



Assessing biodiversity at landscape level in northern Thailand and Sumatra (Indonesia): the importance of environmental context

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Abstract

Most biodiversity assessment methods tend to sample isolated areas of land cover such as closed forest or local land use mosaics. Contemporary methods of assessing biodiversity are briefly reviewed and focus on the relative roles of the Linnean species and plant functional types (PFTs). Recent case studies from central Sumatra and northern Thailand indicate how the range distributions of many plant and animal species and functional types frequently extend along regional gradients of light, water and nutrient availability and corresponding land use intensity. We show that extending the sampling context to include a broader array of environmental determinants of biodiversity results in a more interpretable pattern of biodiversity. Our results indicate sampling within a limited environmental context has the potential to generate highly truncated range distributions and thus misleading information for land managers and for conservation. In an intensive, multi-taxa survey in lowland Sumatra, vegetational data were collected along a land use intensity gradient using a proforma specifically designed for rapid survey. Each vegetation sample plot was a focal point for faunal survey. Whereas biodiversity pattern from samples within closed canopy rain forest was difficult to interpret, extending the sample base to include a wider variety of land cover and land use greatly improved interpretation of plant and animal distribution. Apart from providing an improved theoretical and practical basis for forecasting land use impact on biodiversity, results illustrate how specific combinations of plant-based variables might be used to predict impacts on specific animal taxa, functional types and above-ground carbon. Implications for regional assessment and monitoring of biodiversity and in improving understanding of the landscape dynamics are briefly discussed. © 2004 Elsevier B.V. All rights reserved.

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1. Introduction

The complexity and high cost of assessing and monitoring biodiversity have restricted the numbers of baseline studies needed to identify and calibrate useful indicators. Further, the relatively few published regional studies (Parker and Carr, 1992; Parker et al., 1993; Howard et al., 1996) tend to involve largely id-

iosyncratic methods that are difficult to implement for comparative interregional surveys. Because surveys are intrinsically, logistically and financially demanding, they tend, to be geographically and environmentally restricted. A case in point is a now widely quoted multi-taxa study conducted in a lowland tropical rain forest mosaic in Mbalmayo, Cameroon (Lawton et al., 1998), where the authors concluded that for their study at least, the use of any 'indicator' taxa to predict the occurrence of other taxa could not be substantiated. On the one hand, their study is relevant to the present paper as it has serious implications for biodiversity assessment methods in general. On the

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other, it is useful to consider the conditions surrounding the Mbalmayo study in which all the predictors used were faunal—plant-based indicators were not included in the survey. In a tropical lowland situation where plants are likely to be key indicators of fauna this appears to be a significant flaw in an otherwise comprehensive study.

The study by Lawton et al. (1998) was restricted to a rain forest locality where physical environmental variation was limited to a mosaic of successional forest types and timber plantations. Under such conditions the distribution range of many of the taxa is almost certain to be truncated, with a correspondingly reduced capacity to detect or predict environmental bounds to their distribution. The likely consequence of this is that the construction of useful predictive models of species distribution and the associated indicators will be only marginally useful. We can speculate that if the Mbalmayo study had included a wider range of physical environments or land use intensity gradients it might well have provided very different boundary conditions and thus predictive combinations between taxa. Further, because all or most fauna depend on plant life, the predictive value of indicators may have been considerably improved had plants been included.

Our purpose here therefore is to compare outcomes from inventories that embrace a wider set of predictive attributes including species and non-species-based attributes based on adaptive features, as well as strategies that compare outcomes from samples using both restricted and extended environmental contexts.

To establish a conceptual and operational framework it is necessary to first consider the reasons for undertaking biodiversity surveys and arguments for and against the use of species as the sole unit of biodiversity currency as is the case in the majority of surveys. We then present outcomes of two multi-taxa case studies along land use intensity gradients in northern Thailand and central Sumatra, with the main focus on the latter.

Evidence for the need to conserve biodiversity is well established in literature and is reflected in the international convention on biological diversity that has addressed a series of issues for attention by its signatories. Despite the agreed urgency to develop a framework for biodiversity conservation, there is as yet, no operational definition for biodiversity. According to Weitzman (1995) the implementation of any plan to

preserve biodiversity is hampered by the lack of an operational framework or an objective function and “We need a more-or-less consistent and useable measure of the value of biodiversity that can tell us how to trade off one form of diversity against another.” Miller and Lanou (1995) also maintain “The value of biodiversity is determined largely by the interaction between human society and biodiversity.” This implies that among other things, there should be a dynamic link between biodiversity and productivity for human needs.

These pressures highlight both the need for a working definition of biodiversity and a cost-efficient, generic tool for its assessment that can be used in turn to inform policy planners and managers. While the species remains the sole currency unit for biodiversity assessment (Heywood and Baste, 1996) there will be little progress (cf. Wulff, 1943). Species richness and abundance used alone and in the absence of other attributes of behaviour and performance can seriously mislead and impede biodiversity assessment. In addition, parity in species richness between different sites does not guarantee equivalence in either genetic composition or response to environment. Partly for this reason, an emerging school of thought now considers assessment should include functional features or types as well as species (Box, 1981; Gillison, 1981, 1988; Nix and Gillison, 1985; Cowling et al., 1994a,b; Huston, 1994; Collins and Benning, 1996; Martinez, 1996; Woodward et al., 1996). Varying definitions of functional types are so far most commonly associated with guilds (Bahr, 1982; Gillison, 1981; Huston, 1994; Gitay and Noble, 1996; Mooney, 1996; Shugart, 1996; Smith, 1996; Smith et al., 1996; Gillison and Carpenter, 1997) but as Martinez (1996) asserts “. . . the functional aspects of biodiversity are a broad and vague concept that needs substantial added specification in order to become scientifically more useful.” Cramer (1996) also feels the task of screening all the world’s species for functional types is impossible and that for a global model, a breakdown of the world’s vegetation can only be done based on major physiognomic or otherwise recognisable features. Recent global ecoregional studies (Gillison and Thomas, unpublished) suggest that, to the contrary, broad physiognomic and structural features can mask important functional and taxonomic differences in biodiversity. Gillison and Carpenter (1997) and (Gillison and Alegre, 2004, unpublished) have

also shown it is possible to use generic functional or adaptive morphological attributes to characterise and quantify vegetation response to environmental change such as land use, climate and soil. The rapidly emerging interest in functional types suggests the time may be ripe for extending the species-based context to include genetically determined adaptive responses of taxa in biodiversity assessment.

1.1. Review of plant functional types as biodiversity indicator

A quantitative method has been developed for characterising vascular plants according to a set of adaptive features or plant functional attributes (PFAs) that describe a plant as a three component, 'coherent' (sensu Vogel, 1991) or functional model known as a *modus* or plant functional type (PFT) (see Section 2). This consists of the photosynthetic envelope, modified Raunkiaerean life form (Raunkiaer, 1934) and above-ground root system. As described by Gillison and Carpenter (1997) PFTs are combinations of essentially adaptive morphological or PFAs, e.g. leaf size class, leaf inclination class, leaf form and type (distribution of chlorophyll tissue) coupled with a modified Raunkiaerean life form and type of above-ground rooting system. PFTs are derived according to a specific grammar or rule set from a minimum set of 35 PFAs. An individual with microphyll-sized, vertically inclined, dorsiventral leaves supported by a phanerophyte life form would be a PFT expressed as *mi-ve-do-ph*. The method uses a semantic rule set and grammar (Gillison and Carpenter, 1997) to generate a theoretically finite set of unique PFA combinations for the world's approximately 300,000 vascular plants. Using this rule set, about 7.2 million combinations or PFTs are possible although it is thought that the real number is closer to 4000. There is no a priori interdependence between PFTs and species; the mapping being many-to-many, i.e. more than one PFT can occur within a species and vice versa. The advantage of functional over solely species-based methods is that they can be universally applied by observers with limited botanical and ecological experience. They can be used to compare functional characteristics of individuals and sets of individuals independently of species, e.g. where taxa may be geographically disjunct but possess similar adaptations to environment.

In a comparative study of methods of characterising site productivity and growth patterns in north Queensland rain forests Vanclay et al. (1996) showed the PFA method outperformed traditional methods of site characterisation. The method is now undergoing further tests by the Forestry Department, Qld. DPI (Keenan, Woldring pers. commun.). Gillison et al. (1996) have shown consistently high correlations between total numbers of species and unique *modi* (or PFTs) recorded from 40 m × 5 m plots across a wide range of environments (cf. Baskin, 1994). The implications from this are that in surveys where botanical expertise is lacking, PFTs can be used to predict species richness with a high degree of confidence. This may also benefit rapid assessment of plant biodiversity and improve correlations between plant with animal biodiversity (cf. Gillison et al., 1996). A field proforma specifically designed for rapid survey can now be used by observers with minimal training to characterise site physical features, vegetation structure, species composition and PFTs to rapidly describe a specific habitat for a taxon or set of taxa.

It is one of the tenets of rapid biodiversity assessment (RBA) that for practical purposes, there should be indicators or surrogates of more complex plant and animal assemblages. Whether this is a realistic assertion is a continuing source of debate (Cranston and Hillman, 1992; Reid et al., 1993; Pearson, 1995; Howard et al., 1996) and there is often questionable theoretical support for targeting so-called keystone species (Tanner et al., 1994). There is nonetheless an increasing need for more manageable attribute sets that can be used to carry other information such as the status of key pollinators and seed dispersers that may not be available at the time of survey (Miller et al., 1995). To demonstrate indicator efficiency requires calibration from very intensive baseline studies of taxa and functional types at a comprehensive range of spatial, temporal and environmental scales. Such baseline studies are almost non-existent in complex tropical environments. Ongoing studies within the context of the ICRAF-led consortium on Alternatives to Slash and Burn (ASB) project show varying correlative trends. In a baseline study of Sumatran rain forests, Gillison et al. (1996) showed that while plant biodiversity increased with elevation from 500 to 900 m a.s.l., the converse was true for insects and birds. While such confounding effects can be

accommodated by appropriate regression models and multiple discriminant formulations, predictive models of biodiversity based on environmental correlates such as elevation clearly need to be carefully evaluated before being used by managers. It follows that environmental context and scale are important in designing field studies of biodiversity (see also He et al., 1994).

Most practitioners now concede the landscape matrix is critical to supporting biodiversity (cf. Forman and Godron, 1986; Franklin, 1993) and this has been central to survey design and data collection across all the ASB ecoregional benchmark sites. Because disturbance is a critical determinant of biodiversity (Petraitis et al., 1989; van der Maarel, 1993; Phillips et al., 1994), factors such as agriculture, shifting cultivation and forest fragmentation (Grime, 1979; Bierregaard et al., 1992; Sayer and Wegge, 1992; Margules and Gaston, 1985; Brooker and Margules, 1996) should be considered when designing a biodiversity survey. For this reason the ASB sites were located subjectively to represent a range of dynamic conditions, specifically along successional gradients of land use from pristine rain forest, logged-over forests and plantations, to degraded grasslands.

When considering the relevance of environmental context in field surveys, the issue of plot size is always a source of debate. Recent studies show that for plant diversity, useful information can be recorded from plots as small as 50 m × 2 m (Parker and Bailey, 1991; Parker and Carr, 1992; Parker et al., 1993) and 40 m × 5 m (Gillison et al., 1996). The advantage of 'small and many' versus 'few and large' is that the former is more cost-effective when sampling variation in biodiversity at landscape level (cf. Keel et al., 1992). Variation of this kind demands cost-effective survey techniques (cf. Margules and Haila, 1996). Because the distribution of plants and animals is determined mainly by environmental gradients, gradient-based techniques using the gradsect approach offer one means of sampling such variation (Gillison and Brewer, 1985). With gradsects, sites are located according to a hierarchical nesting of presumed physical environmental determinants such as climate, elevation, parent rock type, soil, vegetation type and land use. This approach has been shown to be more cost-efficient than purely random or systematic (e.g. grid-based) survey design (Gillison and Brewer, 1985; Austin and Heyligers, 1989; Wessels et al., 1998) and because gradients themselves are be-

ing sampled, this will usually enhance the efficiency of extrapolative spatial models.

Issues of biodiversity conservation inevitably raise important questions of site representativeness. For a programme involved in the selection of 'best-bet' options for biodiversity and productivity, a manager may need to choose between different locations to ensure optimal management. For this a range of sophisticated computer-based solutions already exists. These are based mostly on species occurrence but may include environmental features such as land classes (Nicholls and Margules, 1993; Pressey et al., 1996a,b; Csuti et al., 1997). Other species-based approaches use additional levels of higher taxa (Prance, 1995) or a measure of 'phylogenetic distance' to include taxic richness or genealogical relationships as embodied in taxonomic classifications, typically by a weighting of the relative number of species per genus, genera per family, etc. (Vane-Wright et al., 1991; Williams et al., 1992; Faith, 1992, 1993, 1995). A problem with species-dependent approaches of this kind is that for many tropical lowland forests species identification is difficult and time-consuming. In addition, the majority of these algorithms require expertise that is frequently lacking in developing countries. For this reason, and because functional types can be usually more readily identified than species, Gillison and Carpenter (in Gillison, 2002) developed an analogous concept of 'functional distance' based on PFTs. The algorithm is being incorporated in a new data-entry software package VegClass PFAPRO designed to run on a PC as a Windows application (Gillison, 2002). When data from a series of plots containing PFTs have been entered, VegClass has the facility to generate an interplot distance matrix. The matrix can be subjected to exploratory data analysis to help identify attributes that best indicate the occurrence of specific taxa or land use type or habitat condition. Such information can be readily transferred to managers.

Most vegetation classification and survey methods incorporate a combination of broad structural variables coupled with seasonality (deciduousness) and a list of dominant species, e.g. 'very tall evergreen Dipterocarp forest'. While this is useful for mainly geographic purposes it is insufficiently diagnostic for management purposes. In addition, structurally similar vegetation types are usually annotated by regionally different plant species. Within a region vegetation described

according to vegetation structure may be adequate for describing animal habitat but similar structure in separate global ecoregions are not necessarily ecologically equivalent. For ecologically sensitive classifications additional, response-based attributes such as PFTs provide added value. As PFTs are generic and largely independent of species they can be used to make ecological comparisons between geographically remote areas where environments and adaptive features may be similar but where species differ.

2. Methods

2.1. Study locations

Two study areas are used in this paper. The primary area was located at Pasir Mayang in Jambi Province, central Sumatra (Murdiyarto et al., 2002) where an intensive, multi-taxa survey was undertaken in late November, and early December 1997. A subsequent survey restricted to birds, plants and soils was undertaken in the Mae Chaem watershed, north west of Chiang Mai, northern Thailand (Gillison and Liswanti, 1999). In both locations the aim was to capture spatially referenced data across a range of representative land use intensity gradients. At Jambi, these ranged from intact humid lowland rain forest on a lowland plain, through 'Jungle rubber' to rubber monoculture plantations, softwood plantations and subsistence gardens to degraded *Imperata* grasslands (Table 1). At Mae Chaem the gradient sampled was from upland cool moist evergreen rain forest to lowland permanent cropping systems maintained by three primary ethnic land owner groups (Karen, Hmong and lowland Thai).

In Jambi the taxa surveyed included canopy and ground insects, large and small mammals including bats, birds and vascular plants. Details of collection methods for fauna are outlined by various authors (Gillison, 2000). The focal point for all taxa were centred on a 40 m × 5 m strip transect used for vegetation studies. Because we use plants as the primary indicators of taxa the recording method is described here in detail. The plant functional attribute proforma (modified from Gillison, 1988 and updated by Gillison and Carpenter, 1997) was used to record site physical features geo-referenced by a hand-held

global positioning system (GPS) in degrees, minutes and seconds; slope percent (clinometer); elevation (m) (digital aneroid altimeter); aspect in degrees (compass); parent rock type; soil type; vegetation structure (mean canopy height (m), crown cover percent, basal area ($\text{m}^2 \text{ha}^{-1}$)); litter depth (cm); Domin scale cover-abundance estimates of wood plants <2 m tall and Domin estimates of bryophytes; all vascular plant species and PFTs (listed in part in Table 1). Although they tend to be indicative of a species, they are independent of species in that more than one species can occur in one PFT and more than one PFT in a species. PFTs allow the recording of genetically determined, adaptive responses of plant individuals that can reveal infraspecific as well as interspecific response to environment (e.g. LUTs) in a way that is not usually contained in a species name. They have a major advantage in that because they are generic they can be used to record and compare data sets derived from geographically remote regions where, for example, adaptive responses and environments may be similar but where species differ. The data are recorded along a 40 m × 5 m strip transect located along the contour.

The data were compiled in a laptop computer using VegClass (Gillison, 2002). VegClass facilitates compilation according to the rule set developed by Gillison and Carpenter (1997); it also facilitates the summary analysis of meta-data as well as producing graphs of relationships between different plant and vegetation variables. Using PFAPro, data logged for each 5 m × 5 m quadrat allow the generation of cumulative species and PFT totals per unit area and this allows the subjective inspection of asymptotic curves that can indicate whether or not a plot is an adequate sample of the vegetation or LUT.

Four observers (ecologist and assistant, botanist (2×) and two laborers) collected plant voucher material later identified and curated at the *Herbarium Bogoriense*. This method facilitated sampling even the most complex rain forest plot of 177 species in less than 3 h.

3. Results

Plant and bird distribution data from Mae Chaem are used to illustrate the need for ensuring environmental

Table 1
Site physical environment and vegetation features with symbols used in analyses

Site no.	Lat. (S)	Long. (E)	Elev. (m)	Land use type (LUT)	M.Can (m)	CC (%)	M_BA (m ² ha ⁻¹)	PFTs	Plant species	Plant species/PFTs
BS01 (◆)	1°4'47"	102°6'02"	76	Intact rain forest (out side permanent plot)	21	75	27.33	25	50	2.00
BS02 (◆)	1°4'45"	102°5'53"	60	Intact rain forest (BIOTROP permanent plot)	20	65	32.67	38	117	3.08
BS03 (◇)	1°4'43"	102°5'55"	85	Logged over 1984 (old log ramp, secondary forest)	10	35	13.33	33	48	1.45
BS04 (◆)	1°4'53"	102°6'09"	0	Logged over 1979/1980 (secondary forest)	24	80	32.67	37	68	1.84
BS05 (◆)	1°4'56"	102°6'05"	75	Logged over 1983 (secondary forest)	28	70	27.33	30	58	1.93
BS06 (○)	1°4'59"	102°6'43"	65	<i>Paraserianthes falcataria</i> plantation 1993/1994	6.00	40	6.00	47	115	2.45
BS07 (○)	1°3'09"	102°8'10"	55	<i>Paraserianthes falcataria</i> plantation 1993	16	30	8.00	41	100	2.44
BS08 (○)	1°5'25"	102°7'05"	53	Rubber monoculture plantation (8 years)	11	65	14.67	10	11	1.10
BS09 (○)	1°5'27"	102°6'56"	53	Rubber monoculture plantation (8 years)	12	70	15.33	5	7	1.40
BS10 (●)	1°10'12"	102°6'50"	30	Jungle rubber (15–38 years)	14	50	18.00	12	15	1.25
BS11 (●)	1°10'13"	102°6'46"	30	Jungle rubber (15–38 years)	14	50	20.67	13	19	1.46
BS12 (□)	1°35'58"	102°21'11"	40	Tall <i>Imperata</i> grassland	1	90	0.01	31	43	1.39
BS13 (□)	1°35'56"	102°21'12"	40	Short <i>Imperata</i> grassland	1	90	0.01	36	103	2.86
BS14 (■)	1°36'05"	102°21'22"	48	Cassava plantation	1.8	50	0.10	39	111	2.85
BS15 (■)	1°36'00"	102°21'21"	48	Cassava plantation	1.8	40	0.10	35	104	2.97
BS16 (+F)	1°10'13"	102°6'58"	30	<i>Chromolaena</i> , <i>Clibadium</i> 4 year fallow	2	95	0.10	28	43	1.54

Lat.: latitude; Long.: longitude; Elev.: elevation; M.Can: mean canopy height; CC: crown cover; M_BA: mean basal area, all woody plants; PFTs: plant functional types.

representativeness along elevational (climatic) ranges. From Table 2, it is clear that whereas sites restricted to within 700–900 m elevation intercept most of the taxa listed, they do not include sufficient range distributions for modelling or predictive purposes; correlates derived from this restricted range are likely to

mislead if extrapolated beyond the sample bounds using elevation alone.

For Jambi, where elevational range is limited along a relatively flat lowland plain; the major determinants of species distribution are soil and drainage factors overlaid by patterns of land use. Gillison (2000)

Table 2
Elevational range distributions of some key plant and animal taxa: Mae Chaem watershed, northern Thailand

Species	Elevation (m)											
	500	700	900	1100	1300	1500	1700	1900	2100	2300	2500	
Plants												
<i>Dipterocarpus tuberculatus</i>	■	■	■									
<i>Shorea obtusa</i>	■	■	■	■	■							
<i>Castanopsis</i> sp.	■	■	■	■	■	■						
<i>Chromolaena odorata</i>	■	■	■	■	■							
<i>Imperata cylindrica</i>	■	■	■	■	■							
<i>Smilax</i> sp.	■	■	■	■	■	■	■	■	■	■	■	■
<i>Melastoma malabathrica</i>			■	■	■	■						
<i>Arisaema</i> sp.			■	■	■	■	■	■	■	■	■	■
Birds												
Collared Falconet	■											
Sooty-headed Bulbul	■	■	■	■	■							
Red Jungle Fowl		■	■	■	■							
Scarlet Minivet			■	■	■							
Striped Tit-babbler				■	■	■						
Grey-throated Babbler					■	■	■	■	■	■	■	■
Arctic Warbler												■

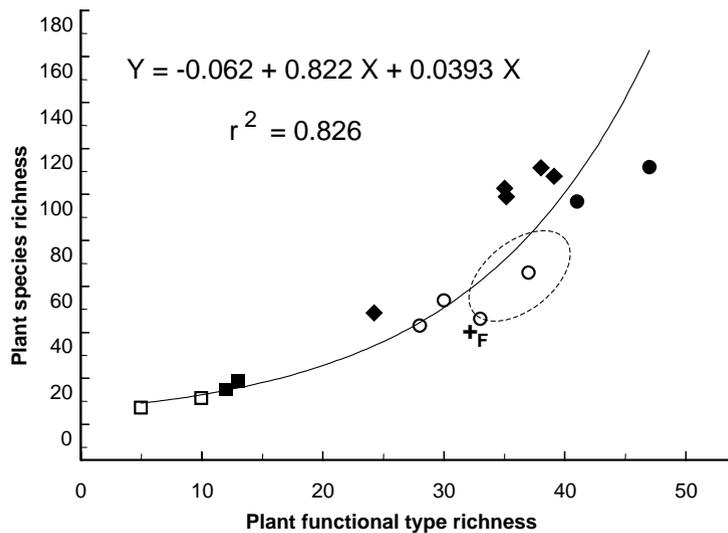


Fig. 1. Relation between plant species richness and plant functional type (PFT) richness in the Jambi survey (refer Table 1 for symbols: solid diamond indicates closed forest, solid circle indicates Jungle rubber).

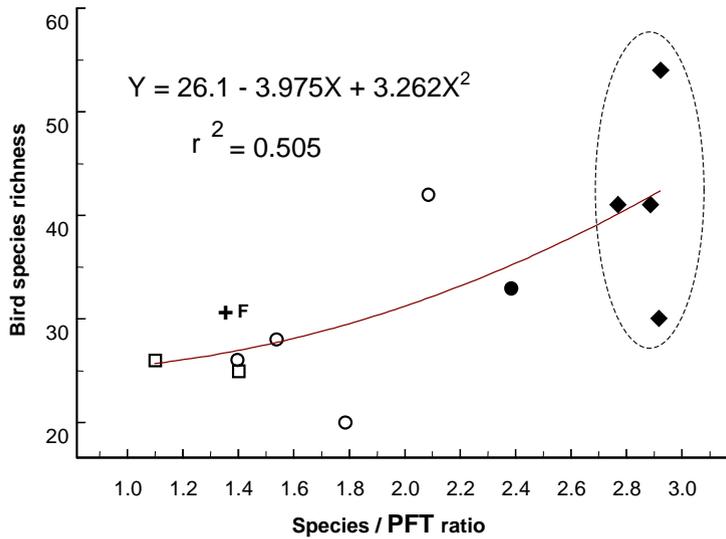


Fig. 2. Relation between bird species and the ratio plant species richness:PFT richness.

found correlations between vascular plant species richness, PFT richness and many animal taxa and site physical variables (soil nutrients, above-ground carbon) were frequently improved by using the ratio of species:PFTs usually with a second order polynomial regression. Here we use graphs to illustrate these regressions with bird species richness, Collembola species richness and above-ground carbon. A regression between richness in plant species and PFTs

(Fig. 1) reveals a highly significant correlation along a gradient of land use intensity. The same relationship is not apparent within the four closed forest types due to reduced habitat variability. This pattern is repeated for birds (Fig. 2) using co-located data from Jepson and Djarwadi (2000) and Collembola (Fig. 3) (data from Watt and Zborowski, 2000) and above-ground carbon (Fig. 4) (data from Hairiah and van Noordwijk, 2000).

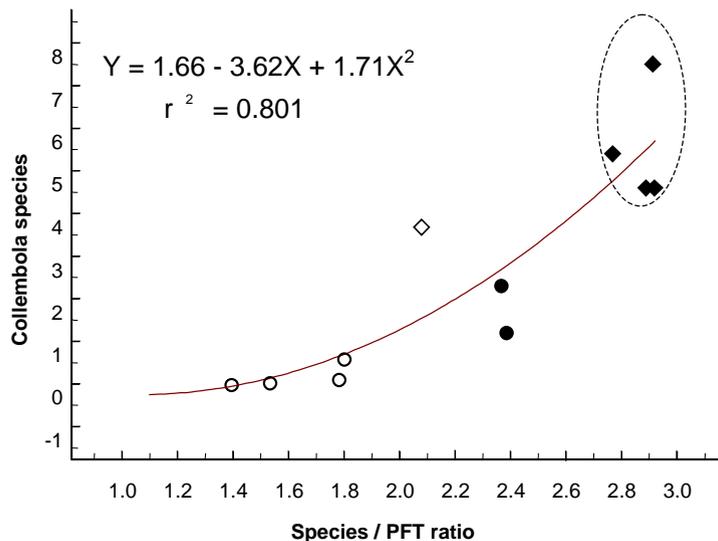


Fig. 3. Relation between Collembola species richness and the ratio plant species:PFT richness.

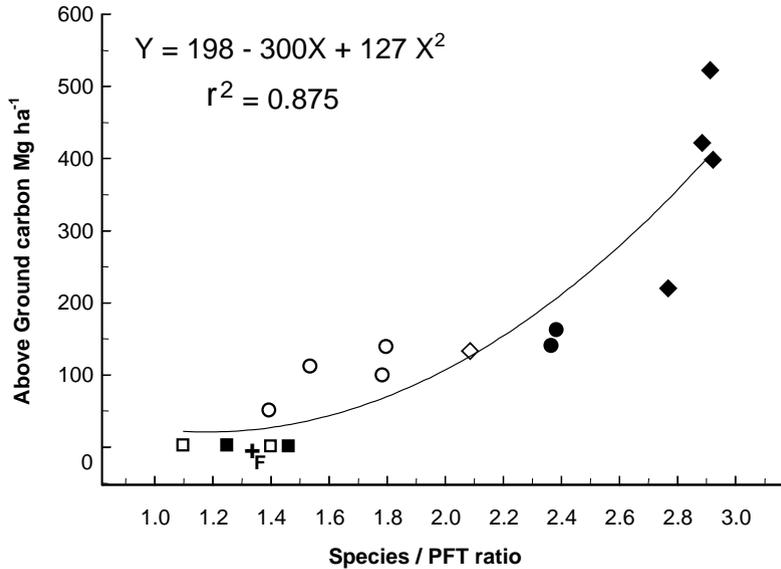


Fig. 4. Relation between above-ground carbon and the ratio plant species richness:PFT richness.

The examples given here are among the best correlates extracted from a much wider range of taxa and soil physico-chemical data. Although correlations differ between groups there is an unmistakable trend with land use intensity. Additional correlation matrices and pattern analyses described by Gillison (2000) show that other correlations between plant species and PFTs and vegetation structural variables are consistent with the pattern described here.

4. Discussion

Although the number of closed rain forest plots is insufficient for an adequate statistical analysis, the pattern of relationships between various taxa and the species:PFT ratios is quite clear. From these outcomes and from other field observations it seems unlikely that additional samples from closed tall forest sites in the region would significantly alter the pattern observed here. At a much finer scale of within-forest variation PFTs are likely to account for significant amounts of variance in soil nutrient availability and soil structure where forest structure and species composition varies across soil types (Gillison, 2000). Where this is secondarily modified by variation in the frequency and intensity of logging there is likely to be a commensurate

response in the composition and richness of plant taxa and PFTs. The extent to which this may be associated with change in the distribution of certain animal taxa, especially insects is, as yet, unclear. Sampling difficulties for certain groups of taxa, for example large mammals (such as Sumatran Tiger, Rhino and Tapir) make difficult speculation about the need for increased sampling ranges although empirical evidence suggests this is required.

The highly intensive sampling strategy required for certain taxa created considerable logistic difficulties in sampling all taxa in all plots. Despite the relative paucity of samples overall, the total number (16) is generally representative of the range of extremes of land use types in the region studied. Paired plots were sampled for at least seven major land use types. Although not all plots were sampled for each taxon (16 for plants and above-ground carbon, 12 for birds and 11 for insects) the results support our contention that effective biodiversity assessment in lowland tropical regions must take into account as far as possible, range distributions of key taxa and functional types and that sampling strategies should include an adequate array of LUTs as well as naturally occurring physical environmental gradients.

The degree to which sampling is 'adequate' will be constrained by the level of available logistic support

coupled with the quality and extent of information about such elements as climate, soils, parent rock types, drainage systems, land cover and land use and the distribution of people and infrastructure. In both Mae Chaem and Jambi considerable information was already available from literature and from digital, geo-referenced, databases. Coupled with ground reconnaissance and access to remotely sensed imagery this provided a comprehensive and informative framework for locating gradsects and for selecting taxa for survey purposes. Parallel studies have been undertaken in Cameroon and the Western Amazon basin (Gillison and Alegre, 2004, unpublished) and at global level (Gillison et al., 2004; Gillison and Thomas, unpublished). These show consistent patterns in the relationship between vascular plant species and PFTs along gradients of land use and naturally occurring physical environmental gradients, in particular climate and soil nutrient availability.

Intensive, calibrational, multi-taxa surveys of the kind undertaken in central Sumatra provide a useful comparative basis for selecting appropriate indicators for biodiversity assessment. The extent to which such studies are useful and relevant to land managers will be reflected in their capacity for extrapolation within the areas being managed for acceptable tradeoffs between sustaining biodiversity and economic returns to landowners and managers. The results from the present study tend to put into question findings from surveys that may be restricted to a local land use mosaic where plants are not used as indicators and where range distributions of many taxa may be significantly truncated.

5. Conclusions

For regional biodiversity surveys where the purpose is to locate and identify indicators of land use impact it is necessary to identify an appropriate sampling context in order to ensure adequate coverage of range distributions of the taxa and functional types of concern to management. Samples should include a representative range of land use types as well as naturally occurring physical environmental gradients that are considered important in defining plant and animal habitat.

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