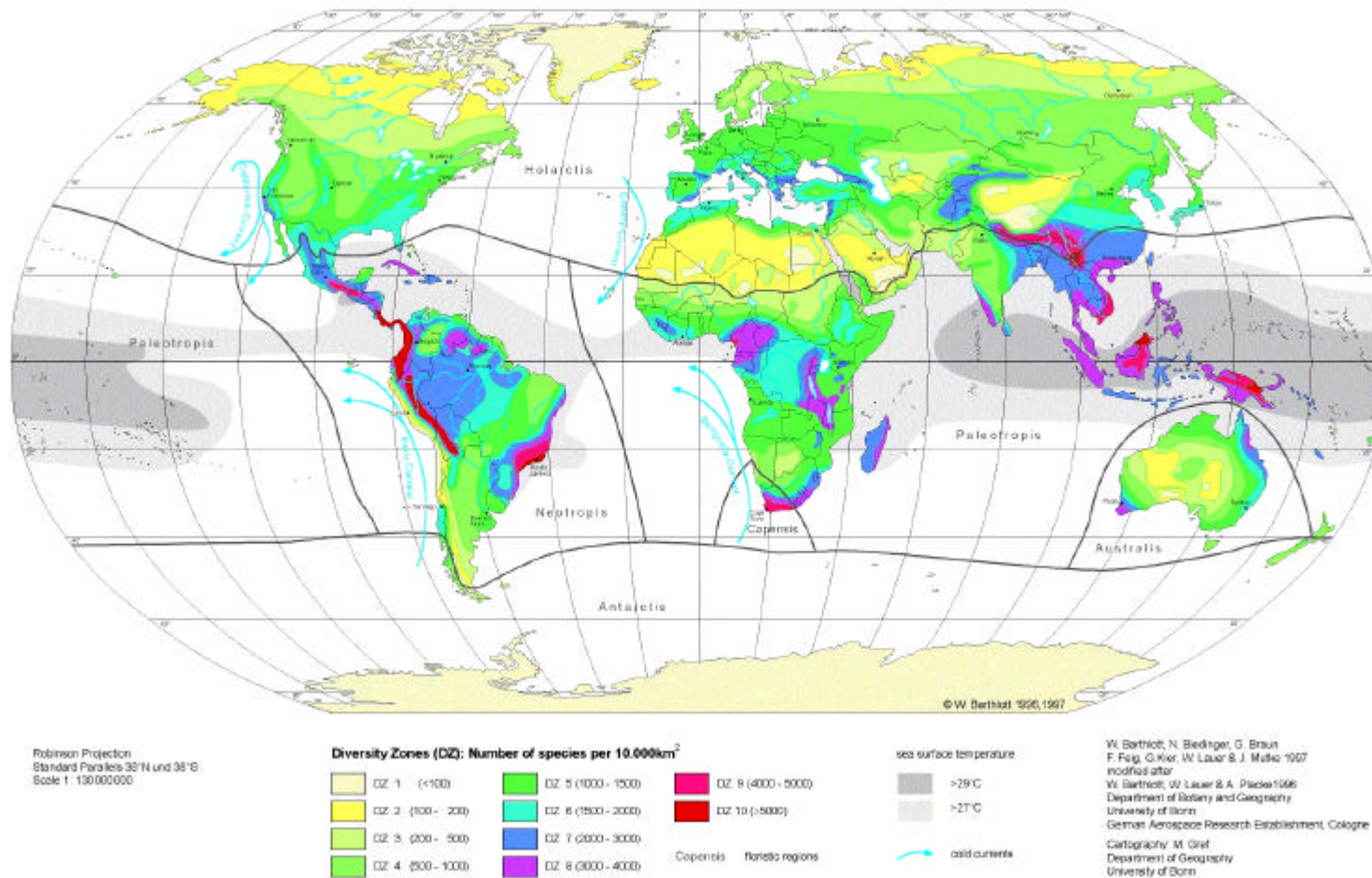


Figure 3. Map of the potential species diversity of terrestrial vascular plants. The six global diversity maxima are all located in the humid tropics and subtropics, and are: 1. Chocó-Costa Rica Centre, 2. Tropical Eastern Andes Centre, 3. Atlantic Brazil Centre, 4. Eastern Himalaya-Yunnan Centre, 5. Northern Borneo Centre, 6. New Guinea Centre. Source: <http://www.botanik.uni-bonn.de/system/biomaps.htm>.

- What about the people who DON'T advocate biodiversity conservation? In the most biodiversity-rich regions, which are highly populated, many people are living in 'absolute' poverty, and 800 million are undernourished (McNeely and Scherr, in press). How high a priority is biodiversity conservation likely to be for these people?
- What about the people whose livelihoods are actually threatened by elements of the local 'biodiversity'? Elephants, monkeys, deer, tapir and wild pigs, for example, can be serious agricultural pests in forest margins. Furthermore, the number of tiger attacks on people is far greater in high-biodiversity buffer zone areas around protected forest, than in areas where low biodiversity agricultural systems adjoin forests directly (Nyhus and Tilson, in press).

SO...why **does** biodiversity matter? **How much?** And **to whom?** We need to ask these questions before attempting any kind of study or research on biodiversity, and in the past this has generally not been done.

Exercise: Stakeholder analysis

Biodiversity at the forest margins.....

- Who are the stakeholders?
- What use is biodiversity to them? How do they value it? What happens if it is lost?

List the possible stakeholders in the first column of a matrix, and use the questions above as further column headings. Fill in the matrix

In the forest margins of the three ASB benchmark areas there are different stakeholders and different socio-economic circumstances driving forest conversion (see Lecture Notes 1 & 2). But the biological effects of forest conversion, and the basic ecological principles involved apply in all sites and to all humid tropical forest zones, so these will be discussed first.

2. How does biodiversity respond to forest conversion?

2.1 What disappears when?

Individuals: if one tree, for example, is chopped down, the organisms living in it go; mobile ones can move to other individual trees. But what if a whole patch is cut or burned? Mobile organisms can find another patch. However, plants and trees are sessile. Some can regrow from stumps, others have to rely on seeds to regenerate. Loss of structurally-large individuals also has specific effects on the community and microclimate.

Populations: a patch of forest may just contain part of the population, so if a small patch is lost, the population left in the area may still be big enough to be self-sustaining. But if the whole habitat in that geographical area/locale is lost (e.g. a 6 000 ha oil palm plantation is established), then a whole population can disappear, and the species can become **LOCALLY** extinct.

But we don't even need to take such a drastic example. There may still be trees in the landscape, even small patches of forest. However, many tropical rainforest (tree) species occur with infrequent distribution e.g. there are many species, but very few individuals of that species in a given area (the population is very dispersed). So there

may not be any conspecifics near enough for them to be able to breed with (either because of the geographical distance, or because there are no mammal/insect dispersers left/able to reach them). So, because trees are long lived, they stay visible in the landscape; they look OK- but really they are the '*living dead*', because they have not been able to reproduce, and when they die that's it, the population has gone. So what you see is not what you'll have in another 50 years time.

A **species** goes extinct if all its populations in the world disappear. Although a number of spectacular species have become extinct due to human activities, the cumulative total so far is a small fraction of the species that exist on planet Earth. The number of species for which long term survival is no longer secured, however, is much larger. IUCN has estimated that 23% of all mammal species, 11% of all bird species and 14% of all plant species are currently threatened with extinction. Species with small geographical ranges are particularly vulnerable. Many species will disappear before they have been described by science. Does not knowing what we lose make the loss less dramatic?

2.2 General ecological principles

Fragmentation of forest patches

Why preserve one large patch of forest in one place? Why not just have smaller patches of forest all over the landscape? If they all add up to the same area, then it wouldn't make any difference would it? You would still have the same amount of species and biodiversity conserved wouldn't you?

NO, BECAUSE...

The number of species per unit area in small patches with an unfriendly 'edge' is less than in large ones that have more of a core area, away from the edge. This is reflected in species-area relationships (Box 2, Figure 4). As you decrease the forest patch size (area), you move towards and then down the steep part of the curve, and so the number of species drops dramatically. This relationship also illustrates clearly that for the first 50% of forest area that you lose, you lose X% of the species (Figure 4). But clearing the remaining 50% of the area you lose all the remaining 100-X% species.

What are the reasons behind the species-area relationship?

Extinction rates are higher in small patches (even if immigration rates are constant and habitat diversity is similar), because of their smaller population sizes. This relationship is not specific to forests, there are many examples and it is one of oldest known ecological principles e.g. species on islands (Rosenzweig, 1995). Why are extinction rates higher? The reasons are illustrated by these cases:

- large animals- the forest fragment may be too small physically to support them (e.g. there may not be enough fruit trees for monkeys or prey for jaguars). Also, large animals often have a large range, and need a big area.
- forest interior species/specialists- these like the dark and the humidity; they need the forest interior microclimate to survive.
- edge effects- the smaller the patch, the greater the edge in relation to the area. So there is a greater proportion of the more open habitat and relatively less of the forest interior conditions. Also, there is a greater possibility of predation or hunting because of the easier access.

Box 2. Species-area relationships

As one samples biodiversity over larger and larger areas of a particular ecosystem (e.g. the increasing box size in Figure 5), the number of additional species observed will increase, but at a decreasing rate (Figure 4). Some of the species found in each new sample plot already will have been encountered in previous plots; only a fraction will be observed for the first time and this fraction tends to decline as the sample size increases.

Eventually the curve levels off, meaning that even if you increase the area that you study greatly, you are unlikely to find any new species. Thus, this is the point where you can be pretty sure that the area you have covered contains all the species that are present in the area.

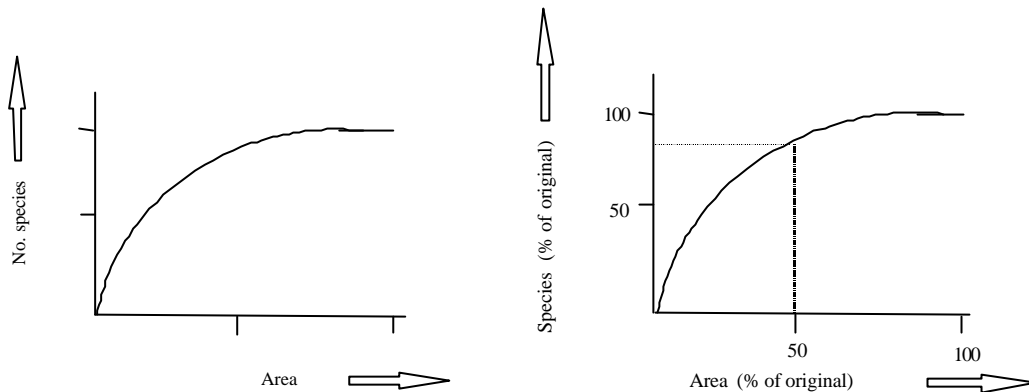


Figure 4. Examples of species-area curves (NB curves have different shapes in different situations, and curves obtained by sampling are not necessarily the same shape as those for long-term survival)

If, however, there are links (corridors) between the fragments of forest, and individuals could move between them, then the area of habitat available to a population would effectively increase. Also, this would allow two separate populations in different patches to interbreed and so avoid problems of in-breeding and genetic ‘bottlenecks’ - keeping a variety of genes in the population, which may be necessary (over evolutionary time) for the species to adapt to future environmental change. Although individual plants obviously cannot move between forest fragments, animals dispersing their seeds can, and vegetation in corridors may be able to provide suitable conditions for seed germination, and so, over time, reduce the reproductive isolation between individuals.

Thus, the landscape mosaic in which forest patches are situated is very important. Various land covers differ in their potential to be barriers or ‘corridors’, or even in providing enough cover for animals to hunt or forage (without necessarily living there). The abilities of different agricultural land cover types to support biodiversity are considered further in Section 3, along with the implications for designing land-use mosaics to ensure maximum biodiversity (Section 4.4).

Box 2. Species-area relationships (Continued)

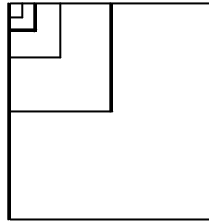


Figure 5. To construct a species-area curve, the cumulative number of species must be counted over increasingly large areas, i.e. the total for each box (plot) is graphed against the area of that box.

Alternatively, species-area curves can be constructed by adding together areas of randomly-chosen sub-units (plots). There are software packages available which will draw curves of average cumulative species numbers, after randomising the sequence of plots a number of times (e.g. the programme EstimateS; Colwell, 1997).

One type of species-area relationship can be described by the equation:

$$S = CA^z$$

Where S is the no. of species, A is the area and C and z are fitted constants which are specific to a data set.

The relationship is often presented in linear form

$\log_{10} S = \log_{10} C + z \log_{10} A$. – this gives a straight line relationship.

2.3 So what happens if you lose biodiversity?

Ecosystem stability and function

Ecosystem stability can be thought of as having two components: resistance and resilience. Resistance is the ‘shock-absorbing’ capacity of an ecosystem- its ability to stay as it is in the face of some environmental change. Resilience is the ability of an ecosystem to ‘bounce back’ after it has been severely disturbed. Loss of biodiversity (loss of species) is assumed to affect both of these things. There are lots of theories, but little hard data! The three main hypotheses were summarised by Vandermeer *et al.*, 1998 (Box 3).

There certainly are cases from agriculture where great simplification of systems has led to severe outbreaks of pests, as the natural enemies of these have disappeared. High levels of agrobiodiversity may make this less likely. However, the insect populations in natural forests are far from stable, and there is always a chance that an insect can ‘discover’ a new way of breaking through the chemical defence of its host plant. It is often believed that below-ground biodiversity may have an important role to play in maintaining ecosystem function (this is considered further in Lecture Note 6).

Box 3. Hypotheses: biodiversity and ecosystem function (Vandermeer *et al.*, 1998)

1. Biodiversity **enhances** ecosystem function because different species or genotypes perform slightly different functions (have different niches) and all together function better than a subset.
2. Biodiversity is **neutral to negative** in that there are many more species than there are ecosystem functions and thus redundancy is built into the system.
3. Biodiversity **enhances** ecosystem function on a **long-term basis** because those components that appear redundant at one point in time become important when some environmental change occurs, which is to say the apparently redundant species are in fact ecosystem buffers.

HOWEVER, a corollary of the redundancy hypothesis is that one species is likely to be the most efficient at performing the particular ecosystem 'task', and all the other members of the redundant set are at least slightly less efficient, suggesting that biodiversity should actually be decreased so as to give preference to the best species...

So, CAUTION is needed when considering the concepts of 'keystone species' and redundancy. We know far too little about processes of ecosystem function to be able to say with certainty that a particular species has no value and is 'redundant'. If it were possible to say that some species are more important than others, in terms of their functional 'value', then some economists would no doubt be very pleased. Unfortunately, however, most biologists take an egalitarian view regarding the relative value of species!

2.4 So what are the issues if you convert forest to agriculture?

- How good is the new type of land cover for biodiversity? Is it structurally complex (like a forest, with many niches for arboreal species/understorey species) or structurally simple (like a pasture, which only consists of low-growing plants)?
- Does the type of agricultural land cover present after forest conversion affect the future options for that piece of land? Is it an irreversible change, i.e. because of the extent or the type of the cropping system, are you unlikely to prevent forest ever regenerating on that site?
- How does forest conversion affect the types of species which make up the biodiversity of that area? Do you lose forest species but gain weedy/pioneer ones? Does overall 'biodiversity' increase if you are measuring species richness? Over the whole area of the landscape (i.e. at the '**landscape level**'), biodiversity (in terms of the number of species) will probably increase with forest conversion, as you'll still have some of the old forest species, but in some patches there may be new light demanding species, or those stimulated to germinate after fire, for example. The forest species that are lost as a result of the disturbance are probably the most sensitive in that respect and arguably the most important in terms of the value of biodiversity.
- How are the new types of land cover arranged spatially, and in what proportion? What about the uniformity/diversity of potential habitat patches? If the entire landscape is monoculture oil palm, then the potential value for biodiversity is very different from a landscape comprising a mixture of different-aged smallholder systems.

This issue of spatial arrangement of land cover types brings us to the ‘segregate/integrate’ issue (below). This can be thought of as a conceptual framework on which we can base our discussion of the biodiversity of various land cover types.

Segregate or integrate?

The theoretical ‘segregate’ option (Figure 6B, upper) keeps agriculture and forest completely separate. The forest remains untouched (with high biodiversity), and agriculture is intensive, using monocultures e.g. oil palm, rubber and foodcrops and high intensities of inputs (very low biodiversity).

The theoretical ‘integrate’ option (Figure 6B, lower) incorporates/conserves as much biodiversity as possible in the farming systems within the landscape e.g. in complex cocoa agroforests, or multistrata mixed treecrop systems (including Brazil nut, mahogany, peach palm etc.) (intermediate biodiversity). This subject is discussed in detail, and with many case studies, by McNeely and Scherr (2001).

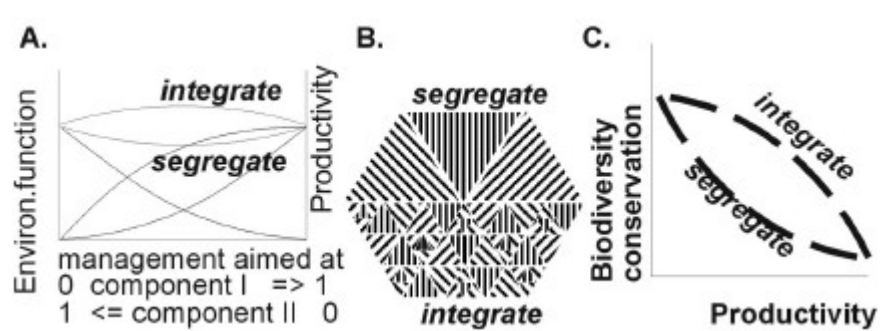


Figure 6. **A.** If management of a land unit is aimed at a specific function, other functions may still be obtained from the same piece of land, but probably to a lesser degree; the total ‘function’ value can be convex, concave or a straight line, depending on the detailed interactions. **B.** Segregated or integrated patterns of land cover types may include the same components and total diversity (i.e. total area of each land-cover type, here represented by different shading patterns) but differ significantly in interactions and local diversity. **C.** General theory suggests that if the trade-off curve between the two functions is convex, integrated solutions may be superior, if the trade-off curve is concave, a spatial segregation is probably more effective.

The consequences for biodiversity of the segregate-integrate choices (Table 1) are again of a mixed nature. On the agricultural side of a ‘segregate’ landscape the main issues of agrobiodiversity may focus on the prevention or control of outbreaks of pests and diseases.

Table 1. Summarising biodiversity conclusions for segregated or integrated landscapes (see also Figure 5 in Lecture Note 1)

Segregated - Agriculture	Segregated - Natural forest	Segregated landscape with Ag + Forest	Integrated - Agroforestry mosaic
Agrobiodiversity is mainly relevant for pest and weed control	Forest reserves are large; this is desirable for biodiversity conservation as they reduce edge and island effects	Sharp (fenced) boundary reduces conflict but increases island effect	Agrobiodiversity with direct value + which provides survival options for a certain proportion of the forest flora & fauna

Biodiversity assessments of agroforests as 'integrated' systems were started in Sumatra in the early 1990s. Figure 7 summarises some of the early results for plants (7A; Michon and de Foresta, 1995) and birds (Figures 7B and 7C; Thiollay 1995). Plant diversity along a standardized transect line was found to be lower in a rubber agroforest than in a natural forest nearby, but in the various plant categories represented here, the agroforest plot contained 50-100% of the number of species of the natural forest. Bird diversity in the agroforest was found to be reduced to about 60 percent of that in primary forest (Figure 7B), with a shift from typical forest birds (including ground dwellers) to birds of more open vegetation (Figure 7C). Data such as these can be used to argue either way in the segregate-integrate debate; agroforests are no substitute for conservation of natural forests, as many specific forest components may be lost, but at the same time their diversity is much higher than that of intensively managed tree crop plantations that represent the 'segregate' option.

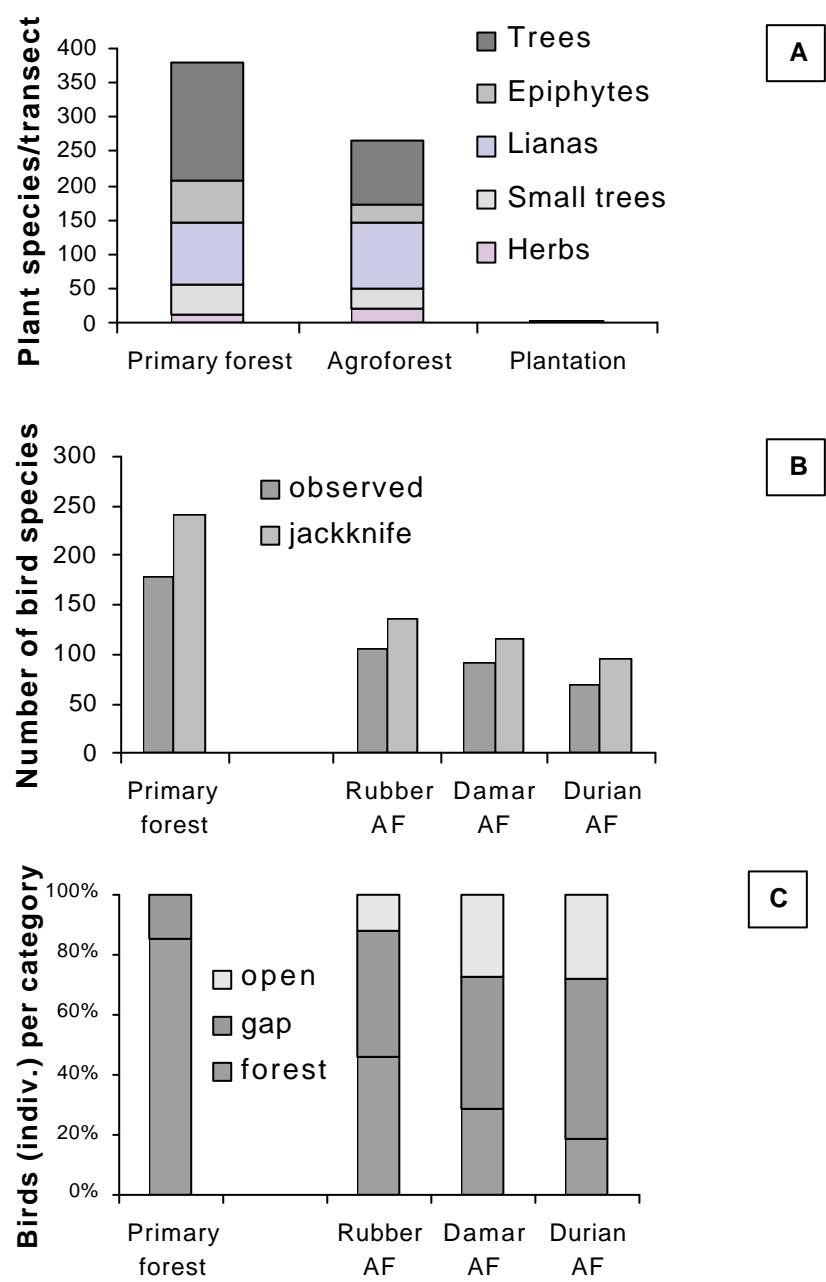


Figure 7. Plot-level comparisons of: A) numbers of higher plant species encountered in one 100 m line transect in three land use types: natural forest, rubber agroforest and monoculture rubber

plantation (Michon and de Foresta, 1995); B) numbers of bird species in natural forest and three types of agroforest (Thiollay, 1995; from direct observation and from extrapolation using the 'jackknife' method*); C) numbers of individual birds in natural forest and three types of agroforest (Thiollay, 1995), categorised according to the species' habitat preferences of 'forest', 'gap' and 'open land'.

* The 'jack-knife' technique is often used to improve the estimate of a diversity statistic (see Magurran, 1988 for full details).

3. How can we compare the biodiversity of different land cover types?

3.1 Sampling: the ASB project-where, when and how?

For the 'Alternatives to Slash and Burn' project ('ASB'), the question of 'where' to sample was defined by the land cover types under study in the different continents (i.e. those described in Lecture Note 2). The methodology for choosing plots can be found in Gillison (2000b). To get results that were comparable across all the benchmark sites (which was the main aim of the ASB project) standard methodologies were used in every place. These studies were complemented by a very detailed baseline study in Indonesia, where a multi-disciplinary team of various experts worked together, sampling in the same plots at the same time. Thus, detailed information on vegetation, birds, insects, soil animals and canopy dwelling species was obtained (Gillison, 2000a).

NB. A useful reference, which considers both theoretical and practical aspects of sampling for research on biodiversity, as well as the use of various diversity indices, is Magurran (1988).

3.2 What can we measure at plot level?

3.2.1 Species richness- how many species?

This is the simplest measure of biodiversity - the presence or absence of species in a plot, and the total numbers of species for a particular group. It is impossible, however, to count every species present in a plot; the sheer number of species is too high, and you may never be sure that you have managed to find everything that is there. One cubic centimetre of soil contains a wealth of microbes that would take more than a lifetime to fully characterise.

So, which groups of organisms should you sample? This is an ongoing debate! Plants are important, as they are the 'primary producers' in the environment, and animals depend on them for food, and also for shelter, sites for reproduction etc. Vascular plant species are relatively well known (e.g. compared with the number of undescribed species of fungi, or canopy beetles that you might encounter). Certain animal groups (e.g. birds and butterflies) have been well studied and appear to be popularly used as 'indicator' taxa. However, the choice of these animals has usually been due to practical considerations like their visibility (and audibility in the case of birds), and the fact that their taxonomy and biology has been relatively well studied, rather than their value in telling us about the biodiversity of a site!

When counting the number of species in a plot, whatever group has been chosen, it is important to be aware that some individuals may be just passing through rather than actually resident in the plot. Therefore we must take care if we try to draw conclusions about the ability of a certain land cover type to support viable populations of a particular species. Also, beware of bias: in different land cover types, the visibility of individuals

may be different (e.g. you may be able to see and hear far more birds in an open Imperata grassland, than in a densely vegetated complex agroforestry system).

In ASB, the minimum standard data collected in all sites was the number of plant species per standard plot (40 m x 5 m). The type of data that we get is found in Table 2, from which we can make comparisons of the numbers of species found in equivalent types of forest and forest-derived land covers across three continents.

Table 2. Plant species richness in various land cover types in three ASB Benchmark sites (number of plant species/standard plot of 200 m²).

Land cover	Brazil	Cameroon	Indonesia
Natural Forests	63	103	111
Managed Forests	-	-	100
Logged Forests	66	93	108
Extensive Agroforests	47	71	112
Intensive Agroforests	-	63	66
Simple Tree Systems	25	40	30
Long Fallow Systems	36	54	43
Short Fallow Systems	26	14	39
Continuous annual crops	33	51	15
Pasture/grasslands	23	25	11
Intensive Pasture	12	-	-

Questions

- Which are the three land cover types that have the lowest biodiversity (in terms of plant species richness)?
- Of the agricultural systems, which have the highest biodiversity (in terms of plant species richness)?
- Which of the fallow systems has the highest biodiversity (plant species richness)? Why could this be?
- What could explain the higher species richness in the logged forest than in the natural forest that we see in the case of Brazil?

3.2.2 Functional diversity – how many functional types?

1. Why do you need another measure of biodiversity besides species?

Other than the difficulty in identifying species, how do you compare the biodiversity of different sites? You just have a list of names! What does the total number tell us anyway? That the site may be very heterogeneous? Research shows that using species alone doesn't give you a strong capacity to predict biodiversity.

So what about looking at the diversity of plants and animals in terms of how they have adapted to their environment: a FUNCTIONAL classification? Not just 'who' they are (their name) but 'what' they do, and 'how' they do it.

For example, classification of organisms that live below ground can be based on groups of animals that perform certain functions in an ecosystem, for example decomposition of fallen leaves etc. (this is considered in Lecture Note 6). Birds can be classified into

functional groups (or ‘guilds’) by, for example, their eating habits. Species would fall into certain ‘diet guilds’ depending on what they ate (e.g. fruit, nectar, insects or seeds), or into certain ‘foraging guilds’, depending on where they ate (e.g. in the tree canopy, in the understorey vegetation, on the tree trunks, or on the ground). You could then compare different land cover types according to the percentage of species falling into each guild. For example, it was found that the percentage of bird species in the tree canopy feeding guild was lower in industrial tree plantations than in complex agroforests (Jepson and Djarwadi, in Gillison, 2000a) and this was probably due to the different structure of the vegetation.

Plants can also be classified into functional groups. ‘Adaptive traits’ i.e. characteristics that plants have developed to help them cope with, or exploit the conditions in a particular environment, are likely to be similar in that TYPE of environment wherever it may occur, e.g. in S.E. Asia, or the Congo basin. So, plants of different functional types do the same job/fill the same type of niche in the forests of the Amazon as in the forests of Cameroon, even though the actual species are different. For example, in S. America, Africa and Asia, the first trees to grow in an open patch of land often have very large leaves, even though they belong to different plant families. This means that one would be able to compare the functional types of plants, across continents, in different parts of the lowland tropics. This was done in the ASB project, classifying plants on the basis of their **adaptive characteristics** or ‘**Plant Functional Attributes**’ (‘PFAs’) (Box 4). Specific combinations of these PFAs are called ‘Plant Functional Types’ (‘PFTs’ or ‘modi’).

NB The following sections present new results from the ASB project regarding the use of PFAs and PFTs as indicators of the biodiversity of different vegetation types and animal groups. It must be stressed, however, that although the methodology is highly innovative and has produced some exciting results, especially when comparing biodiversity across continents, it is not *currently* a standard text-book approach.

Box 4. Examples of ‘Plant Functional Attributes’ (‘PFAs’) and ‘Plant Functional Types’ (‘PFTs’ or ‘modi’).

PFAs are based on:

- leaf size class (9 classes)
- leaf inclination (4 categories)
- leaf chlorotype (5 categories)
- leaf morphotype (6 categories)
- plant life-form (5 categories)

For a certain plant, one category is chosen from each of the characteristics (bullet points) above. Each category is represented by a two-letter code. All the relevant two letter codes for the plant are then strung together to give a ‘Plant Functional Type’ (PFT or ‘modus’) e.g. a rubber tree (*Hevea brasiliensis*) found in one plot in Indonesia was: no-ve-do-ct-ph. The next rubber tree might belong to a different PFT, and the next tree of a different species might belong to the same PFT.

Further details can be found in Gillison (2000b), Gillison and Carpenter (1997) and Vanclay *et al.* (1997).

2. How does the number of plant PFTs relate to the number of plant species?

For 21 sites in Cameroon, which encompassed land cover types from forest through agroforests to annual crop fields, a direct (linear) relationship was found, where the number of plant PFTs could account for 81% of the variation in species numbers between the plots (Figure 8). NB The 'R-squared' value (abbreviated to r^2 or R-sq) indicates how strong the relationship between the two factors is (the higher the r^2 value, the stronger the relationship).

In a similar study of 28 sites in Thailand, the relationship was even stronger; 87% of the variation was accounted for by plant PFTs. So it looks as though a very quick survey, just counting PFTs could be very useful in predicting how much plant diversity there is in a plot.

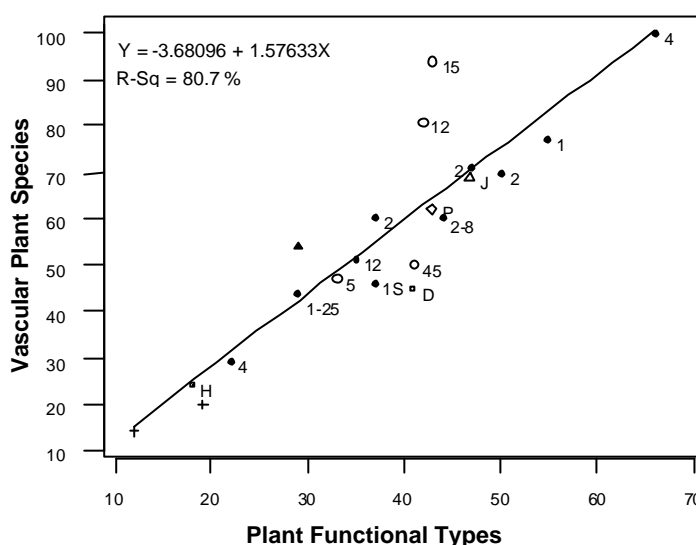


Figure 8. Relationship between the numbers of vascular plant species and PFTs along a gradient of land cover types in Cameroon.

3. How well do the numbers of plant PFTs predict the numbers of animals, or of the total amount of carbon in a plot?

Taking termites as an example, the relationship between number of termite species and numbers of plant functional types is not as strong ($r^2=47\%$) as if we used the number of actual plant species ($r^2=70\%$) (Figure 9b and a). Although all land cover types contain termites (so the functional group is present), the number of species declines rapidly when one moves from a forest to an Imperata grassland. However, the strongest relationship between the number of termite species and the characteristics of the vegetation is given by a ratio of the two plant measures: the number of species divided by the number of PFTs (modi). This relationship then explains 97% of the variation in the data!

This type of result was not only seen for termites. In Indonesia, over 11 plots, the number of bird species was more strongly related to the plant species/modi ratio ($r^2=69\%$), than to the number of plant species or the number of PFTs alone. In the same plots, the number of species of Collembola (tiny insects known as 'springtails') was also more strongly related to the plant species/modi ratio ($r^2=81\%$), than to the number of plant species or to the number of PFTs when used individually.

What was the reason for investigating the use of this species/modi ratio? In itself, the ratio could be seen as a measure of biodiversity, as it tells you how many species fall

into each of the 'functional types' which are equivalent to what ecologists would call 'niches'. So, the greater the number of species per 'niche', the greater the number of species 'waiting in the wings' (as in point 3, Box 3), and the greater the diversity. So, it seems as if this ratio does have some ecological basis, and the relationships found would thus seem to make ecological sense. However, it must be stressed that these are still only **ideas**, based on some interesting new results from the field. Whether or not this plant species/modi ratio could be used in the future to **predict** the species richness of certain animal groups remains to be seen. This hypothesis would require rigorous testing using new, independent data sets.

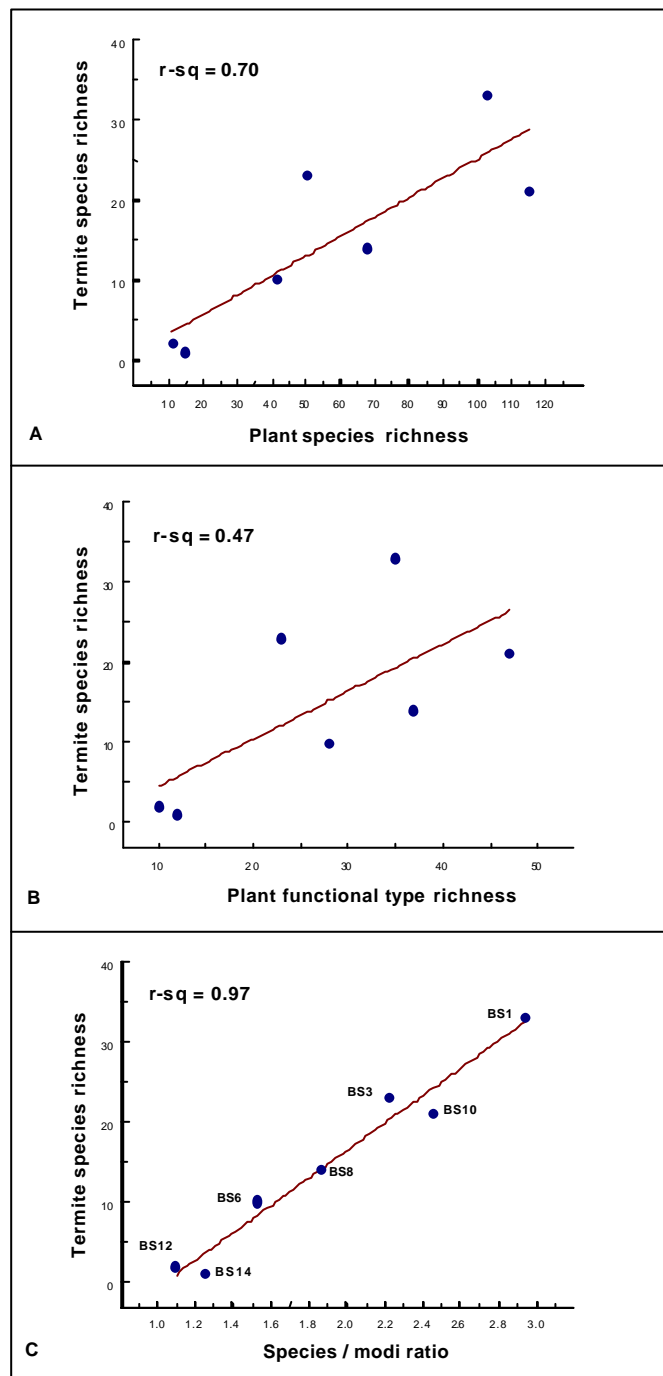


Figure 9. Comparative relationship between Termite species richness against: (A) Plant species richness, (B) Plant functional types richness, and (C) Species/modi ratios along a gradient of land use types, Jambi, Lowland Sumatra, Indonesia.

The importance of assessing vegetation in terms of carbon stocks has been discussed in Lecture Note 4. It was found that above-ground C stocks were also more strongly related to the species/modi ratio ($r^2=81\%$), than when compared with either separately (Figure 10). Thus, to get the strongest possible relationship between the diversity of the vegetation and the diversity of some animal groups (or even the carbon stocks present) you would need to be able to calculate the species/modi ratio. In that case, you would still need to be able to count the number of species accurately, and so would probably still need a botanist in your survey team.

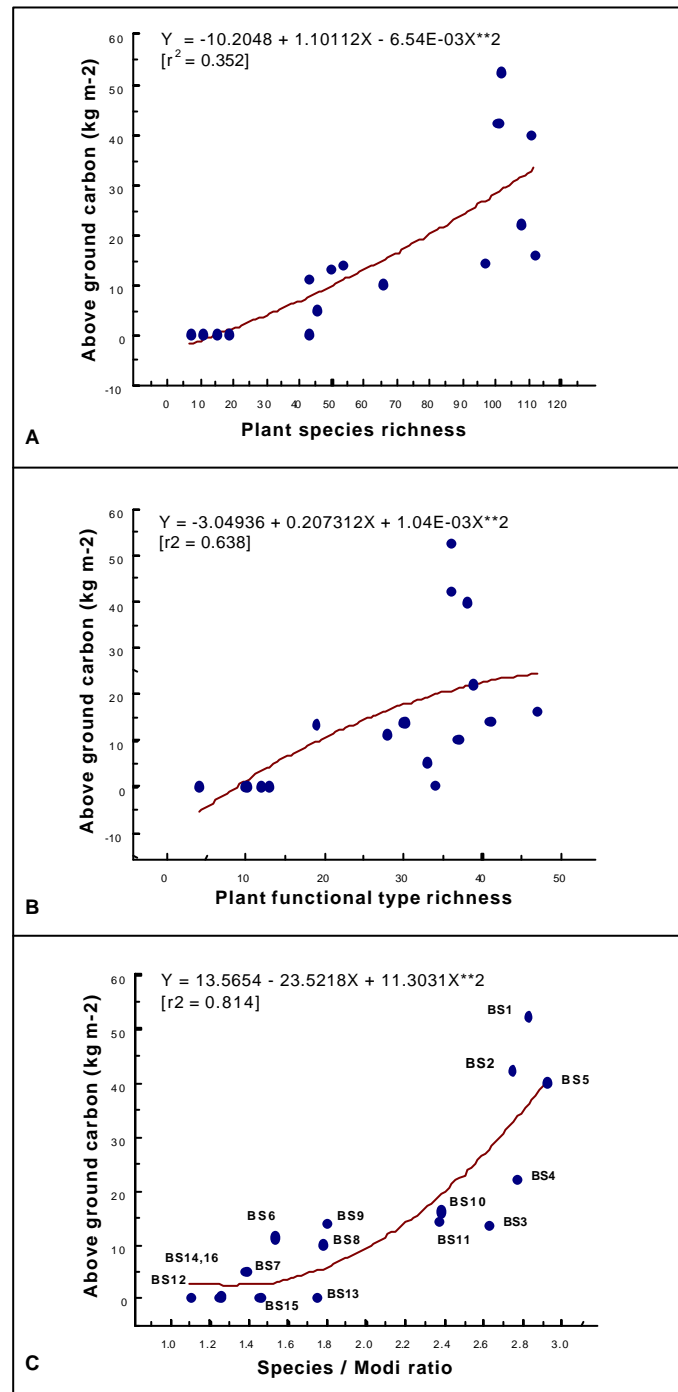


Figure 10. Comparative relationship between above-ground carbon stocks against: (A) Plant species richness, (B) Plant functional types richness, and (C) Species/modi ratios along a gradient of land use types, Jambi, Lowland Sumatra, Indonesia.

3.3.3 Similarity to forest ('V' index)

The 'V' Index, used in the ASB project (Gillison, 2000b; Box 5) is a vegetation index which is calculated using a set of plant-based variables that are known to be highly correlated with land-cover type, plant and animal richness and soil nutrient availability. It was used specifically in the ASB studies as a potential indicator of land use impact on biodiversity and profitability, and is based on key vegetation structural, plant taxonomic and functional types (PFTs). Again, it must be stressed that this is a new, quite sophisticated method, not in general use in biodiversity surveys. However, details are presented here to illustrate the similarities and differences among the land use types that were studied in the ASB project.

The 'V' index is not a direct measure of biodiversity, but more a habitat or site characterisation indicator. However, it does include vegetation structure (which is important in determining biodiversity), and there are close correspondences with plant and animal biodiversity.

Box 5. Deriving the 'V' Index

The basic measurements used to calculate the 'V' index are:

- mean canopy height,
- basal area ($\text{m}^2 \text{ha}^{-1}$),
- total number of vascular plant species,
- total number of PFTs or functional modi
- the ratio of plant species richness to PFT richness (species/modi ratio)

The index is calculated using a technique called 'multi-dimensional scaling', and the results are scaled between 0.1 and 1, with 1 being the value for the forest. So each value of the index, for each land cover in a particular geographical area, indicates how much that land cover differs from the local natural forest that serves as a reference point.

You need access to just about any principal coordinate analysis (ordination) program for which you can specify a single vector solution. The eigenvector scores are then simply ranked 1-10, with the highest scores matched usually with the highest richness values (typically rainforest) across a series of plots. And that's it. The 'V' Index is a purely relative, singular ranking measure for the sites used in a particular study or group of studies in one location - it has no generic value *per se* and it is not a biodiversity index.

The 'V' index was calculated for a range of land cover types (Lecture Note 2) in Cameroon, Indonesia and Brazil, as part of the ASB project (Figures 11, 12 and 13). The index corresponds closely with observed impacts of land use on biodiversity, crop production and associated 'time since opening' (e.g. clearing for cropping or harvesting). For example:

- In all sites, the 'V' index tends to be highest for primary forest, then decreases through secondary and logged-over forests, then complex agroforestry systems, tree plantations and fallow systems and is lowest in annual foodcrop systems, grasslands and pasture.

Complex agroforestry systems based on economically valuable tree crops have a much greater similarity to forest than monoculture plantations of the same tree crops: compare jungle cocoa and plantation cocoa in Cameroon (Figure 11), and jungle rubber and plantation rubber in Indonesia (Figure 12).

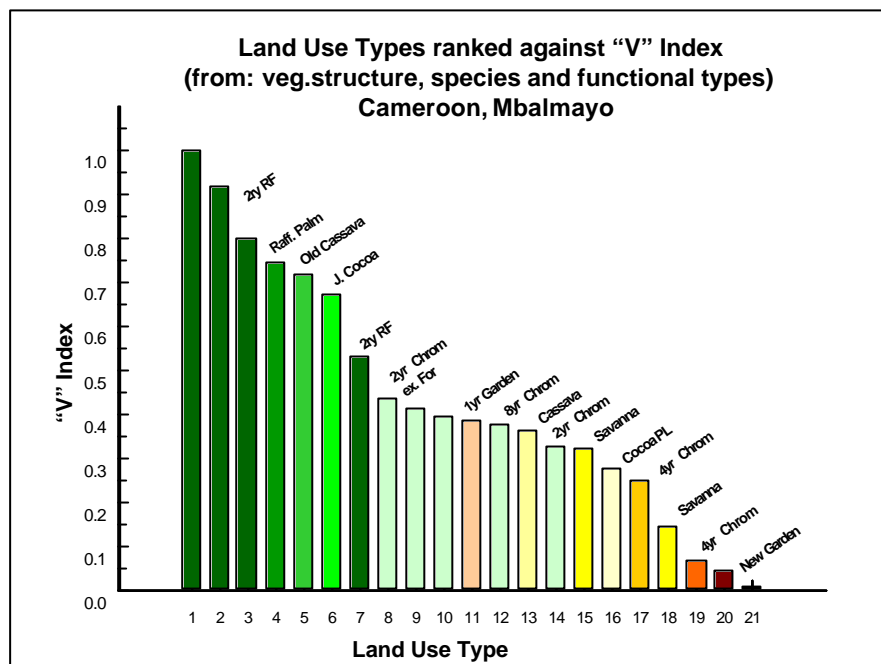


Figure 11. Land-cover types ranked against ‘V’ Index in Cameroon: RF= Rainforest; Raff. palm= Raffia palm; J. cocoa= jungle cocoa; Chrom= *Chromolaena odorata* (fallow); Cocoa PL= cocoa plantation (monoculture). See Lecture Note 2 for descriptions of the land-cover types.

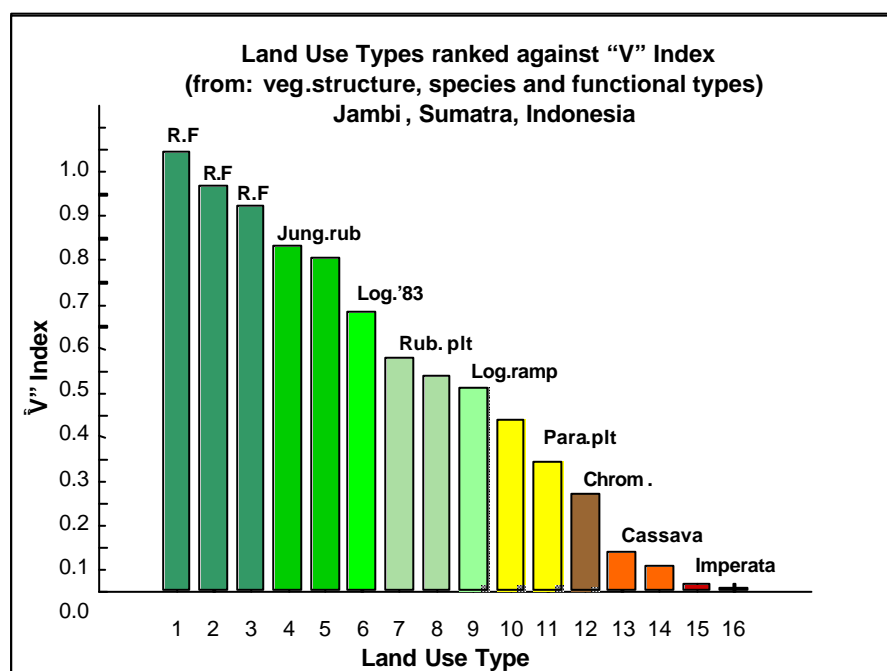


Figure 12. Land-cover types ranked against ‘V’ Index in Indonesia: RF= Rainforest; Jung.rub= jungle rubber; Log.’83= Logged-over rainforest (1983); Rub plt.= Rubber plantation; Log. ramp= Logging ramp; Para. plt= *Paraserianthes falcataria* plantation; Chrom.= *Chromolaena odorata*. See Lecture Note 2 for descriptions of the land-cover types.

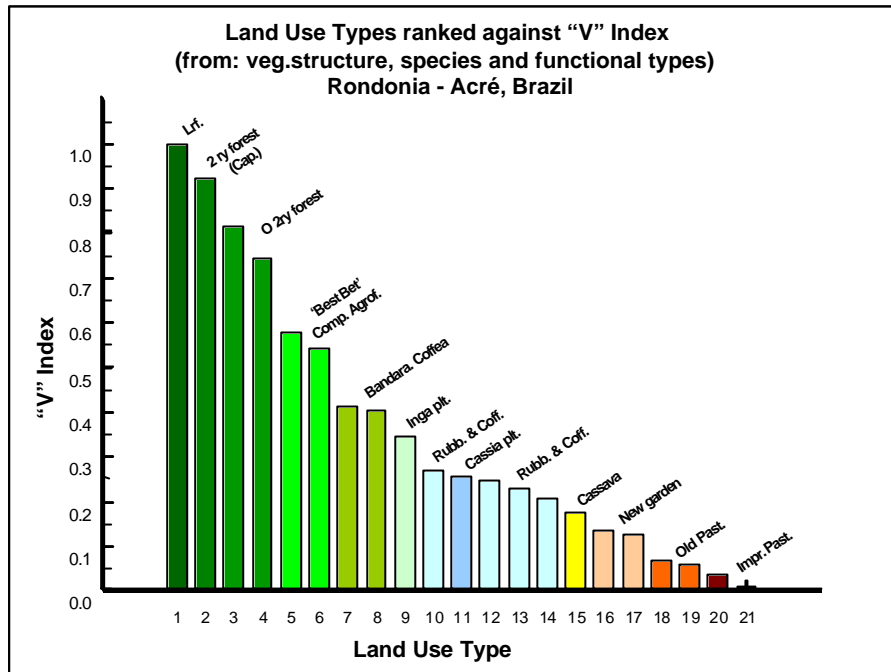


Figure 13. Land-cover types ranked against 'V' Index in Brazil: Lrf= Logged rainforest; Comp. Agrof.= complex agroforestry system; Rubb.&Coff.= Rubber & coffee; Impr. Past= Improved pasture. See Lecture Note 2 for descriptions of the land-cover types

Summary

The 'V' Index is a measure of the complexity of the vegetation and is important because, in theory, the greater the structural complexity, the greater the number of ecological niches available for plants and animals, and so the greater is the potential biodiversity.

The most important measurements necessary to characterise a site in terms of its biodiversity are:

- physical site characteristics (soils, slope etc.)
- vegetation structure
- taxa (no. of species present)
- PFAs (no. of functional types present)
- Cover-abundance of understorey vegetation.

4. How can we scale up from the PLOT to the LANDSCAPE LEVEL?

4.1 Extrapolation

The previous section concentrated on measurements of biodiversity at the PLOT level. Unfortunately, however, extrapolating results from this level to larger scales (such as the LANDSCAPE level) is not straightforward. Diversity measures can be expressed per unit area and per unit time, but can not easily be converted to other units of area or extrapolated in time. For example:

- Although survey data can show which plants and animals are currently present in a given sampling area, the really important question of **how many of these species would survive over a time frame of X years**, can not be directly assessed (Rosenzweig, 1995).
- **You can't add biodiversity values across plots.** If you have 10 species in one plot and 10 in two others, then you cannot say that in the combined area of two plots you will have a total of 20 species, and in three plots a total of 30 species. In the latter case, the real number of species may be anywhere between 10 and 30. This is because of species overlap- the same species may be found in a number of plots, and so the number of species present doesn't increase linearly with area. The shape of this 'species-area relationship' is actually curved (see Box 2). This also explains why you cannot compare diversities of two different sized plots by just dividing the number of species by the area of each plot.

These issues are illustrated in Figure 14, which shows that the total biodiversity within a landscape (*gamma diversity*) is a function of local or 'within habitat diversity' (*alpha diversity*) and differences in species composition or 'turnover' of species, between habitats or localities (*beta diversity*).

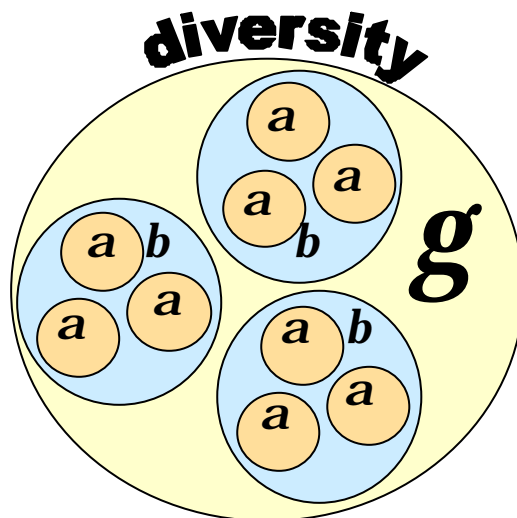


Figure 14. Biodiversity at landscape and at plot level.

Biodiversity cannot be directly added across these scales: subhabitats of high internal (*alpha*) diversity can comprise a landscape of limited total (*gamma*) diversity if all the subhabitats are similar (low *beta* diversity), whereas if a landscape is made up of widely differing habitats (high *beta* diversity), all of fairly low alpha diversity, the gamma biodiversity may be fairly high (Giller *et al.*, 1997).

4.2 The case of different species-area curves

To complicate matters further, scaling relations (the shape of the species-area curve) may differ between types of vegetation (Box 6, Figure 15), or between types of species. This variation in the shape of the curves may be due to fundamental differences in the ecology of the species or vegetation type. Therefore, just looking at species richness per plot (for plots of the same size) in two different land covers will allow us to compare the two plots on that scale **ONLY**. We **CANNOT** assume that the comparison will show the same results at different scales. This is a very important point, as even in recent literature, data from plot level studies have been used wrongly in drawing conclusions about the landscape scale.

Box 6. Species area curves from ASB studies in Cameroon

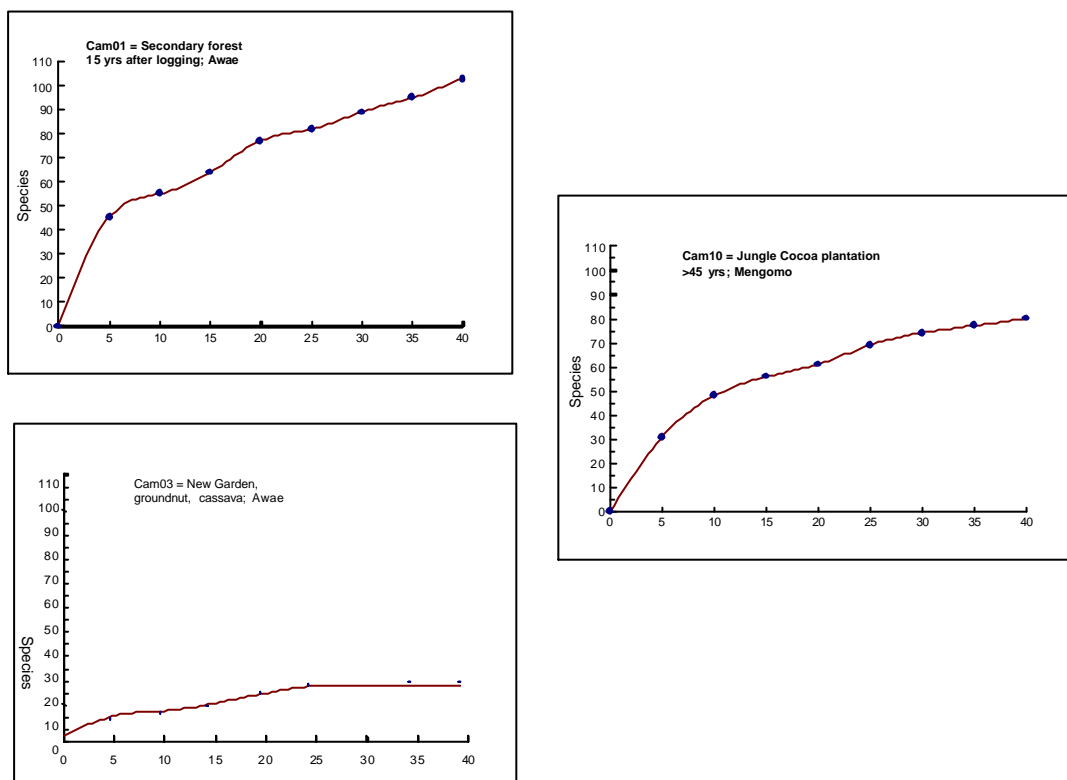


Figure 15. Different-shaped species area curves for three land cover types in Cameroon: secondary forest, a jungle cocoa garden and an annual food crop field. The points refer to the cumulative number of species that were found in successive 5 m x 5 m subplots within a 40 m x 5 m plot.

Note that the curve for the secondary forest has not levelled off, even after sampling the last subplot within the main plot.

QUESTION What does this tell us about the sampling effort needed to characterise the biodiversity of this land cover type?

Example 1: tree species diversity on farms

An interesting research topic could be an investigation of the proportion of fruit and medicinal tree species on farms. This sounds like a very straightforward thing to do. We could count the number of species falling into each group on a farm, and divide by the total number of trees on the farm. We could repeat this for a number of farms, and

take an average value across all farms. Simple? Yes, IF the scaling relations over a number of farms are the same for different groups of tree species.

Recent research, however, on the diversity of trees on farms in Kenya (Kindt *et al.*, in prep.) has shown that scaling relations differ for different groups of tree species; this has important implications for how you might report ‘the *proportion* of fruit and medicinal tree species on Kenyan farms’. The Kenyan research results showed that:

- construction of species-area curves for these two groups showed very great differences in the slopes and shapes of the two curves;
- with increasing numbers of farms, the number of fruit tree species increased rapidly, then levelled off when few or no new fruit tree species were encountered (Figure 16);
- for the group of trees that were used for medicinal purposes, the curve was less steep at first, but at very large numbers of farms (at the right hand side of the graph) the curve was still rising. This was because the total number of species that could potentially be used for medicine was larger, but they occurred much less frequently in the landscape than the fruit trees. This probably reflected the lower management intensity accorded to medicinal species by farmers, as they were not as highly valued as fruit trees (i.e. there is a real reason behind this pattern).

The two curves are shown in Figure 16; Table 3, below, shows the data on which the species curves are based, and also the proportions of fruit tree species (relative to the total number of species found).

QUESTION: How does the proportion of fruit tree species change when your sample size (number of farms) increases? How does this affect your perception of diversity at the plot (one farm) level, and at the landscape (200 farm) level?

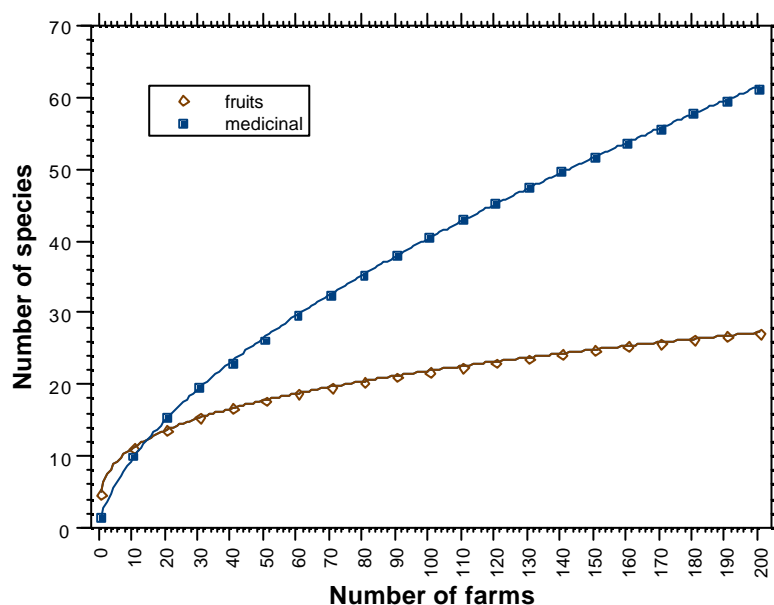


Figure 16. Cumulative number of fruit and medicinal tree species encountered with increasing number of farms studied (Kindt *et al.*, in prep.).

Table 3. Data on numbers and proportions of fruit tree and medicinal tree species on farms (Kindt *et al.*, in prep.).

No. of farms surveyed	No. of fruit tree species	No. of medicinal tree species	Total no. of species	% Fruit tree species
1	5	1	6	83
10	11	10	21	52
100	22	40	62	35
200	26	61	87	30

Example 2: rubber agroforests

A study of plant diversity in rubber agroforests (see Lecture Note 2 for a description of the system) showed that local species richness was at least half that of a natural forest, when a 40 m line transect was used in each area (Gouyon *et al.*, 1993). This does not mean, however, that the same relationship would hold if you compared 1 ha of rubber agroforests with 1 ha of natural forest: the agroforests may not even contain (let alone conserve) half of the forest species at that scale. Comparisons at a larger scale again (e.g. the level of a province) would be even more uncertain. This could be because the 50% of forest species found in the jungle rubber are ‘generalists’, which occur in forests throughout the province, whereas the forest species not present in the jungle rubber are local specialists, with a different diversity/scale relationship. This issue was further investigated by Beukema (in press) see Box 7.

Box 7. Scaling relations and fern biodiversity (source: Beukema, in press)

To compare the biodiversity of ferns in primary forest with that in rubber agroforests (‘jungle rubber’) and in monoculture rubber (‘plantations’), species richness of terrestrial ferns was measured in standard sized plots in the three land cover types.

CASE 1 ALL FERN SPECIES

The results showed that:

- The **average species richness per plot** was not significantly different between the forest, jungle rubber and plantations (values were 9.4, 11.7 and 11.9 respectively).

HOWEVER...

- The **species-area curves WERE different** (the slope of the curve for jungle rubber was significantly higher than the slopes of the other two land covers).
- This means that for the ferns in jungle rubber, **the scaling relations were different** from those of ferns in the other land cover types. This was probably due to a greater diversity between plots of jungle rubber (*beta*-diversity); as the area sampled increased, the number of new species encountered in jungle rubber was greater than in the other land covers.

CONCLUSION

- Plot-level species-richness does not directly indicate the (relative) richness of a land cover type at the landscape scale.

Box 7. (Continued)

CASE 2 'FOREST-SPECIALIST' FERN SPECIES

Some fern species can be classified as 'forest-specialists' on the basis of their ecology (i.e. they are known to be forest-dwelling and require shade). For this group of 'forest-specialist' fern species only:

- there was a clear difference between land cover types in the average number of forest species per plot: 2 in plantations, 5 in jungle rubber and 8 in primary forest.

(This is very different to Case 1 (above) where there was no difference in the average number of species present.)

- the slope of the species-area curve for primary forest was significantly higher than that of jungle rubber, and the gap widened as area increased (Figure 17). Thus when we scale up from one plot to an area of 10 plots, there is an even bigger difference between species richness of land cover types: 10 species in plantations, 16 in jungle rubber and 26 in primary forest (Figure 17).

(So, again we see a difference in scaling relations between land cover types (as in Case 1), but for these 'forest-specialists', the between-plot variation in species composition of natural forests is much larger than that of rubber agroforests).

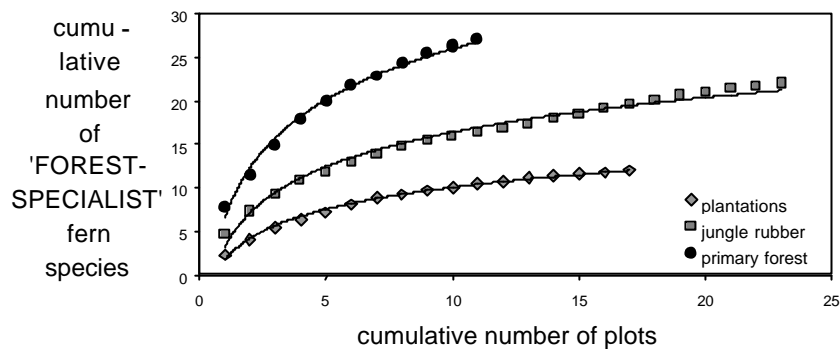


Figure 17. Species-area curves of 'forest species' of terrestrial pteridophytes in 0.16 ha plots in rubber plantations (lower line), jungle rubber (middle line) and primary forest (upper line), in Sumatra. Source: Beukema (in press).

CONCLUSIONS

- Just taking the average number of fern species in plots in different land cover types doesn't identify any differences in 'biodiversity' between primary forests and rubber plantations.
- Different scaling relationships occur in different land cover types.
- Different scaling relationships occur for different 'types' of species i.e. 'forest-specialists' as opposed to 'all' species in different land cover.

Question

From your knowledge about scaling issues in biodiversity, how would you critically assess the following statement if you came across it in a paper?
'complex, multistrata agroforests contain about 70% of all the regional pool of plant species'

So far, we have considered scaling up from species richness at plot level within ONE particular land cover type to the landscape level, where we looked at how the species varied (using species-area curves) between the plots in an entire landscape composed of that SAME land cover type.

A further level of comparison is necessary when we consider a landscape composed of DIFFERENT land cover types. We must look at the complementarity (species overlap) between these types of vegetation, i.e. by constructing species-area curves over a landscape area which includes a representative range of vegetation types. Only then can we get an idea of the biodiversity at the scale of an entire spatial mosaic.

This concept can be extended to try to picture biodiversity over the lifetime of an agricultural system. For example, imagine the 40 year 'life-cycle' of an imaginary (but 'typical') complex agroforestry system. The biodiversity in the first 2 years of the 40-year cycle may be typical of that found in a food crop system. The biodiversity in the next 5 years of the 40 for example, may be seen to be the same as that found in young secondary vegetation (of course there will be economically important tree crops in there as well). The biodiversity in the next 10 years could be assumed to be representative of intermediate aged secondary forest, and so forth. This system's 40 year lifecycle could be represented spatially, if you imagined a grid of 40 squares, each representing 1 year. Thus 2 of the 40 squares would have the low biodiversity seen in foodcrop systems, 5 of the 40 would have higher biodiversity corresponding to the young secondary vegetation, and so forth. Thus biodiversity values over time could be modelled using a spatial representation. This is illustrated in Lecture Note 2 (Figure 1), and is explored in detail in Lecture Note 11 which explains how you can use the 'Fallow' model to make your own simulations of biodiversity changes over time in relation to land use change.

4.3 Implications

- Plot-level studies alone cannot answer the question of how much biodiversity will be lost for each hectare of forest converted to another land use.
- Larger scale studies are necessary to understand how biodiversity varies across a landscape (i.e. between the plots studied).
- The number of species seen on a small study area (plot) can not tell us how much land is needed to conserve those species. If that piece of land were to be surrounded by land under different uses, the number and types of species could change dramatically. These species' long-term survival prospects depend on the extent of their habitat, but this is influenced by the pattern of land cover in the landscape.
- There is good cause for optimism, however, that the pattern of land cover in the landscape can be managed to ensure that species' habitat extent is maximised: strategically placed 'corridors' of vegetation, linking patches (or 'islands') of forest refugia have been found to be very effective for this. These issues are discussed further in Section 4.4 below.

4.4 Island biogeography and its application

Some ecological theory exists that addresses these issues of scale. The basic ideas go back to the study of islands of various sizes and various distances from the nearest continent. Species richness (of birds, for example) was found to be related to both these factors in a predictable pattern. The rate of local extinction is related to the size of an island, and the chances of recolonisation by the same (or different) species is related to the distance that must be travelled from the nearest source.

To some extent, patches of forest left in an otherwise agricultural landscape can be thought of as 'islands'. Efforts have been made to relate the richness in such forest patches to the distances to be travelled and the degree to which the 'sea' of agricultural land is hostile. In a study in Costa Rica, for example (Harvey, 2000), it was found that species richness of regenerating forest trees in agricultural windbreaks was very much higher when the windbreaks were directly connected to a patch of forest than when a clear gap (e.g. a field of annual crops) existed between the windbreak and the nearest forest. Thus there are clear benefits to be gained from strategic 'links' of perennial vegetation throughout the landscape mosaic.

5. Farmer management of biodiversity

5.1 'Planned' and 'associated' diversity

The 'planned diversity' in farmers' plots includes the mixture of crop species and economically important plants. Farmers' management decisions about this planned diversity, for example, involve choices regarding intercropping, crop rotations and the diversity of farm enterprises. In addition, some forest-derived species may also be present in the agricultural system, and these have been termed the 'associated diversity' (Vandermeer *et al.*, 1998). Some of this associated diversity may be valuable to the farmer, and he/she may harvest it (Figure 18).

Associated diversity is a result of the interaction between farm management and the landscape context of the farm. Belowground biodiversity usually falls into this category (see Lecture Note 6). Whereas the harvested components are directly linked to the way agroecosystems productivity is measured and evaluated by the farmer in the short run, the non-harvested components play a key role in the functioning of the agroecosystem, its sustainability and long term productivity (Figure 18).

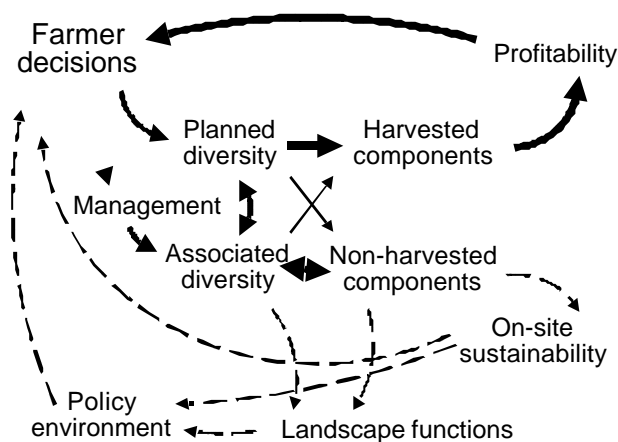


Figure 18. A conceptual scheme of relationships within in agroecosystems, regarding complexity and function (modified from Swift and Ingram, 1996).

5.2 Farmers' perceptions of associated diversity

What is interesting is how farmers perceive this associated biodiversity; how they value it will dictate how they manage it (Table 4). Farmers may 'tolerate' the associated diversity even though it may not have a direct value to them e.g. they retain spontaneously regenerated plants which are not 'weedy' enough to be worth taking out, or they may allow insects and other animals to stay on below a 'pest threshold'. This has important consequences for biodiversity at a landscape level in agricultural areas.

Table 4. Farmer management options for associated biodiversity

What farmers do with associated biodiversity	How do they do it?	Farmers' perceived value of associated biodiversity
REMOVE IT	Regular weeding	Negative
Tolerate it	Do nothing	None
Encourage it	Weed around seedlings to help them survive	Intermediate
Actively manage it	Weed it, transplant it, propagate it	High

Evidence that there may be a high level of 'tolerated' biodiversity was found in a study which inventoried farmers' knowledge of the tree species found in their locality (Joshi *et al.*, 1999). In this landscape in Sumatra, which was dominated by complex rubber agroforests, the 16 farmers who were questioned identified 81 tree species in total. However, these particular species accounted for only 29% of all of the tree species found in a botanical census in the same area (140 species in total, from 16 plots of 0.2 ha that were censused). Therefore, the majority of the tree species present in the rubber agroforests weren't recognised as having any value, nor even recognised!

5.3 Back to the 'segregate/integrate' debate: how farmers trade off biodiversity and profitability

A potential trade-off between profitability and biodiversity conservation remains to be addressed concerning smallholder systems. Farmer management aimed at increasing productivity of systems often decreases biodiversity. For example, farmers may be less willing to tolerate the associated diversity and will remove it. This was seen in Kalimantan in Indonesia in rubber agroforests: as the importance (to the farmer) of rubber production increased, the number of rubber trees per unit area increased, and the numbers of other tree species decreased correspondingly (Lawrence, 1996). The extreme case may be where economically important tree species are grown as monocultures.

Whether or not this apparent trade-off between productivity and biodiversity is inescapable is the subject of debate--and further research. It is possible, that by adding higher-value components, such as genetically-improved planting material, to high-biodiversity agricultural systems (see Williams *et al.*, in press, for an example) profitability will increase, and farmers may retain the associated diversity in their plots.

Very little is actually known about the shape of the curve describing the trade-off function, or even whether a trade-off always exists (Figure 19). If the relationship is convex to the origin, even modest productivity gains cause great loss of biodiversity. If the relationship is concave, biodiversity loss is relatively slow for initial increases in productivity. In this case, raising productivity to an intermediate level may involve a

modest trade-off in terms of biodiversity loss. Thus, two of the most important research questions regarding the selection of ‘best bet’ land use types in Sumatra are:

- what is the shape of this curve? and
- what factors influence the biodiversity of these complex, multistrata systems as productivity of their components increases?

So while there may be a trade-off between potential profitability and aboveground biodiversity in tree-based production systems, this requires further verification.

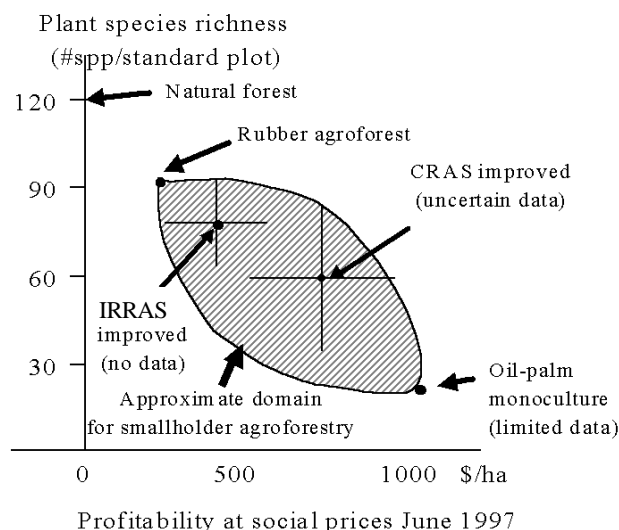


Figure 19. Potential profitability versus biodiversity for new technologies (‘CRAS’ and ‘IRRAS’) relative to the farmers’ existing ‘rubber agroforest’ system and to ‘oil palm monoculture’. ‘CRAS’ represents a cyclical rubber agroforestry system (i.e. the whole field slashed and burned at the end of every rotation) where high-yielding clonal trees have been substituted for the farmers’ existing low-yielding varieties. ‘IRRAS’ represents a ‘internal rejuvenation rubber agroforestry system’ where no slash-and-burn is practised, as high-yielding clonal trees are introduced incrementally by gap-replanting. Source: Tomich *et al.* (1999).

6. Conclusions

- To conserve the greatest possible amount of biodiversity, forest must be kept as forest, and not converted to other land cover types.

This is the theoretical ‘segregate’ option. However, in reality, preservation of pristine forest is rarely possible. Therefore, sustainable use of forests e.g. under community management may be a practical solution (as long as this provides realistic livelihood opportunities and incomes for local people). We have shown that this type of land cover gives the highest biodiversity values (in terms of numbers of plant species per standard plot, species/modi ratios, and values of the ‘V’ index) and is closest to that of natural forest.

- Among the land covers studied, complex, multistrata agroforests are best for conservation of local biodiversity in agricultural landscapes.

This is the medium intensity ‘integrate’ option, and has intermediate biodiversity value (species richness, species/modi ratios, and values of the ‘V’ index). These agroforests also have advantages for the farmer in terms of resilience (in the face of pests and diseases) and also in risk management (because of the diversity of economic products that may be harvested).

However, if the pressure to intensify land use increases, and farmers demand a greater profitability per unit area, then farmers' perceptions of associated diversity and its value are critical. Farmers may not keep a complex agroforest as a complex agroforest unless:

- there are no other options which are more attractive (taking into account environmental conditions, profitability, efficiency of labour use, access to markets etc.)

or

- the complex agroforest as a whole is perceived to be valuable i.e. if the ecological and economic value of the associated diversity is perceived to be high. However, if only certain components are perceived to be valuable, then the system may become simplified, with only these economically valuable species present. The challenge is to create a policy and incentive environment where systems high in associated diversity are valued as such.

Finally, in conclusion:

Based on present findings, the message for managers of forested and agroforested lands is to maintain a mosaic of land cover types to maximise the availability of ecological niches. Not only is this likely to enhance biodiversity, recent experience suggests this may have a beneficial effect by facilitating biological pest management as well as providing increased flexibility for varying management options under conditions of environmental and socio-economic change.

III. Reading materials

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- 6B. Standard methods for assessment of soil biodiversity and land use practice
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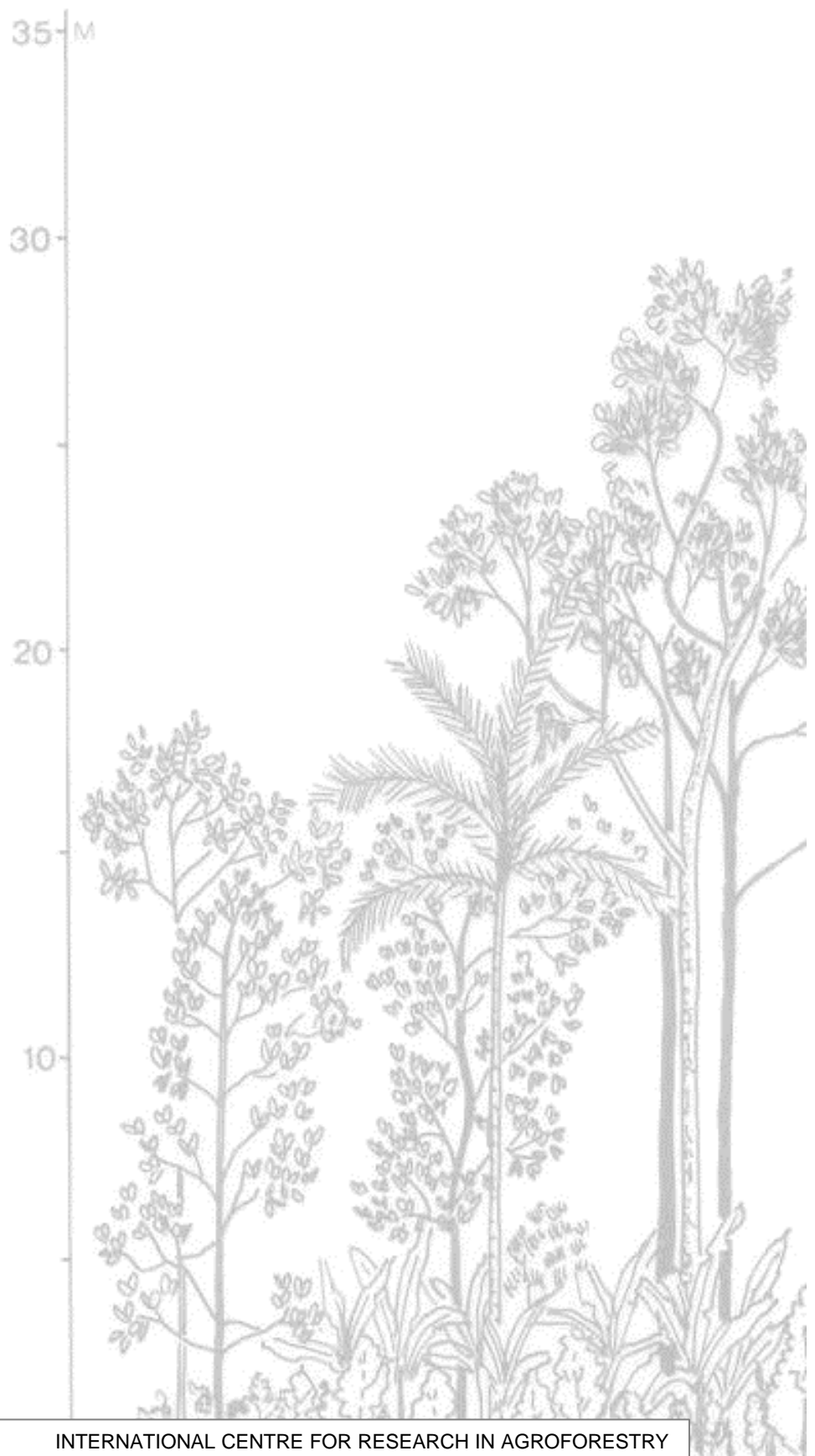
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