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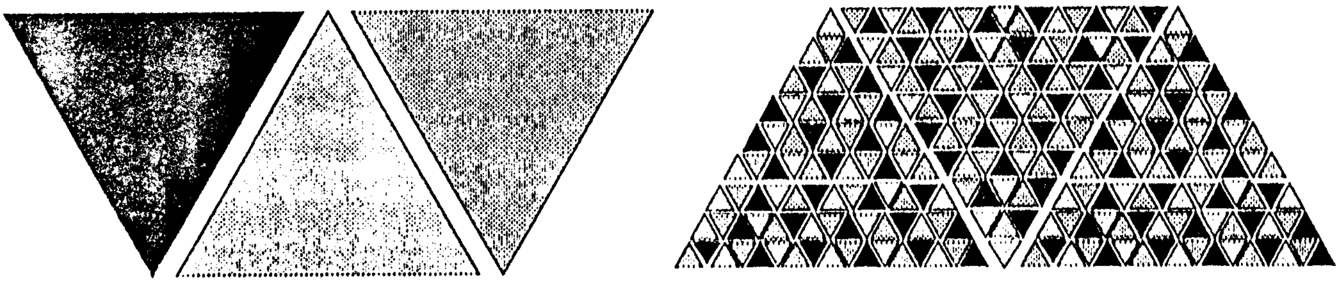
Segregate or Integrate Nature and Agriculture for Biodiversity Conservation



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Segregate or integrate nature and agriculture for biodiversity conservation? Criteria for agroforests

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Abstract

Human use of biotic resources ('agriculture' in its widest sense) and biodiversity ('nature' in its widest sense) are both needed by society at large, but there are generally conflicts between these two aspects of 'land use'. Conflicts between 'nature' and 'agriculture' can be solved by *segregating* nature and agricultural land (maximizing agricultural production on a relatively small part of the land will leave as much land for nature as is possible) or by *integrating* nature into agricultural land through the adoption of production systems that allow sufficient agricultural production while ensuring conservation of considerable parts of the biodiversity of the natural system. Multi-functional forests and agroforests are examples of the 'integrate' option, intensive agriculture plus nature reserves are an example of the segregate pathway. Mixed strategies are feasible where nature reserves coexist with pure agricultural production systems for some commodities and where production systems integrate nature and agriculture for other commodities. All three options have strong advocates, and it is not clear which solution is optimum under which conditions. Objective criteria are needed for distinguishing which solution may best meet the multiple goals formulated under different circumstances.

A simple model is used to derive a decision scheme. It distinguishes 'internal' biodiversity of a land use system and 'external' biodiversity, by requiring only a part of the area for agriculture. If two production systems are compared, biodiversity conservation will be maximized if the system is chosen with the highest agricultural productivity per unit biodiversity loss. If agricultural intensification is treated as a continuous process, a similar criterion can be used to distinguish between situations where 'segregate' or 'integrate' forms the best solution. Further research is needed to check the assumptions behind the proposed

equations, to quantify the scaling function of biodiversity in order to assess the effectiveness of both 'internal' and 'external' biodiversity conservation, and to determine the feasibility of implementation of options in the 'real world'.

Introduction

Human use of biotic resources ('agriculture' in its widest sense) and biodiversity ('nature' in its widest sense) are both needed by society at large, but there are generally conflicts between these two aspects of 'land use'. Conflicts between 'nature' and 'agriculture' can be solved in three ways:

- by *segregating* nature and agricultural land; maximizing agricultural production on a relatively small part of the land will leave as much land for nature as is possible,
- by *integrating* nature and agricultural land through the adoption of production systems that allow sufficient agricultural production while ensuring conservation of a considerable part of the biodiversity of the natural system,
- by segregating nature and agriculture for some production systems and integrating it for others.

It is important to notice that the area available for complete protection of biodiversity decreases when agriculture remains below its potential productivity under the integration option. All three options have strong advocates, and it is not clear which solution is optimum under which conditions (Fig. 1). Objective criteria are needed for distinguishing which solution may best meet the multiple goals formulated under different circumstances.

In this presentation we will restrict ourselves to two of these multiple goals, **productivity** and **biodiversity conservation**, and we will not touch on the important aspects of equitable sharing of benefits among the population and the institutional mechanisms and bottlenecks in achieving these goals in the real world. We will focus the discussion on the humid tropics.

Productivity is here defined as the value of output minus production costs discounted over the complete lifetime of the production system, expressed per unit area. Where multiple products come from the same unit of land, they are added on the basis of their market value.

Biodiversity conservation is defined from a global perspective, which means that only conservation of viable populations of the native forest species contributes to the 'biodiversity value'. The appearance of cosmopolitan or ubiquitous species, linked to the clearing of large tracts of forest has no value in terms of global biodiversity conservation. The richness of

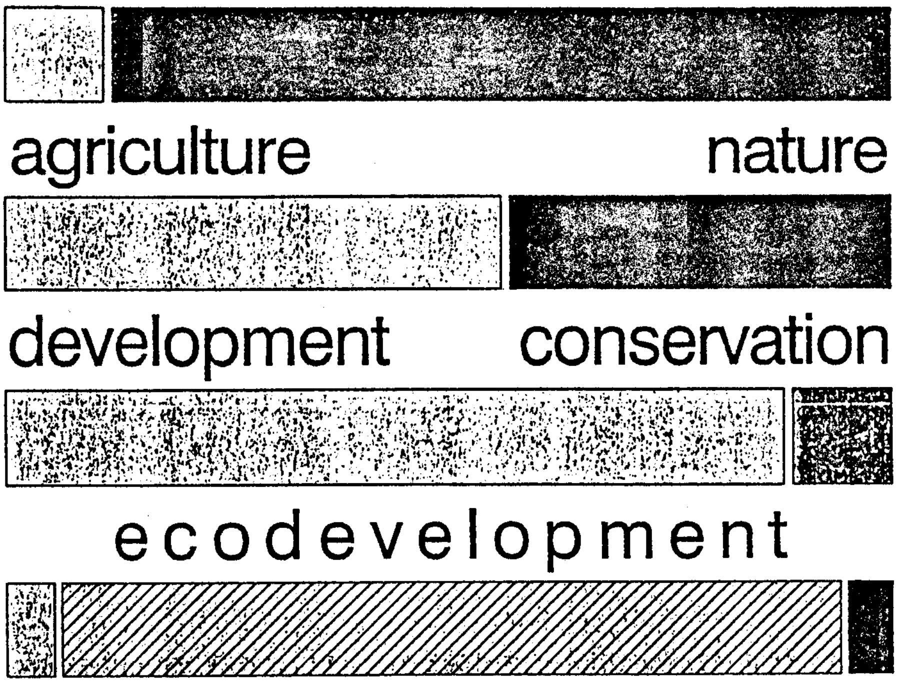

Figure 1.. The relation between agriculture and nature can be treated by creating and maintaining sharp boundaries (segregation) between the two, or by aiming at an integrated 'ecodevelopment' pathway

original forest species present in a certain land use system is an important indicator of its biodiversity value, but it is long term reproduction and survival of populations with sufficient internal genetic diversity which forms the real criterion.

High expectations exist that 'agroforests' can help to conserve biodiversity while allowing sufficient production of economically attractive crops, such as rubber or resin (damar). Agroforests contain considerable biodiversity value, as their planned biodiversity of planted trees is augmented by naturally invading species of the original forest (Michon and De Foresta, 1992, 1994).

Agroforests are not monoculture plantations. On the contrary, they assume patterns of diversity and heterogeneity similar to a natural forest ecosystem (high botanical richness, multi-layered vertical structure) as well as specific patterns of forest dynamics. This "forest reconstruction" appears as a consequence of a particular mode of management which favors the re-establishment of the original biodiversity. The planting process, associating various useful tree species, recreates the skeleton of a forest system. Then, common mechanisms of natural vegetation dynamics are given the major role in the evolution and the shaping of the cultivated ecosystem. As in any secondary vegetation dominated by trees, the maturing agroforest provides a suitable environment and convenient niches for the establishment of forest plants carried from the neighboring forests through natural dispersion. It also offers shelter and feed to forest animals. In this natural enrichment and diversification process, humans merely select among the possible options given by ecological processes. The establishment process restores integral biological and ecological processes which constitute resources in their own: these are "functional" resources more than commodities, but they are essential to the overall survival and reproduction of the agroforest as an ecosystem. In a sense, the damar agroforests of Krui (West Lampung, Indonesia) form the 'archetype' of agroforests as described here (Michon et al. 1994), but similar characteristics hold for the much larger areas of rubber and fruit tree agroforests in Sumatra and Kalimantan.

Rubber agroforests (sometimes called "jungle rubber") cover over 2 million ha in Sumatra and Kalimantan and are probably the most widespread complex agroforestry system in Indonesia. A variety of products tend to be harvested in addition to latex, including many types of fruits. This system's success is closely related to swidden agricultural practices. Indeed, it is through *ladang* (unirrigated upland plots) opened to produce upland rice and other crops that young rubber is established. After 1-2 years of annual crop production, the subsequent fallow can freely develop along with the rubber trees. Besides its ecological advantages, including a forest-like environment that retains biodiversity, this process is totally suited to smallholder management since it benefits from the site preparation carried out for *ladang* establishment, it involves minimal additional investment in labor and capital, and it can be established in conjunction with activities related to the maintenance of the *ladang* crops.

Figures 2 and 3 show the considerable capacity of agroforests to conserve much of the forests' biodiversity, but also show the loss when compared to natural forest. It is not enough, however, to state that such agroforests represent a vastly higher biodiversity value than tree crop monoculture systems. If productivity of the monocultures is substantially higher and if benefits are equitably shared among the human population, it might allow a larger area of natural forest to be conserved and, under certain conditions, this might satisfy the biodiversity agenda to a larger degree. We need a quantitative criterion to evaluate the two options. 'As far as environmental impact is concerned, large-scale development of complex agroforests as those developed by peasants in Indonesia appears highly desirable. However, their productivity in terms of cash income per unit land is still low and irregular.

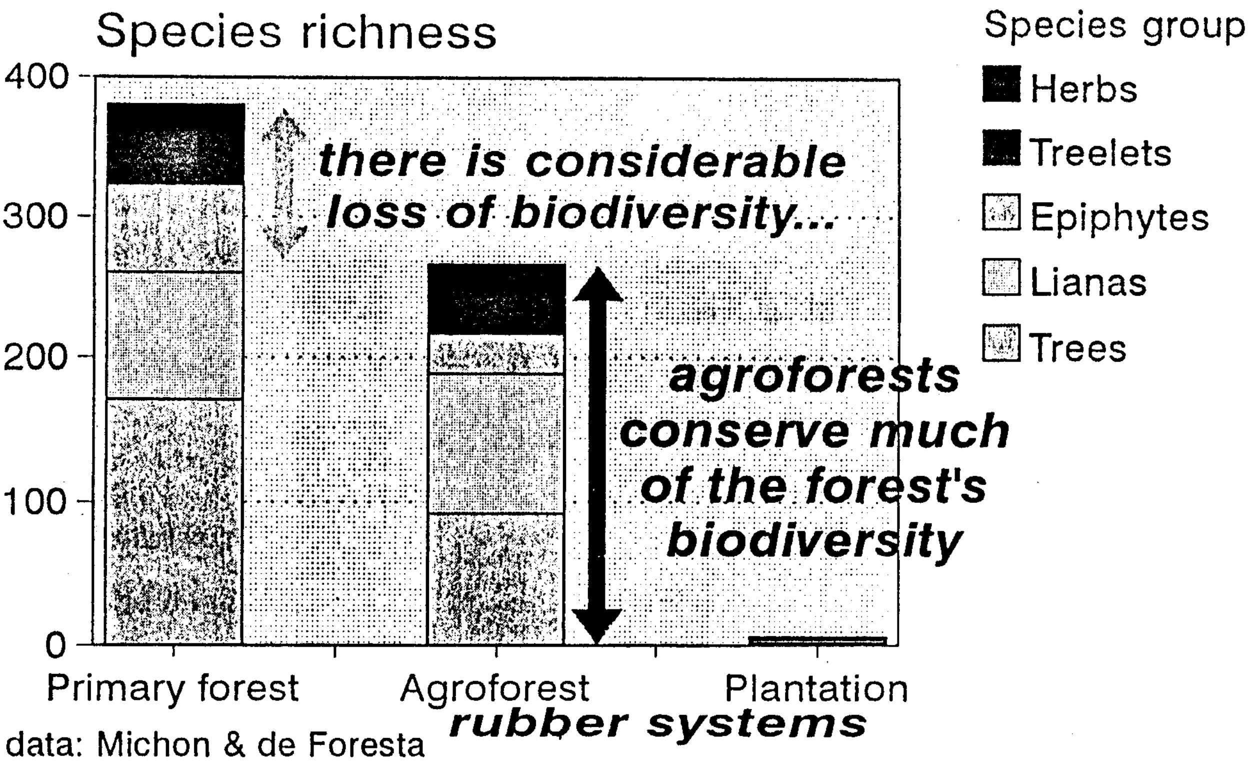

Figure 2. Species richness of higher plants along 100 m line transects in primary forest, rubber agroforests and rubber plantations in Sumatra (based on Michon and de Foresta, 1994)

Complex agroforestry systems can no longer compete with other agricultural systems which may be more risky, but are more profitable in the short term' (de Foresta and Michon, 1992). However, recent research supports a more nuanced interpretation. Some agroforest types, like damar agroforests are indeed highly profitable at present compared to most other production systems. Some other agroforest types, like rubber agroforests for instance, had been highly profitable in the past, even compared to rubber monoculture estate plantations, but their economic comparative advantage has narrowed mainly because high yielding rubber material adopted by large-scale plantations was not adopted by smallholders. Increasing the profitability of these complex agroforestry systems may be based on genetic improvement of the main cash earning components of the system, or by more complete utilization of the existing components, such as the timber. The development pathway here is one of 'intensification' (obtaining a higher productivity) by diversification, rather than by specialization on single commodities.

In order to avoid raising unrealistic expectations of the biodiversity conservation potential of such 'integrated' systems, we need a clear criterion to judge for which parts of the total

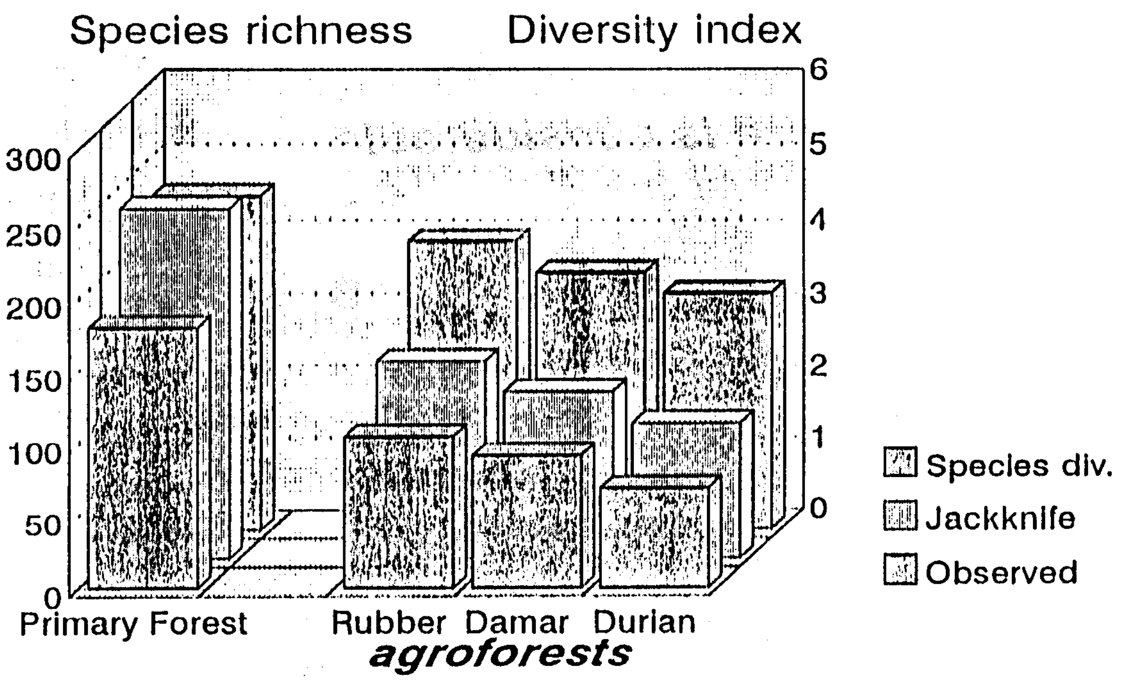

Figure 3. Species richness and diversity index of birds in primary forests and agroforests in Sumatra (based on Thiollay, 1995)

biodiversity and for which commodities such an approach may indeed be possible and for which ones not. 'Agroforests can drive back natural forests' locally, as suggested in the title of Mary and Michon's (1987) paper, and in that sense they are just like any land use system in expansion. Yet, the agroforests conserve a much larger part of the 'forest functions' than other land use systems.

The segregate - integrate debate is not confined to 'agroforests'. The on-going debate about 'multiple functions' of forests shows important parallels (Vincent and Binkley, 1993, 1994; Helfand and Whitney, 1994).

Discrete systems

Suppose that there is a choice between two land use systems, one with productivity Y_1 and internal biodiversity value B_1, and one with Y_2 and B_2, respectively. The Y_1 and B_1 are expressed per unit area (see below for a discussion of the scaling of biodiversity). As a first approximation we assume the land to be homogeneous in potential productivity as well as biodiversity values (this 'homogeneity' of biodiversity implies that the species composition differs between all sub-units to an equal degree).

If not all land is needed for production, it can be used as 'nature' with biodiversity value

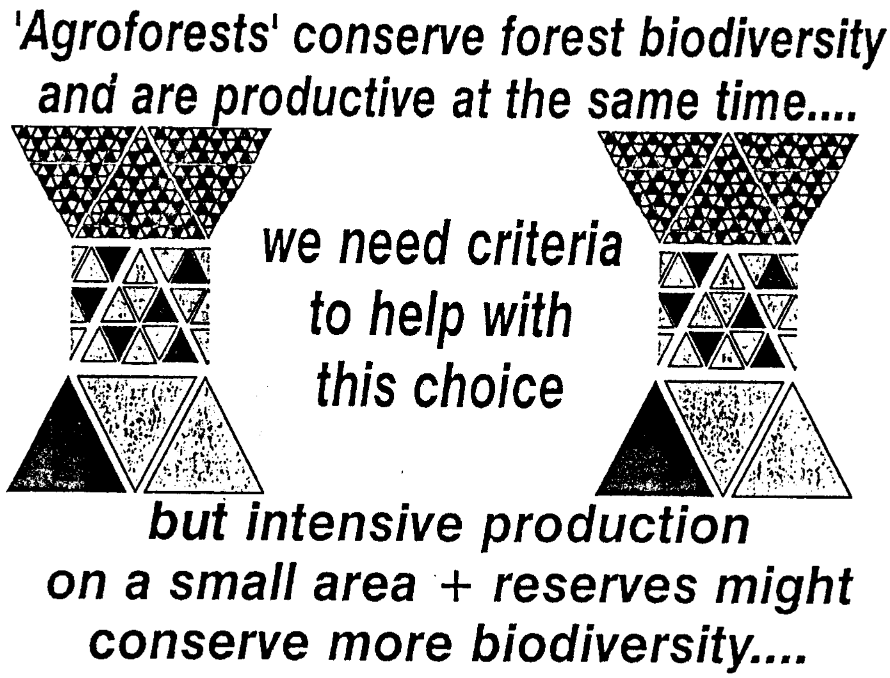

Figure 4. The segregate - integrate dilemma and the need for criteria

B_n and a zero productivity. If f_1 and f_2 indicate the area (expressed as fraction of the total land area) needed for production under the two systems, a comparison at equal total output (area * productivity per unit area) leads to:

$$f_1 \; Y_1 = f_2 \; Y_2 \quad , \therefore f_2 = \frac{f_1 \; Y_1}{Y_2} \quad (1)$$

For the same level of total productivity the two systems may differ in their biodiversity value, which consists of an '**internal**' (f_1 B_1 and f_2 B_2, respectively) and an '**external**' component $(1 - f_1)$ B_n and $(1 - f_2)$ B_n, respectively. System 1 will result in greater biodiversity for the same output if:

$$f_1 \; B_1 + (1 - f_1) \; B_n > f_2 \; B_2 + (1 - f_2) \; B_n \quad (2)$$

Rearranging and substitution of equation (1) leads to:

$$\frac{Y_1}{Y_2} > \frac{1 - B_1/B_n}{1 - B_2/B_n} \quad (3)$$

or,

Equation (3) compares relative productivities of the two systems and relative biodiversity losses (taking B_n as point of reference), equation (4) compares the 'agricultural productivity

$$\frac{Y_1}{1 - B_1/B_n} > \frac{Y_2}{1 - B_2/B_n} \quad (4)$$

per unit biodiversity loss' for the two systems.

If 'plantation rubber' is four times more productive per unit area than 'jungle rubber' and jungle rubber has three-quarters of the biodiversity value of natural forest, while plantation has a biodiversity value of near-zero, the 'segregate' or 'integrate' debate comes to a draw, as both the left and right hand term of equation (3) are 4.

The equations suggest that in order to make the choice between system 1 and system 2 we do not need to know the absolute biodiversity in either system, but only the *relative* value of internal and external biodiversity. Perhaps this can simplify the indicators needed.

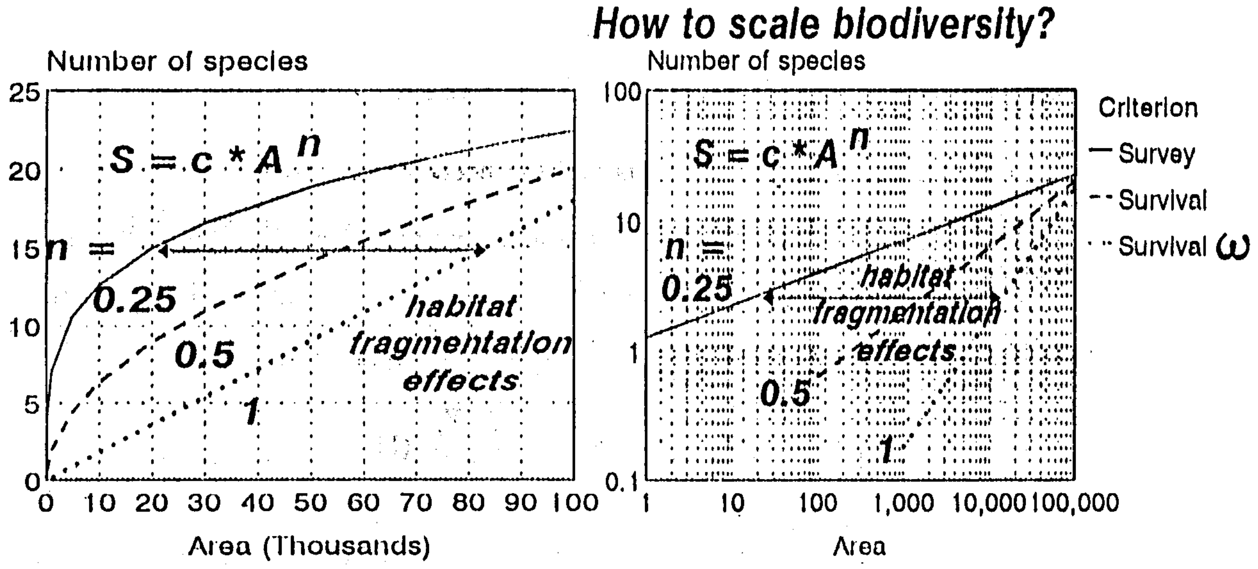

Figure 5. Schematic scaling relationships for biodiversity in surveys, medium and long term conservation; left with linear, right with logarithmic axes; results for various taxonomic groups would differ in position on the graph (c parameter) but not necessarily in slope (n parameter)

An important assumption in this approach is that biodiversity values of two parts can be added to obtain a total biodiversity value. This is a critical assumption, referring to the scaling of biodiversity. From surveys and species counts it is known that there are diminishing returns of encountering new species when the sample size (area) is increased (Fig. 5). If species richness is treated as a power function of the area sampled, a power (fractal dimension) of about 0.25 is often found. The biodiversity conservation versus area curves, however, are different. If we compare how much biodiversity survives recent fragmentation of the habitat to various sizes, the power may be about 0.5 (Van Schaik, *in press*). If we want to secure long term conservation and add arguments about minimum population size and minimum genetic diversity required within the populations to deal with future stresses, we may expect that the curves are shifted further to the right and the power increases. A power of 1 (i.e. biodiversity conservation is proportional to the area conserved) is probably an overstatement, but it is a convenient choice for heuristic purposes as it simplifies the mathematics. We can relax this assumption and derive results for any 'fractal dimension' of biodiversity (results forthcoming), but there is a clear lack of empirical data on how this dimension differs among habitats and taxonomic or functional groups of organisms.

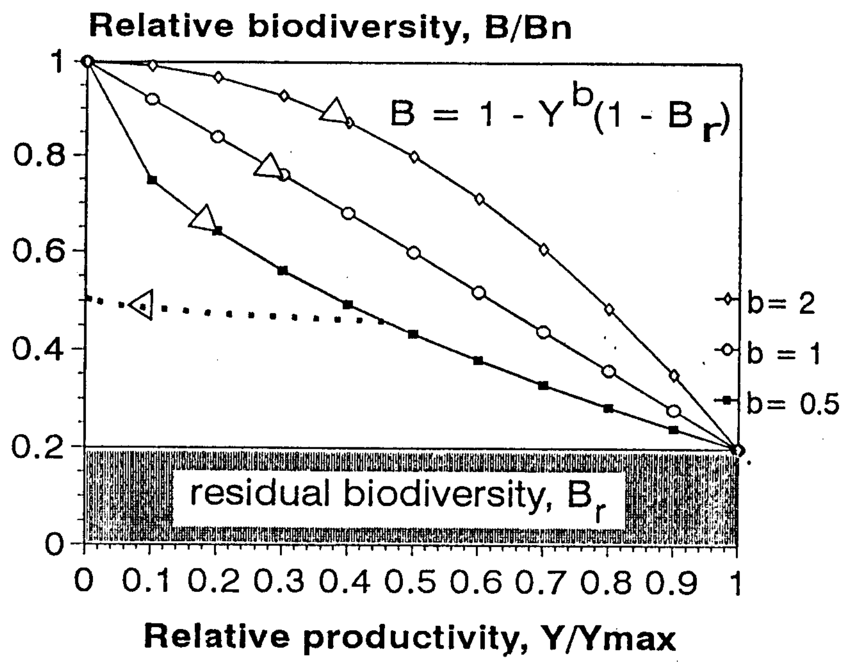

Figure 6. Relative (internal) biodiversity B_t as function of relative productivity (actual divided by maximum); curves can be convex, linear or concave, depending on the value of the parameter b.

Continuous intensification, with homogeneous land quality

Rather than describing discrete versions of land use systems, we may consider an 'intensification continuum'. Figure 6 shows a generalized relation between 'internal' biodiversity' and agricultural productivity; both are scaled to the [0 - 1] interval by dividing the actual by the maximum value. Convex, concave or linear curves can be described by varying the value of the parameter b. If we follow the 'equal total output' comparison of the discrete case, we can express total biodiversity as a function of relative productivity (Fig. 7). The figure shows decreasing curves if $b > 1$, leading to the conclusion that it is best to 'integrate', as well as increasing curves if $b < 1$, leading to the conclusion that it is best to 'segregate'. Results of a mathematical analysis (Van Noordwijk *et al., in prep.)* confirm that for resource use systems with a b parameter above 1 (concave curves in Fig. 6) the integration pathway may be best, below 1 (convex curves in Fig. 6) segregation is better.

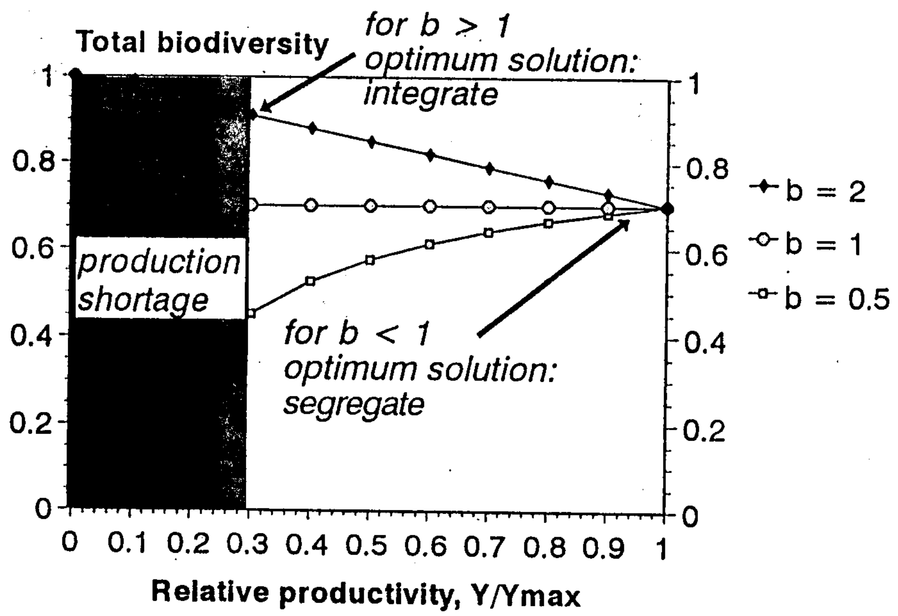

Figure 7. Total biodiversity (internal *plus* external) as a function of relative productivity, for different values of the b parameter (total output P = 0.3, $B_r = 0$)

If systems with intermediate productivity are associated with a less than proportional biodiversity conservation value, the best solution will be to segregate and maximize production on a small area. From the available evidence, most food crop based production systems fall in this category, as annual plants will not grow well unless major changes in the vegetation (such as 'slash-and-burn' activities) have been made, to reduce competition. If systems with intermediate productivity allow a more-than-proportional biodiversity, 'integration' will be the best solution, based on the lowest degree of intensification which still meets the total production target.

However, the equations in Figure 6 and 7 are based on the assumption that whatever the crop, the production system or ecozone considered, maximum productivity is reached when

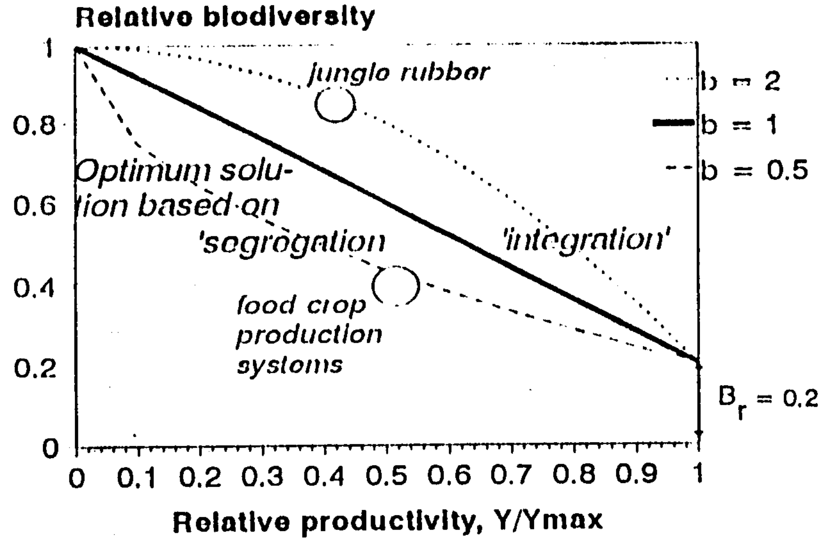

Figure 8. Decision scheme for the 'integrate' versus 'segregate' option for maximizing total biodiversity in the internal biodiversity - relative productivity relationship.

relative biodiversity is minimum. In other words, the assumption here is that in order to increase productivity, biodiversity must be reduced and that maximum productivity cannot be reached through integration. There is ample evidence that this assumption is quite valid for food crop systems, but it probably is not valid for many tree crop systems. In food crop systems, increases in productivity are obviously linked to decreases in biodiversity; however, the relationship is not gradual. Food crop production implies a dractic biodiversity reduction right from the begining simply because food crops themselves are not able to grow into a forest environment -most food crops are herbaceous species strongly depending on high light intensity. For continuous food crop systems, maximizing agricultural productivity can only be obtained through segregating natural forest biodiversity from agriculture. In tree crop systems, the situation is different because tree cultivation can recreate a forest structure that usually allows some niches to be fulfilled by other forest species without detrimental effects on productivity. In that way, the association of carefully selected tree crops occupying various niches with different and complementary ecological requirements would maximize productivity. Therefore, at least for some tree crop systems, maximum agricultural productivity can be obtained through integrating natural forest biodiversity and agriculture, as maximum productivity occurs for biodiversity levels higher than the minimum.

Practical application: jungle rubber in Sumatra

From the evidence available, the jungle rubber found in the lowlands of Sumatra in comparison with the best available approximation of 'primary forest' has about equal species richness for soil mesofauna as evidenced by Collembola (Deharveng, 1992), very similar lists of observed mammals (Sibuea and Herdimansyah, 1993), 30% less species of higher plants (Michon and De Foresta, 1994) and 50% less species of birds (Thiollay, 1995). For the 'biodiversity conservation' value of the jungle rubber, we should note that the reduction of typical 'forest' bird species richness is more than 50%, but there is an increase in species typical of open vegetation. We may assume that these values were about the same in the 1930's when the first generation of jungle rubber systems reached maturity. Rubber started spreading as a smallholder crop in Sumatra at the beginning of this century. In the 1930's rubber yields of the jungle rubber (about 500 kg ha^{-1} y^{-1} of dry product, Van Gelder 1950) were close to the maximum attainable in monoculture plantations. Now, jungle rubber yields are still about 500 kg ha^{-1} y^{-1}, but monocultures can reach 2 000 kg ha^{-1} y^{-1} (or even more) under research station conditions and at least 1 500 kg ha^{-1} y^{-1} in commercial practice. This increase is largely due to genetic selection of clones suited for the plantation environment. Whether or not these same clones are suitable for the rubber agroforest environment is largely an open question. Genetic selection specific for this environment, may be expected to increase the productivity of the rubber agroforest, without a complete overhaul of the system.

The situation in the 1930's would have clearly indicated that 'integration' was the best choice (Fig. 9). At current production levels, however, the conclusion depends on the relative weight one attaches to the various components of biodiversity. A bird watcher will favour 'segregation', a collembola enthusiast 'integration' (80% of the species in the survey were new to science) and a botanist should feel hard-pressed to make a choice. Increased productivity by genotype selection for rubber agroforests might get us back to the situation of the 1930's.

Discussion and conclusions

The first conclusion is that the segregate <-> integrate debate is open to quantitative analysis. Such an analysis shows clearly what type of assumptions are necessary to make the comparison and focus research on obtaining the data which are most needed to make

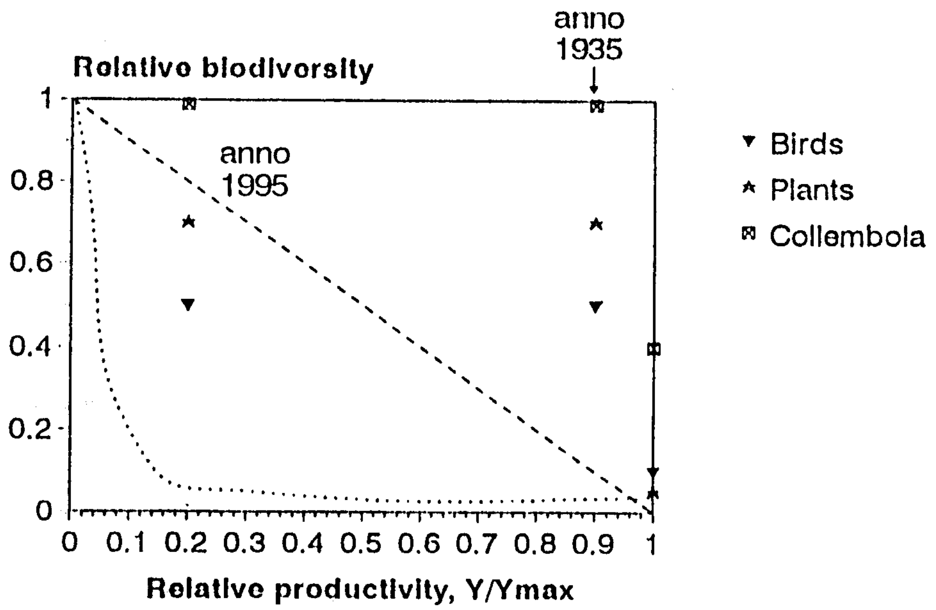

Figure 9. Tentative application to jungle rubber systems, showing the current biodiversity estimates, but two values of the 'relative productivity'

decisions.

The impression so far is that for foodcrop-based production systems the segregate option may be best, but that for tree-based systems the outcome can be either way and more data are needed. The most sensitive assumptions for the model are the ones made in scaling biodiversity. For real world applications, both the 'internal' and the 'external' aspects of biodiversity conservation need to be quantified and feasibility of options need to be critically assessed.

The myriad constraints and the more nuanced objectives of the real world are likely to produce a richer mix of solutions than appear in this heuristic model. Which among these real world issues are likely to shift the balance most between the extremes of "segregate" or "integrate"? Constraints in public funds and in administrative capacity are two important practical considerations. By design -- but also by default -- these constraints will tend to favor "integration" over "segregation" simply because the latter requires more funds and more intensive administration.

Because *any* conversion from primary forest results in a significant decline in biodiversity (Figures 2 and 3), conservation reserves always have an important potential role in biodiversity conservation. The extent that this is feasible depends on existence of institutional arrangements and policy mechanisms for monitoring and enforcing primary forest boundaries. Bufferzone agroforestry does not seem to be sufficient in a setting like Sumatra; profitable agroforestry technologies may even induce forest encroachment under certain conditions (van Noordwijk *et al.*, 1995). Whenever establishment of conservation reserves conflicts with the livelihood of the local population--as it does in many, if not most, instances--"no conservation program will work without major investments in regulation or compensation" (Sayer, 1995). Until a lot more is known about effective implementation of incentive schemes and/or regulations that involve acceptable financial and social costs of monitoring and enforcement of forest boundaries, "integration" will be the default outcome and the primary forests that survive will be residuals of the conversion process rather planned reserves.

There also are questions of feasibility on the agricultural intensification side of the "segregate" strategy. The scope for sensible expansion of irrigated agriculture in Sumatra is limited (Tomich, 1992). And while continuous foodcrop production may be sustainable on soils in Sumatra's uplands from a *technical* perspective, the costs of the necessary inputs may mean these land use systems are not *financially* feasible. In other words, while continuous-foodcrop systems are of scientific interest, their practical implications as a means for smallholders to earn a livelihood may be quite limited in Sumatran uplands.

Large-scale block-planting schemes that were intended to achieve big productivity increases for smallholder rubber have faced similar problems. Moreover, the high costs and administrative intensity of conventional smallholder rubber projects restricted coverage to a small proportion (only 15%) of rubber smallholders in Indonesia (Tomich, 1991). Large-scale oil palm plantations and, perhaps, industrial timber estates may have better prospects for profitability. But even institutional arrangements like the Nucleus Estate/Smallholder (NES) model have not enabled participation of a significant number of local farmers in these schemes. Constraints on public funding restrict scope for government sponsorship to a much smaller role in Indonesia compared to Malaysia. And the preference of large-scale private investors often is for something akin to a hacienda system, with the result that local farmers are displaced and forced to make a living in other locations, including in some cases, forest margins. Thus, an intensification pathway that concentrates control of land is likely to make it even more difficult to enforce forest boundaries.

Whether for biodiversity conservation or for economic development, increased productivity of land use systems matters as much for its role in poverty alleviation as it does as an end in itself. A workable strategy to raise productivity of rubber agroforests could play an important role in poverty alleviation in Sumatra. Constraints on public funds and administrative capacity mean that, for the foreseeable future, most of Sumatra will be neither a conservation reserve nor highly-intensified agriculture. The remaining middle ground is where the agroforest pathway may conserve more biodiversity than alternative land uses. From this standpoint, perhaps the most urgent question for further research is: what factors influence the 'internal' biodiversity of these agroforestry systems as productivity of their components increases?

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