CHANGING VALUES OF MALAYSIAN FORESTS: THE CHALLENGE OF BIODIVERSITY AND ITS SUSTAINABLE MANAGEMENT

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ASHTON, P. S. 2008. **Changing values of Malaysian forests: the challenge of biodiversity and its sustainable management.** The meaning of the term biodiversity and the challenge of its evaluation are discussed in this paper. Requirements for its conservation within indigenous production forests are weighed in context of the homogeneity of rain forested landscapes for different organisms, and the impact of logging on biodiversity. A hypothesis, aimed at defining that method of management which can optimize both sustainable timber production and biodiversity conservation, is presented for testing by research.

ASHTON, P. S. 2008. **Mengubah nilai hutan di Malaysia: cabaran dan pengurusan mampan kepelbagaian biologi.** Maksud istilah kepelbagaian biologi serta cabaran penilaiannya dibincangkan dalam kertas kerja ini. Keperluan pemuliharaan kepelbagaian biologi dalam hutan pengeluaran asli ditimbangkan dalam dua konteks iaitu kehomogenan landskap yang dilitupi hutan hujan untuk organisma berbeza serta impak pembalakan terhadap kepelbagaian biologi. Satu hipotesis yang bertujuan untuk mengenal pasti kaedah yang dapat mengoptimumkan pengeluaran balak secara mampan dan juga pemuliharaan kepelbagaian biologi diutarakan untuk diuji dalam penyelidikan.

INTRODUCTION

In economies such as the Peninsular Malaysian which are undergoing rapid and successful development, urbanization brings a fundamental change in relative values, from products such as timber, game and traditional medicinals, to services such as water quality and reliability, weather amelioration, national heritage and recreation. Biological diversity, commonly abbreviated biodiversity, is the service value of tropical lowland evergreen forests unequalled in any other terrestrial ecosystem. It is estimated that more than half the total diversity of this planet is sequestered only in the lowland evergreen tropical rain forests. Further, the biodiversity of the Sunda Shelf, notably Malaysia, Borneo and Sumatra, is second in biodiversity only to that of central and the Andean hinterlands of South America.

Conservation planning can aim to be comprehensive, adequate or representative (Margules & Pressey 2000). Comprehensive conservation plans can only be achieved when adequate areas remain in all ecosystems. In Peninsular Malaysia on the contrary, surviving areas of the inland lowland dipterocarp forests, almost certainly the most biodiverse of Malaysia's ecosystems, are scattered and minute. Unlogged primary hill forests are now confined to the Taman Negara which, though large, lacks legislated corridors to the other residual primary fragments, now mostly in the north. It has been argued that the area of strictly conserved indigenous forest in Peninsular Malaysia may not have increased in the last 70 years, new areas legislated being equaled by formerly protected forests suffering rescission, excision or intrusion (Aiken 1994). At best, Malaysia can yet plan to conserve an adequate network of forest conservation areas representative of the hill and montane, the western coastal and the limestone forests; but for the hyperdiverse lowland forests remaining primary forest areas are neither adequate nor representative. Of utmost importance, continuity between strictly conserved areas must be assured through a network of forest corridors. Now, the great majority of the residual rain forest, where such corridors remain a possibility, is within the forest reserve system. This was primarily set aside for sustainable timber production although certain special habitats, especially watersheds, are at least in principle retained in primary forest condition. Conservation policy must, therefore, include the forest reserve network as a critical integral part of an overall conservation plan.

There is growing evidence that most vertebrates can survive, and some even increase, in well managed indigenous production forest (Aiken & Leigh 1992). But what of biodiversity overall? What is the impact of successive felling cycles? Little information is as yet available from biodiverse tropical rain forest and such research is now a critical prerequisite.

WHAT IS BIODIVERSITY AND WHY DOES IT MATTER?

The term biodiversity has been used in respect to structural diversity of a community, ecosystem or landscape, or even the diversity of their history. It has also been used with respect to the structural and functional complexity of ecosystems, their trophic structure and the temporal and spatial complexity of their dynamic cycles. Alternatively, it has been adopted for phylogenetic and species diversity, and richness which refers to the number of species in a community or ecosystem. Fundamentally though, it is the diversity of gene sequences sequestered in living organisms (Noss *et al.* 1997). Biologists use species, that is groups of organisms that are capable of interbreeding with one another but rarely successfully do so with other species, as convenient proxies when assessing biodiversity. Biodiversity-rich ecosystems such as rain forests are therefore analogous to libraries in their case of genetic information. We know from history that, like the books in a national or research library, this information is availed of and brings major benefits only at long intervals, but that information can then be immensely valuable. What would the Malaysian economy be like if the Amazon forest had already been converted to soybean and sugar, and the rubber tree had gone extinct before it was brought over, or if the West African oil palm had likewise gone? It seems unlikely that major commodity crops such as these remain to be discovered; but we cannot afford to ignore that micro-organisms evolve hundreds of times more rapidly than do trees, and that the pathogens of these crops will gradually and inexorably be accidentally brought to them in the Far East. Wild relatives of these crops and wild relatives of their pathogens and herbivores hold the genes needed for the ongoing battle to protect them. Other genes in other organisms may yet serve to protect us and our domestic animals as our numbers increase and the potential for global epidemics increase with them.

I have emphasized the economic values of biodiversity here, but we should not forget that, like historic cities, great buildings or works of art, biodiversity represents the history of its region in this case biological and evolutionary and over millions rather than hundreds or thousands of years. Based on molecular combined with paleontological evidence, our tree species are now known to have arisen mostly more than 3 million years ago. Once lost, it would take a similar period to recreate replacements in nature. It must be a challenge for civilized society to ensure that this is unnecessary.

HOW CAN BIODIVERSITY BE SURVEYED AND ASSESSED?

Here I will focus on the challenges faced in biodiversity assessment, and discuss how it may optimally be conserved in ecosystems, such as tropical forests, which serve multiple uses for multiple beneficiaries.

The spatial patterns of biodiversity

Biodiversity overwhelmingly consists of insects mostly beetles and micro-organisms including pathogens. The evaluation of changes in biodiversity through direct measurement of its entirety is impossible. Instead, a group of organisms whose diversity correlates well with overall biodiversity can act as a surrogate (Margules & Pressey 2000).

Tree species serve as a reasonable proxy for overall biodiversity in tropical rain forests: plants are organisms that receive solar energy and carbon into the ecosystem. They are the primary producers upon which all other organisms depend directly or indirectly for food. Plants have therefore evolved an extraordinary diversity of chemical as well as physical defenses against what to them are pathogens, predators and herbivores. It is the co-evolution between plants with the biggest biomass, i.e. trees, of a rain forest and their host specific herbivores, which are mostly insects and pathogens, which has created the rain forests' extraordinary biodiversity (Novotny *et al.* 2006). There is growing evidence that this diversity of tree defenses, often species-specific, explains how biodiversity is sustained in rain

forests, and why rain forests are so much richer in biodiversity than other terrestrial ecosystems (Janzen 1970, Connell 1971, Gilbert & Webb 2007). First, like children catching a cold in school, the further apart individuals of a tree species are, the less likely they are to be discovered by a species-specific herbivore, or infected by a species-specific pathogen. Conspecific trees growing close together often therefore suffer higher mortality. Thereby, space is opened up which can be more favourably occupied by other species prone to attack by other herbivores or pathogens. This can explain how so many species can still coexist within one physical habitat of soil and successional history. Second, in other forests which experience annual and varying drought or cold unusually hard adverse seasons are well known to strike herbivores and pathogens more severely than the trees themselves, though trees too are adapted to these conditions to varying extents. Reduction of host-specific pathogens and herbivores by adverse weather provides the opportunity for one or a few species to dominate, competitively excluding others and thereby reducing tree species diversity and, therefore, biodiversity overall.

Plants remain rooted to one spot through their lifetime, except during dispersal of seed or, in the case of their male gametes, pollen and these in most rain forest cases move but a short distance. As can be expected, plant species are more physical and biotic habitat-specific than motile organisms except those, like many insects and micro-organisms, that depend on specific plants themselves. Research, in Malaysian Borneo especially, is showing that rain forest tree communities vary floristically with soil drainage and fertility, even within mixed dipterocarp forest (MDF) (e.g. Ashton 1964, Potts *et al.* 2002, Davies *et al.* 2005). More than two thirds of species on sandy loam soils there are absent from clay soils, except near ecotones where their populations are subsidized from those on their preferred habitat nearby. As we learn more concerning the ecology of individual species there, we can infer more concerning the ecology of species and their communities in Peninsular Malaysia. For example, MDF rich in balau (*Shorea* section *Shorea*) in Borneo prevail on drought-prone soils on freely draining sandy soils, on ridges and along rocky coasts. This appears to be the case in the peninsula both with balau and cengal (*Neobalanocarpus heimii*), though Wyatt-Smith and

Mitchell (1963) was unable to identify consistent habitat specificity in lowland MDF there.

High physical habitat-specificity leads to the division of species between those that occupy 'matrix habitats', that is widespread habitats continuous within one climate, and 'island habitats' that occur in more or less isolated patches like an archipelago within the matrix. A long recognized example of the latter is the limestone karst hills with its distinctive flora, but the drought-prone sandy soils and rocky coastal habitats within the MDF occur in archipelagoes similarly. The geographical distribution of flora of these similar habitats were early recognized in and around Peninsular Malaysia as the Riau Pocket (Corner 1960), and is now known to extend from Singapore up the east coast hills and well drained lowlands, and coastal Perak north of Lumut to Penang, as well as in Riau and north-west Borneo north of a line from Pontianak to the Kapuas Lakes, then through lowland Sarawak and Brunei to south-west Sabah (Ashton 1992, 2005). These islands of yellow sandy soil are set in a matrix of yellow/red clay and sandy clay loams, overlying granite and sedimentary phyllites, shales and clays.

Now of course, the lowland forest matrix has been fragmented and greatly reduced by conversion to plantations and urbanization. Until then, its flora was relatively uniform and there is evidence that its species continued to exchange genes thoughout each main region (Lee *et al.* 2000). By contrast, morphological and the limited genetic evidence so far available suggests that isolation of the sandy islands has led to rapid diversification and speciation since they were formed ca. 2–7 million years ago in the case of north-west Borneo (Kamiya *et al.* 2005). Evolution may also have been accelerated by the relatively small areas of habitat and consequent relatively small sizes of interbreeding populations (Leigh *et al.* 2004). An extreme case appears to be the ultramaphic exposures in eastern Sabah, notably Bukit Silam and Bukit Tawai, Karamuak, both rich in distinct habitat-specific endemics of widespread sister species. The mountain peaks, though not rich in species, are also important islands of specialized and endemic biodiversity. An important habitat which is both specialized yet also widespread and relatively continuous is the hill forest, with its distinct flora including seraya, *Shorea curtisii* (Symington 2004).

How big are the areas required?

Conservation priorities of tree floras and attendant overall biodiversity of these species of habitat islands must consequently differ from those of matrix habitats. In the case of the matrix ecosystems a single large representative area and several scattered small areas to represent the modest geographical variation should be optimal. Peninsular Malaysia has achieved this optimum in principle with the combination of Taman Negara and the lowland virgin jungle reserves (VJRs), though the area of MDF in Taman Negara is limited and the VJRs, supplemented by Pasoh research forest and a few other similar intact sites, is close to minimal in reality, as it now is also in Sarawak and Sabah.

The specialized habitat islands pose the greater challenge. Each includes some level of point endemicity (species unique to one or a few local sites). Further, these habitats are often the most endangered by land conversion, mining and settlement. In addition, pollinators and seed dispersers are particularly endangered and increasingly lost (e.g. Harrison & Rasplus 2006), although the 40-ha Bukit Timah Reserve within the City of Singapore provides a magnificent example of what little of the flora is lost if there is a will and active management (Turner 1996).

It can be seen that the criteria and priorities for conservation of vertebrates, particularly larger birds and mammals, are substantially different from those for plants and, in particular, trees therefore overall biodiversity. This poses a serious conundrum, because the supporting public are overwhelmingly most interested in these creatures. The life cycles of vertebrates is short in comparison with most trees, and their fecundity often low. Most important, they are mostly habitat generalists and are motile requiring large areas for survival. Tree species, and much of their associated biodiversity by contrast, have always existed in circumscribed and often quite small areas. Tree life cycles are long. The richest known tree communities in the Old World (now gone) were confined to the ca. 20 km^2 rhyolite exposure in the Ulu Arip, Balingian, Sarawak. Similar communities existed in Segan Forest Reserve, Bintulu, also gone, but survive in the ecological (and now by land use) island of Lambir National Park, Miri, ca. 50 km^2 and in the minute but uniquely important ca. 100 ha surviving primary

fragment of Semengoh Forest Reserve and natural arboretum, Kuching, all in Sarawak.

Major emphasis has rightly been put, by conservation planners and agencies including the World Wildlife Fund (WWF) and the International Union for the Conservation of Nature (IUCN), on the impact of reduction of habitat area on extinction rates. The Theory of Island Biogeography (MacArthur & Wilson 1967) predicts that a reduction of a continuous habitat area of 90%, which has certainly happened in MDF in Peninsular Malaysia and some other regions, will lead to extinction of 50% of the species inhabiting it in the absence of active management to sustain populations. This prediction has been confirmed for vertebrates in the U.S. and some other park systems. Few, if any, vertebrates are restricted to specific habitats within MDF so, for them, this habitat is continuous (though populations of many in low fertility landscapes may depend on nearby patches of higher fertility and productivity such as floodplains). The reduction in the total area of MDF may therefore provide a reliable prediction of future vertebrate extinctions, even in the absence of hunting. In the case of terrestrial plant species including trees, only extinction levels of the species of the matrix clay soil habitat can reasonably be predicted on this basis, though forest fragmentation will lead to restriction of genetic variability before it will lead to species' extinction. Many species are already restricted to ecological islands, isolated from gene exchange over the few decades during which we have the opportunity to influence the fate of biodiversity. Forest conversion generally eliminates whole islands, so that extinction rates will be mediated by the number of islands remaining. As these islands have mostly remained close to their present size for many centuries, even millennia, they are in species equilibrium relative to their area and the extinction rates within those remaining will not be influenced. However, many species in them also occur in habitats adjacent to these habitat islands. On infertile sandstone, coastal hills, limestone and ultramafic substrates, which are often rich in tree species and high in endemics, vertebrate and other seed dispersers and pollinators are generalists relying on more fertile adjacent habitats, some of which must be retained and (if greatly reduced) actively managed if the dependent plant species

populations of infertile habitat islands are to survive.

The original theory of island biogeography predicted the ultimate level to which species richness will be reduced when a habitat is reduced in area, but it does not predict how long it takes for this new equilibrium to be achieved. That depends on the length of life cycles and the dispersal rates and distances of a species. In the case of vertebrates, it has already been shown that reduction in numbers can be achieved within a century. We do not know how long such reduction will take in tree communities but the exceptional richness of quite small habitat islands in MDF in Sarawak imply that reduction will be slow, taking many centuries, provided pollinators and seed dispersers are conserved. At Bukit Timah, however, the only tree taxa showing evidence of extinction are those whose seeds are dispersed by the now extinct large frugivorous birds, the hornbills and imperial pigeons, apparently because dispersers now extinct have been replaced by more robust species of disturbed habitats. Hornbills and imperial pigeons are also most severely threatened by hunting in Borneo.

These facts leave us with two conclusions for biodiversity conservation in rapidly changing landscapes: that islands of specialized habitat often rich in endemism, once identified, should carry maximum conservation priority; and that adequate representative conservation areas of the once widespread matrix MDF habitat need to be set aside in each region before it is too late.

THE IUCN ENDANGERMENT CRITERIA AND BIODIVERSITY ASSESSMENT

The IUCN endangerment criteria, laid out for forest managers in the second edition of Symington (2004), put emphasis first in reduction of original known area of a species and second on a reduction in the numbers of its reproductive individuals. In hyperdiverse ecosystems, including lowland tropical rain forests, such an approach is only workable for assessment of threats to overall biodiversity if certain totemic species are used as proxy, or if a group of easily identifiable species are known or predicted to vary in composition and abundance with overall biodiversity.

It appears that IUCN assessments have mostly focussed on the first criterion nevertheless, using totemic vertebrates. As explained earlier, this approach should work well using widespread tree species for overall biodiversity threat assessment within the 'matrix' habitat in hyperdiverse terrestrial ecosystems such as rain forests. It will also highlight the massive reduction in their area and therefore numbers, and the fragmentation of what were originally continuous populations with potential for uninterrupted gene exchange. However, IUCN regards any species that has experienced a reduction in population of more than 50% over the last three generations as endangered, and those with a 20% reduction as vulnerable. Is it realistic to expect governments of countries formerly mostly covered by hyperdiverse ecosystems to conserve the vast tracts thereby implied? What revenue can be generated by such resources, especially in developing economies? Is there any indication that the industrialized nations would be willing to subsidize the cost? Rather, the best that should realistically be expected by the world community, all of whom are beneficiaries and all of whom should therefore be contributing, is to set aside well chosen examples of the matrix habitat, representing each geographical area and large enough to include 200 reproductive individuals of the rarest species. This area would likely be a minimum of 500 ha more where forest edges are in danger of degradation. In Malaysia, the virgin jungle reserves, instituted 50 years ago and in many cases well maintained, serve as a fine example of this approach.

The second approach, using the dipterocarps, has been adopted by the Forest Research Institute Malaysia using the 162 dipterocarp species in Peninsular Malaysia as indictors (L. G. Saw, personal communication). It has proven successful. As an example, an initial survey of the point endemic *Hopea subalata* defined its present range, which was used in successful negotiations leading to protection of this species from alignment of a major new road and from housing development. *Hopea subalata* is confined to a rare habitat, namely, coarse sandy soils overlying quartzite. Its locality also includes the only known surviving natural population of kapur, *Dryobalanops aromatica* and, nearby, *Rhodoleia championi* (Hamamelidaceae), a tree of lower montane forests rare in the peninsula. *Hopea subalata,* as a rare species confined to a rare habitat, therefore effectively acts as an indicator of a site rich in endangered species.

Such an approach is only occasionally valuable for vertebrates, but of vital importance for plant, including tree and therefore overall biodiversity and its conservation planning. It provides the means for rigorous rapid large-scale assessment. That is of critical importance where—as especially in rain forest—assessment of total biodiversity is impractical while a national survey of the distribution of easily identifiable tree species would not be completed before the options had long been lost. It is unrealistic to expect every habitat island to be set aside for biodiversity conservation. Rather, the present priority must be to identify islands that remain, then undertake thorough surveys upon whose results a ranking of priority for conservation can be made. The method therefore entails an initial identification of major habitats on the basis of surface geology maps (if available) and land form. This allows surveys to focus on a few representative examples of each landscape component, to assess their floristic distinctness. Conservation of habitats with distinct floras, especially those rich in endemics, should then aim to legislate, for representative examples of whole ecological island habitats (where less than 1000 ha), to include a buffer zone of adjacent habitat especially when it is known to be essential to conservation of pollen and seed dispersers.

In summary, conservation of a few large areas of lowland and other forest such as Taman Negara is essential for wildlife sustainment, but it is insufficient for conservation of biodiversity. These large areas must therefore be complimented by a network of smaller 'virgin jungle reserves' representative of biodiverse ecosystems which vary both with geographical distance apart and with physical habitat.

LOGGING AND BIODIVERSITY

It is sometimes questioned whether carefully managed logging, in particular selective logging with high minimum harvesting diameters, has a significant effect on biodiversity. This notion is supported by the undoubted increase of some wildlife, consequent on the higher productivity and nutritional value of many pioneer and successional plant species which increase following logging. This increase only occurs, of course, where hunting is restricted.

Primary forests consist of patches of trees, known to foresters as stands, which share the previous canopy opening. These gaps may be caused by a lightning strike or death of an emergent individual from a pathogen, in which case the tree may die standing, the branches gradually rotting off, with minimal damage to individuals beneath and little increase in light at the forest floor. Alternatively the gap may be caused by a windthrow or landslide, when several to many trees may be uprooted and the soil surface scarified of litter or even removed.

When a canopy opening leads to soil exposure, as in a windthrow, the forest will initially regenerate through germination of dormant or freshly immigrating seeds of a distinct but relatively species-poor guild of pioneers. Most of the ground exposed by most canopy gaps experiences little disturbance though, and forest succession is dominated by the diverse surviving saplings of shade tolerant species which were already established before the gap occurred. The faster growing of these species will dominate initially, and are therefore known as successional. Gradually, juveniles of more shade tolerant species succeed to the canopy replacing successional species if they die without disturbing the juveniles in the understorey. The subcanopy specialists likewise come to be dominated by a diverse array of slow growing shade tolerant climax species. In MDF, pioneer species comprise at most 10% of the species in primary rain forest, successional species roughly a further 30–50%. Successional species often comprise more than half the individuals, though not half the species, of the emergent guild which nevertheless also comprises less than 10% of the total tree species richness. Climax species comprise the great majority beneath the mature canopy, and also within the main canopy which is where the overall majority of tree species reach maturity in the forests of tropical Asia.

Different physical habitats, with their more or less distinct tree floras and therefore by implication biodiversity, permit differing rooting depths, experience differing levels of soil water deficit during droughts. Soils in floodplains, and those dominated by short-lattice clays therefore with minute pores, are frequently or permanently anoxic at shallow depths, and their tree roots shallow; frequent windthrow is ubiquitous in

floodplains and shallow peat swamps. Steep slopes experience higher landslip frequency and, therefore, often include large areas of successional stands. Thus these forest habitats therefore experience differing proportions of individual versus multiple tree deaths. Differing geomorphologies provide differing levels of shelter from windthrows and are differentially prone to landslips. These different habitats therefore experience different frequencies and intensities of canopy opening. Their tree floras include differing proportions of pioneer, successional and mature species in their canopies. Although canopy openings occur episodically and are unpredictable within the scale of our lifetime or that of a tree, they differ consistently in both frequency and intensity between habitats over the millennia that is required to reach stable species numbers in the distinctly different tree communities that occur in these different habitats and their landscapes. In Sarawak (Ashton & Hall 1992) and also in Sri Lankan MDF (Gunatilleke *et al.* 2004) we found that species richness is greatest at intermediate levels of canopy disturbance (Table 1). There, emergents are scattered and often in clumps, with space for a well developed and species rich main canopy of varying heights in between (Lambir, in our table). Where landscape scale catastrophe occasionally occurred, in our case probably severe drought (Bako in table) emergents suffered most but the drought, likely here in combination with low soil fertility, apparently affected overall tree species and therefore probably biodiversity. Unexpectedly, we also found that in sheltered well watered sites, including on fertile soils (e.g. Bukit Mersing in the table), rarity of emergent canopy disturbance leads to formation of extensive stands of such maturity that emergent individuals form a closed and continuous canopy. Their crowns are dense in these sites which may never experience soil water deficits. The main canopy is patchy and frequently absent, the subcanopy sparse, and the tree species richness low, even among the emergents. Nevertheless, each of these disturbance regimes and physical habitats supports its own distinct flora, worthy of conservation.

Each of these forests over the long term supports different proportions by area of stands at different successional stages. It ap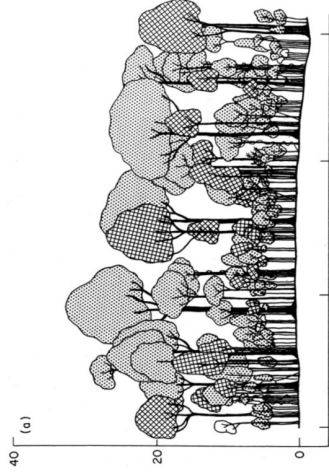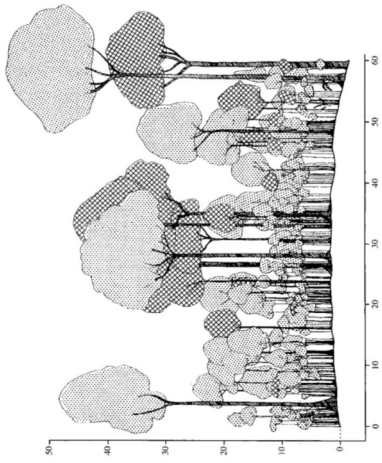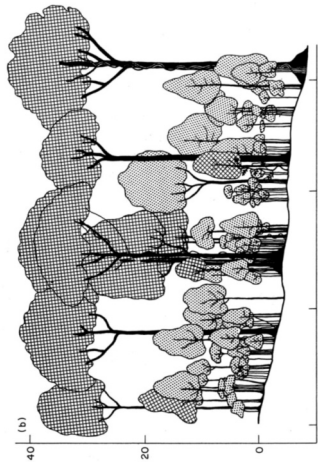pears though as yet we have no supporting evidence that the observed differences in species richness of forests with differing long-term disturbance regimes are due to the differing area, therefore differing balance between immigration and extinction rates, of the species specialized to each stand development phase. Our field observations imply too that species richness is greatest where late successional and climax species occupy, and may often co-occupy, the greatest proportional area of the forested landscape.

On the basis of these observations, what predictions can be made concerning the impact of logging on tree species richness, and therefore by implication biodiversity?

It must be accepted that the species richness of a tree community and its habitat cannot be increased by modifying its canopy disturbance regime. Increase would either be dependent on dispersal and competitive success from adjacent forest, which would take many centuries to reach the centre even of moderate-size forest compartments, or to even longer speciation processes. Claims that logging can lead to increased tree species richness are based on an artifact resulting from insufficient area sampled. Recent gaps occupy less than 15% by area in most rain forests (Whitmore 1984); their pioneer species are distributed in patches and often evade sampling until after logging. Then, they become more widespread therefore more likely to be sampled, thereby indicating an increase in species richness at the scale of the sample. However, the number in the forest as a whole will not have altered, unless an exotic weed tree species has been introduced as a consequence of the logging operation.

Logging, however carefully executed, fundamentally alters the canopy gap regime. This results in different relative areas of the gap, building and mature phases of the forest. Initially, the area of gap will increase, later that of the building phase, but the area of the mature phase, which is richest in species at reproductive maturity, will hardly increase in production forests before the next felling cycle is initiated. Further, slow-growing species will rarely reproduce sufficiently to sustain numbers, being cut before reaching sufficient size. Provided the soil and established regeneration is strictly protected during timber extraction, the first logging may lead to critical reduction of only a few species, occurring in nature in very low populations in

Table 1   Comparison of three forest types in Sarawak

Locality	Bako National Park	Lambir National Park	Bukit Mersing, Anap
Site characteristics	Drought-prone coastal slope; infertile freely draining sandy soil	Moderately drought-prone moderately infertile sandy loam soil; ridge and gentle slope	Mesic lower slopes; deep fertile basaltic clay loam soil
Profile diagram			
Number of species	223	321	143
No. pioneer species (%)	18 (8)	30 (9)	15 (10.5)
Emergent species (%)	10 (4.5)	40 (12.5)	8 (5.5)
Main canopy species (%)	111 (50)	147 (46)	43 (30)
Subcanopy species (%)	84 (38)	104 (32)	77 (54)

the mature phase stands. Examples nevertheless include genera of high utilitarian conservation value, such as several wild *Durio* and *Mangifera* and the heavy hardwood emergent legumes.

Logging in hill forests, if carried out strictly according to the rules, excludes forest on steep slopes and near water courses. Would not these include sufficient surviving mature phase stands to sustain the most threatened climax species?

What I have said is predictive, inferred from what knowledge we do have, but not yet supported by rigorous field tests. The Forest Research Institute Malaysia, with support from the Government of Malaysia, the Global Environment Facility of the United Nations Development Program, the International Tropical Timber Organisation and Harvard University, and the participation of members of the Malaysian research community, has initiated research in Temenggor Forest Reserve aimed at answering these questions. The project focuses on a central set of challenges: How can conservation and continued timber production together be optimally combined, on both economic and ecological criteria, in a hypodiverse forested landscape? Are they better achieved by modifying logging procedures to accommodate biodiversity conservation requirements, or by setting aside strict conservation virgin jungle reserves while managing elsewhere for optimal sustainable timber production?

Opportunities cannot yet exist to test the impact of successive logging cycles on biodiversity because these require samples in which the impact of all previous logging has been meticulously recorded. The current research must therefore document and establish permanent field samples which can provide such future possibilities. In the meantime, comparative data from samples documented before and after their first felling can be used to develop predictive models which can serve as initial tests of my hypothesis.

Whatever the results, two questions will remain:
(1) The evidence from forests already logged shows that few concessionaires have kept strictly to the rules. At present, it is unlikely that they will do so unless strictly overseen by a committed and incorruptible forest service (see Pearce *et al.* 2003), or a corporation representing the interests of far-sighted forest owners. This is because keeping to the rules reduces profits sometimes close to the margin. How can incentives be formulated which will induce concessionaires to keep to them in future, when the rules ensuring conservation will inevitably be stringent and demanding if they are to achieve their objective?
(2) If the Government of Malaysia is to cover the significant cost, whether of timber harvesting constraints or of removing conservation areas from the production forest estate, and including the cost of protection and hunting controls, it could reasonably lay national claim to genetic resources thereby protected. But does that make sense, when the fact that Malaysia's major crops have all depended for their introduction on the acceptance of genetic resources as a global resource? Yet, if that broad-minded view of genetic resources is to be accepted, those nations likely to benefit must volunteer realistic contributions to the cost of their conservation. How can we induce them to do so?

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