Abstract

New Technology for Rapid Assessment and Monitoring Change in Forest Dynamics

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The rapid onset of global change requires new, cost-effective approaches to assessing and monitoring change in forest condition. The dimensions of the global problem also demand a generic approach using harmonious, low-cost, high-return data-gathering procedures where data can be readily compared at local, regional and global scale. The data acquired should be easily understood and applied by planning and implementing agencies worldwide. Recent developments combining remote sensing technology with on-ground vegetation assessment are presented. Traditional, descriptive vegetation classification and survey methods are now enhanced by the addition of easily-recordable measures that reflect plant response to environmental change. The rapid survey methodology known as 'VegClass' [www.cbmglobe.org] employs a recording protocol that includes site physical features as well as plant species, vegetation structure, plant functional types and land use history. Because the method is generic, all stages of forest development can be assessed along a maritime/boreal/ arctic continuum in the Russian Far East and directly compared with data similarly acquired in other world regions. Forest data from 37 countries including boreal/arctic regions are briefly compared. Recent results from an integrated baseline survey in Mozambique (East Africa) are presented. These results show that the VegClass data can now be linked with new remote sensing technology to help monitor effects of environmental change from space as well as on ground. The user-friendly, computer software is freely available and intensive training operations in a number of countries indicate the methodology is readily transferable. The relevance of this approach to solving problems of forest management in the Russian Far East is briefly discussed.

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Forest managers, plant ecologists and economic planners are experiencing new demands in the face of climate change. In environmental extremes such as high latitudes and high elevations, changes in thermal regimes are already resulting in measureable shifts in plant and animal habitat with noticeable consequences in species composition. More than 70% of Russian Far East forests are located on permafrost soils [Kondrashov 2004, Gordon n.d.]. Warming, thawing, and degradation of permafrost have been observed in many locations in recent decades and are likely to accelerate in the future as a result of climatic change resulting in potentially high impacts on existing ecosystems [Anisimov and Reneva 2006]. The advent of wildfire may also lead to the collapse of the permafrost mantle leading to expansion of peatland[Myers-Smith *et al.* 2008]. These changes that are compounded by increasing resource exploitation present a major challenge for scientists, land managers and governments. No longer can we rest comfortably on traditional approaches to natural resource assessment when the species that make up community classifications of the past are subject to new and in some cases, rapidly changing assembly rules. There is now, quite clearly, a case for complementing static concepts of vegetation and habitat classification with more dynamic approaches that facilitate assessing and monitoring change according to response-based variables. Nowhere is the sense of urgency more evident than in the world’s forests.

This brief presentation will examine first, the kinds of biophysical data required for forest management; second, the types of data currently in use and third, explore recent advances in data acquisition and analysis that may be applied to forests under changing environments.

Traditional western silvicultural management has focused mainly on the commercial production of cellulose. Forest inventory in Russia is largely concerned with stem biomass although the data may be subject to different assessment methodologies [Kukuev *et al.* 1997, Alexeyev *et al.* 2004]. In North East Asia, forest management in densely populated countries such as Japan and Korea tends to be far more comprehensive, embracing not only wildlife but a wide range of other non-timber forest products. For the most part, forest inventory remains based on static principles and general vegetation classification remains heavily biased towards plant species [Krestov 2003, Nakamura *et al.* 2007] . For most commercial purposes, formal forest inventories are tree-based, being centred around measurements of tree structure and biomass, complemented by growth and mortality data of desired species where these are available. These types of data then become the focus of aerial and space-borne surveys (Houghton *et al.* 2007) in which much potentially valuable non-tree resource data are excluded. Attempts to use remote sensing applications to model changes in forest ecosystems in the Russian Far East [Gaston *et al.* 1997] have incorporated *a priori* global vegetation indices (GVI) and normalized difference vegetation index (NDVI) as input. While such modelling can provide a useful tool for modelling gross change in land cover and vegetation it rarely includes the ground truthing required for management. In the past two decades, diminishing global resources, increased awareness of biodiversity values, climate change impact and an urgency to undersand the dynamics of carbon sequestration have exerted new demands on forest inventory that has become increasingly multipurpose as a result. An unfortunate outcome is that quantification of these additional elements does not conform easily with traditional inventory formats. Forest inventory procedures nonetheless appear to influence non-commercial biodiversity surveys e.g. in species-rich complex humid tropical forests that remain for the most part based on tree structure and tree species [*cf.* Dallmeier and Comiskey 1996].

Effective 21st century forest management now requires a very different approach; one that embraces not only dominant commercial tree species, but also a more comprehensive range of biodiversity-oriented species and life forms and their environmental determinants. The problem for most forest managers is that there are few, if any, cost:effective inventory methods available that satisfy this purpose. The world's remaining forests are now being so severely impacted by global change that their ecological integrity is clearly open to question. In Russian forests for example, allometric relationships between plant parts have reportedly changed over the past four decades (Lapenis *et al.* 2005). In many cases, plant and animal species that may have been restricted to forests have undergone change in spatial and temporal distribution. Examples of species whose distribution ranges extend beyond forests boundaries are numerous (Gillison *et al.* 2008a). As a consequence, dynamic models of forest performance that fail to take into account these factors run the risk of generating misleading outcomes for managers. Many plant species exhibit a wide variety of phenotypic and genotypic responses to environmental change. Depending on site characteristics and silvicultural treatment for example, many so-called 'tree' species can exhibit change in leaf and stem structure from single- to multi-stemmed with accompanying changes in leaf inclination and size. As a consequence of exposure to canopy opening, specific tree species may also show an increase in stem photosynthesis while others do not. In tropical forests, depending on successional stages, certain fast-growing 'pioneer' species can change dramatically in leaf and stem form in a relatively short lifetime. These responses are difficult to quantify through purely species-based inventories, and these and related response-baed phenomena have consequences for modelling forest performance and for assessing and monitoring wildlife habitat.

For management to be able to adapt to the effects of environmental change, forest inventories should aim to maximize sampling of the range distributions of key forest biota within and beyond closed forest boundaries, especially along environmental gradients that are considered to influence both the composition and behaviour of forest-dwelling species. To undersample such gradients is likely to generate misleading models of forest performance and limit understanding of forest dynamics. The traditional role of the species in forest inventories also needs close attention. Species names by themselves carry little response-based information that can be readily applied to model impacts of climate change on forests. A reliance on purely species-based data also limits comparisons between forested areas elsewhere, where environments may be similar but where species differ. Not surprisingly, there is a global trend away from the use of species and towards more generic, response-based 'functional types' ("*..sets of organisms showing similar responses to environmental conditions and having similar effects on the dominant ecosystem processes*". [Diaz 1998]). Unfortunately for foresters, no consistent typology or ready means of measurement exists for plant functional types. Classification of PFTs varies with user and circumstance typically ranging from well known growth forms such as 'tree' 'shrub' 'herb' to more extended life forms [Raunkiaer, 1934; Mueller-Dombois and Ellenberg 1974], to plants with specific metabolic pathways or specific functional adaptations concerned with survival, dispersal and establishment [Gillison 2002a]. Additional typology may include functional or 'leaf economic' 'traits' such as leaf lifespan, leaf mass per area, photosynthetic capacity, dark respiration, and leaf nitrogen and phosphorus concentrations, as well as leaf potassium, photosynthetic N-use efficiency and leaf N : P ratio [Wright *et al.* 2005]. While useful to modellers, such traits are currently impractical for most forest inventory purposes or for management.

Other developments in functional typology atempt to bridge the gap between scientist and practitioner. The VegClass system is one such case where, instead of using discrete, unconnected traits, an individual is described as a coherent functioning entity consisting of a photosynthetic envelope, a vascular support structure and above-ground rooting systems. These are further described according to a generic set of 36 Plant Functional Elements (PFEs) that are combined according to a specific rule set or grammar [Gillison and Carpenter 1997]. Using this system, an individual of the Birch *Betula* *platyphylla* for example, might be described by the PFEs: microphyll leaf size, pendulous leaf inclination, dorsiventral leaf, deciduous, a photosynthetic stem or cortex, supported by a phanerophytic life form, the PFT resulting in the combination mi-pe-do-de-ct-ph. A shift in any one PFE (e.g. from phanerophyte to chamaephyte, even within the same species) would result in a new PFT. The VegClass software provides algorithms for calculating metric distances within and between PFTs and plots and thus a quantitative basis for classifiying and comparing sample plots. This numerical approach facilitates quantitative linkages with other measureable elements such as soils, hydrology, productivity and economic variables such as net present value (e.g. returns to land, labour ...) [Gillison 2000] . The method is described elsewhere in detail [Gillison and Carpenter 1997; Gillison 2002a and www.cbmglobe.org]. The VegClass recording protocol incorporates other generic biophysical variables [Table 1] including all vascular plant species, vegetation structure and site physical features relevant to most forest inventory needs but also to biodiversity and wildlife habitat. For sampling purposes, the protocol employs a standard 40 x 5m transect that is known to be empirically useful across all vegetation types studied tus far (Gillison *et al.* 2008a). While the system may appear complex at first sight, the user-friendly design allows rapid recording of data in most vegetation types. Studies in northern Mongolian forests suggest that sampling a 40 x 5m transect in Russian Taiga would take less than 40 minutes with an experienced two-person team.

The vastness of forested lands in the Russian Far East creates difficulties for implementing statistically designed, ground-based inventories that, as a result, are now increasingly the subject of space-borne sampling procedures. Such logistic difficulties are by no means restricted to the Russian Far East and present a problem worldwide. For surveys where it is necessary to maximise the capture of information about species and functional type distribution it has been found useful to implement gradient-directed transects or gradsects [Gillison and Brewer 1985]. Gradsects are designed according to a hierarchy of environmental variables considered from all available information to be the main determinants of vegetation (or forest) performance and that of related biota. A typical hierarchy might range from climate (precipitation and thermal gradients), through drainage sequences, geological substrate, to local soil catenae. Such a hierarchy would be commonly modified by gradients of land cover and land use type and intensity. By arranging georeferenced sample sites within hierarchical clusters it is possible to improve chances of accommodating the range of environmental variability in the area under study and thus improve extrapolative GIS mapping. It would appear that the gradsect approach may be well suited to large forested areas such as the Russian Far East where the ground logistics limit ground-truthing of randomly sampled points located through satellite imagery [Kashpor and Arkhipov 2007]. Where statistical estimates of elements such as stem volume per hectare are required, stratified random placement of plots within gradsects can be used. For general purposes, including wildlife surveys, gradsects tend to be far more cost:efficient than random or purely systematic (e.g. grid-based) designs [Wessels *et al.* 1998]. Partly for this reason, they are becoming increasingly used worldwide [UNEP 1996, FAO 2002, USGS 2003].

The VegClass system has been applied in more than 50 countries from sub-polar to equatorial regions resulting in more than 1800 transect datasets to date. Unlike regional datasets from many different sources using different methodologies, the uniform sampling protocol allows all data to be readily compared. Table 2. illustrates a range of differences in species, PFT richness and a measure of Plant Functional Complexity (Gillison 2002a) between forest types in 37 countries. Regional, multi-taxa baseline gradsects of forested lands in Brazil (Mato Grosso), Indonesia (Sumatra), India (Arunachal Pradesh and Assam) Mozambique and Thailand have produced the following outcomes:

- Quantitative baseline information and contribution to a dynamic information framework (DIF) linking vegetation, soils, land use and biodiversity that can be used directly by planners and managers across all landscapes.
- Generic, readily observable indicators of forest biodiversity, site potential and vertebrate (birds, elephant, tiger..) and invertebrate habitat .
- Correlative linkages between soils, vegetation and remotely sensed data that can be used directly via spatial modelling to map areas of high conservation value and agricultural and forestry potential.
- Rapid technology transfer through intensive training of in-country personnel in rapid appraisal methods and spatial modelling.

Methods of natural resource appraisal are rapidly expanding their focus from closed forests to 'whole-landscape' approaches where forest biota may considered to be interacting with other biophysical elements in landscape mosaics containing a variety of land cover and land use types. Such an approach has been incorporated successfully in intensive regional baseline surveys in Indonesia and Brazil [Gillison 2000, 2002b]. Those studies revealed new and highly significant correlations between a range of biophysical variables from which readily testable biodiversity indicators could be identified (Figs 1,2). Among other things, the studies illustrate the predictive synergy to be obtained by combining species with PFTs and PFEs. Whereas in many cases the predictive value of species and PFTs considered alone may be relatively low, predictive capacity frequently improves significantly when richness ratios of species : PFT are combined; for example as predictors of both biota and aboveground carbon (Fig. 3).

A more recent multidisciplinary, integrated, natural resource baseline study in the lower Zambezi valley of Mozambique in East Africa [Fernandes *et al.* 2006; see also www.cbmglobe.org] provides an example of how such an approach might facilitate a dynamic information framework for forest management in the Russian Far East. In the Mozambique study, using the rapid ground survey methodology described above, scientists and practitioners were able to identify highly significant correlations between ground-based vegetation, soils, land use and remotely sensed imagery along a regional environmental gradient. The study applied a newly developed remote sensing application where the core methodology (a spectral mixture model) breaks individual satellite pixels into constituent cover fractions of surface materials. The model employs a general, probabilistic spectral mixture model for decomposing satellite spectral measurements into sub-pixel estimates of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV), and bare substrate (soil) covers. This model is based on an algorithm developed for forest, savanna, woodland and shrubland ecosystems [Asner and Heidebrecht 2002, Asner et al. 2004] that is described in further detail in Fernandes *et al.* [2006].

In analyzing survey data, the predictive value of groups of attributes may be greater than where single attributes are used. From the Mozambique data, single eigenvector solutions derived from multidimensional scaling of raw data from each of the soil, vegetation and remote-sensing datasets provided a basis for exploring between-set correlations from which relative contributions of each variable could be obtained (Figs 4,5 - to be submitted as a separate publication [Gillison *et al.* 2008b]) and are included in the Forum as slide presentations). From the results in Mozambique, readily observable indicators of biodiversity and potential agricultural productivity were identified, coupled with a derived soil fertility gradient score. Subsequent and readily testable potential patterns of biodiversity and soil fertility (Fig. 6) were then mapped according to the remotely sensed data. The entire land-based study involving 32 transects along the lower Zambezi valley was completed in seven days with a team of four observers.

Conclusions

While no data are available from the Russian Far East to enable uniform comparison with other countries, available information suggests that the methods described above could be readily applied to forested lands in the Russian Far East. In addition to complementing existing inventory data, a representative study along selected key environmental gradients would assist in producing a dynamic information framework that could be readily accessed by planners and managers. Such a framework would facilitate:

- The adoption of a harmonious method for data collection, thus facilitating more efficient data analysis and interpretation within and between regions as well as direct comparison with global datasets constructed using the same methodology.
- The collection of plant-reponse-based data that could be used directly or indirectly in modelling the impact of environmental change on forested lands
- The identification of science-based, readily observable indicators for potential agricultural and forest productivity, biodiversity and wildlife habitat
- A basis for generating regional allometries for estimating aboveground carbon and mapping aboveground carbon distribution
- International, public domain datasets that facilitate direct comparison of transect data within and between countries and regions.
- Local, regional and global scale data that can be used to model climate change impact on forests including contributions to global datasets such as LEDA [Kleyer *et al.* 2008] and TRY
- Compatibility with global terrestrial observation systems such as GTOS
- The selection of appropriate indicators for forest audits and certification [*cf.* Zaharaenkov 2001]
- Linkages with remotely-sensed imagery to enhance detailed and readily testable mapping of forest production potential, biodiversity and wildlife habitat
- Quantitative linkages between biophysical and socioeconomic variables thus facilitating economic analysis, especially for biodiversity
- A basis for the ready transfer of rapid resource survey technology via the training of persons with limited scientific background
- A ready means of data compilation and analysis for publication in scientific journals

With 26% of Russia’s forest reserves, the Far East has an excellent opportunity to contribute to solving numerous ecological problems, both local and international, including carbon sequestration, biodiversity conservation, regeneration and forest disturbances. (Kondrashov 2004). It is hoped this paper will contribute to this process by raising an awareness of new methodological opportunities.

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Table 1. List of data variables recorded for each 40x5m plot (VegClass)

Site feature	Descriptor	Data type
Location reference	Location	Alpha-numeric
	Date (dd-mm-year)	Alpha-numeric
	Plot number (unique)	Alpha-numeric
	Country	Text
Observer/s	Observer/s by name	Text
Physical	Latitude deg.min.sec. / or decimal degr.(GPS)	Alpha-numeric
	Longitude deg.min.sec./ or dec. degr. (GPS)	Alpha-numeric
	Elevation (m.a.s.l.) (aneroid and GPS)	Numeric
	Aspect (compass deg.) (perpendicular to plot)	Numeric
	Slope percent (perpendicular to plot)	Numeric
	Soil depth (cm) (sample taken 0-10, 10-20cm)	Numeric
	Soil type (US Soil taxonomy)	Text
	Parent rock type	Text
	Litter depth (cm)	Numeric
	Terrain position	Text
Site history	General description and land-use / landscape context	Text
Vegetation structure	Vegetation type	Text
	Mean canopy height (m)	Numeric
	Crown cover percent (total)	Numeric
	Cover-abundance (Domin Scale) – bryophytes	Numeric
	[To add cover-abundance of lichens..ref: RFE]	“
	Cover-abundance (DS) woody plants <2m tall	Numeric
	Basal area (mean of 3) (m^2ha^{-1});	Numeric
	Furcation index (mean and cv % of 20)	Numeric
	Profile sketch of 40x5m plot (scannable)	Digital
Plant taxa (vascular)	Family	Text
	Genus	Text
	Species	Text
	Botanical authority	Text
Plant Functional Type	Plant functional elements combined according to published rule set.	Text
Photograph	Hard copy and digital image	JPEG

Table 2. Comparative diversity in plant species, PFTs and Plant Functional Complexity (PFC) values among a range of forests in 37 countries. *

No.	Country	Location	Georeference	CBM Transect ID	Forest type	Species diversity	PFT diversity	PFC value
1	Indonesia (Sumatra)	Tesso Nilo, Riau Province	0º 14’ 51” S 101º 58’ 16” E	TN02	Primary forest, partially logged 1997	217	73	370
2	India	Arunachal Pradesh Tipi – Pakke Sanctuary.	27º 2’ 3” N 92º 36’ 58” E	NBL06	Primary forest selectively logged	107	74	314
3	Cameroon	Awae Village	3º 36’ 05” N 11º 36’ 15” E	CAM 01	Late secondary forest. Previously logged	103	43	232
4	Papua New Guinea	Kuludagi / West New Britain Province	5º 38’ 46” S 150º 06’ 14” E	KIMBE2	Primary forest	99	52	234
5	Costa Rica	Braulio Carillo Parque Nacional	10º 09’ 42” N 83º 56’ 18” W	CR001	Partially disturbed forest, palm dominated. Many epiphytes	94	71	336
6	Brazil	Pedro Peixoto, Acré (West Amazon basin)	10º 01’ 13” S 67º 09’ 39” W	BRA19	ICRAF ASB Site, Secondary forest (Capoeira) 3-4 years after abandonment	82	43	230
7	Perú	Jen. Herrera, Ucayali river (W. Amazon basin)	4º 58’ 00” S 73º 45’ 00”W	PE02	‘High terrace’ primary forest - selective logging	72	39	208
9	Vietnam	Cuc Phuong National Park Ninh Binh Province	20º 48’ 33” N 105 42’ 44” E	FSIV02	Partly disturbed primary forest on limestone	69	46	252
10	Fiji	Bua, Vanua Levu	16º 47’ 36” S 178º 36’ 45” E	FJ55	Disturbed lowland forest on ridge	60	37	258
11	Thailand	Ban Huay Bong, Mae Chaem watershed	18º 30’ 42” N 98º 24’ 13” E	MC18	Humid-seasonal, deciduous *Dipterocarpus tuberculosus* forest fallow system	59	44	200
12	Malaysia (Borneo)	Danum Valley, Sabah	4º 53’ 03” N 117º 57’ 48” E	DANUM3	Primary forest subject to reduced impact logging, Nov 1993	56	39	208
13	Kenya	Shimba Hills near Mombasa	4º 11’ 33” S 39º 25 34” E	K01	Semi-deciduous forest in game park area. Previously logged	56	33	214
14	Guyana	Iwokrama forest reserve	4º 35’ 02” N 58º 44’ 51” W	IWOK01	Primary swamp forest in blackwater system.	52	34	192
15	Philippines	Mt Makiling, Luzon	14º 08’ 46” N 131º 13’ 50” E	PCLASS1	Regenerating forest planted in 1968 with *Swietenia macrophylla, Parashorea, Pterocarpus indicus*	52	26	194
16	Australia (tropical)	Atherton tableland North Queensland	17º 18’ 28” S 145º 25’ 20” E	DPI06	Upland humid evergreeen forest managed for sustainable timber extraction	46	25	160
17	Panama	Barro Colorado island	9º 09’ 43” N 79º 50’ 46” W	BARRO1	Primary evergreen forest, ground layer grazed by native animals	43	30	196
18	Bolivia	Las Trancas, (Santa Cruz)	16º 31’ 40” N 61º 50’ 48” W	BOL02	Primary forest,. Logged 1996	42	31	198

No.	Country	Location	Georeference	CBM Transect ID	Forest type	Species diversity	PFT diversity	PFC value
19	Mongolia	Bear cub pass, Khentii Mts	48º 58’ 35” N 107º 09’ 18” E	MONG04	Mixed Conifer/broadleaf forest *Larix sibirica, Betula platyphylla*	40	25	188
20	Vanuatu	Yamet, near Umetch, Aneityum Island	20º 12’ 32” S 169º 52’ 33” E	VAN11	Coastal primary forest, partially logged with *Agathis macrophylla* (Kauri) overstorey	38	22	180
21	Mexico	Zona Maya, Yucatan peninsula	19º 02’ 26” N 88º 03’ 20” E	YUC02	Logged secondary lowland forest	37	26	148
22	Georgia	Baikuriani	41º 45’ 46” N 43º 31’ 16.8” E	CAUC01	Managed conifer/Broadleaf forest. *Picea abies*, *Fagus orientalis*	34	24	174
23	West Indies (France)	Near Mont Pelée, Martinique	0º 47’ 48” N 117º 06’ 23” E	MQUE01	Humid, lowland forest on volcanic slopes, locally disturbed	32	24	286
24	Argentina (central)	Iguazú Parque Nacional de las Cataratas	25º 39’ 00” S 54º 35’ 00” W	IGUAZU01	Lowland forest, disturbed	28	24	208
25	Mozambique	Supita, near Mopeia	17º 56’ 21” S 35º 43’ 34” E	MOZ019	Deciduous vine forest, Community forestry reserve	28	24	144
26	French Guyana	B.E.C. 16 km from Kourou	14º 49’ 23” N 61º 7’ 37” W	FRG05	*Terra firme* forest on siliceous sand	28	18	110
27	New Zealand	Lake Hauroka, South Island	45º 59’ 39” S 167º 23’ 03” E	NZS07	Mixed conifer/ broadleaf Podocarpus spicatus, Nothofagus menziesii	23	18	122
28	Austria	Heiligenkreuz	48º 03’ 19.4” N 16º 07’ 47.8” E	AUSTRIA01	Mixed broadleaf *Acer pseudo-plantanus, Ulmus glabra*	22	15	108
29	England UK	Newbridge, Dart River, Devon	50º 31’ 23” N 3º 50’ 7.5” W	ENGL13	Deciduous broadleaf Oak forest *Quercus robur, Alnus glutinosa*	20	19	160
30	Switzerland	Champery	46º 50’ 0” N 6º 59’ 0” E	SWITZ01	Managed conifer/ broadleaf forest *Larix, Acer* spp.	15	13	124
31	Finland	Lammi	61º 10’ 0.1” N 25º 4’ 0” E	LAMMI01	Mixed natural forest *Picea abies, Acer plantanoides*	12	11	68
32	Scotland UK	Isle of Skye	57º 17’ 52.4” N 6º 21’ 24.7” W	SCOT01	Mixed conifer/broadleaf open forest *Larix, Plantanus* spp.	11	13	116
33	USA	Newfield NY Ithaca	42º 04’ 0” N 76º 33’ 43” W	NAM10	Hemlock forest, *Tsuga canadensis, Fagus grandifolia*	11	10	144
34	Canada	Cathedral grove Vancouver island	49º 26’ 0” N 125º 02’ 0” W	CAN02	Tall conifer forest *Pseudotsuga menziesii* dominant.	10	11	92
35	Argentina (South)	Tierra del Fuego	54º 50’ 0” S 68º 31’ 0” W	TDF02	Deciduous broadleaf forest *Nothofagus pumilio, N. antarctica*	10	9	92
36	Germany	Schlachtensee	52º 26’ 29” N 13º 12’ 52” E	GER01	Mixed man-made forest. Betulaceae, Fagaceae	9	8	42

No.	Country	Location	Georeference	CBM Transect ID	Forest type	Species diversity	PFT diversity	PFC value
37	Australia (Tasmania)	Lower Gordon river	42º 27’ 0” S 145º 36’ 0” E	TAS02	Mixed conifer/ broadleaf *Lagarstrobus franklinii, Nothofagus gunnii*	9	7	62
38	Chile (South)	San Carlos de Bariloche	41º 09’ 0” S 71º 21’ 0” W	BARILOCH02	Mixed conifer/ broadleaf *Austrocedrus chilensis, Nothofagus dombeyi*	8	8	68
39	Sweden	Abisko East	68º 20’ 23” N 18º 43’ 0” W	ABISKO01	*Betula tortuosa* woodland	7	7	58
40	Japan	Mt Fujiyama, lava cave area	35º 10’ 0” N 138º 37’ 0” E	JAP01	Conifer/broadleaf, *Chamaecyparis, Pseudotsuga* spp., Fagaceae	6	8	78

* Data summary from transects with highest records of vascular plant species and Plant Functional Type (PFT) and Plant Functional Complexity (PFC) values for each country extracted from global, ecoregional surveys and mainly restricted to areas < 1000m a.s.l. All data collected using a standard ‘VegClass’ sampling protocol and 40 x 5m (200m^2) transects (Gillison, 2002a). Forest conditions range from relatively pristine to secondary. *Source:* International Centre for Agroforestry Research, Alternatives to Slash and Burn Programme (ICRAF/ASB); Center for International Forestry Research (CIFOR); WWF AREAS project, India, PróNatura (Brazil), UNDP/GEF and Center for Biodiversity Management (CBM www.cbmglobe.org). *Table prepared for Third International Ecological Forum: Nature Without Borders, Vladivostok 11-16 Nov. 2008*

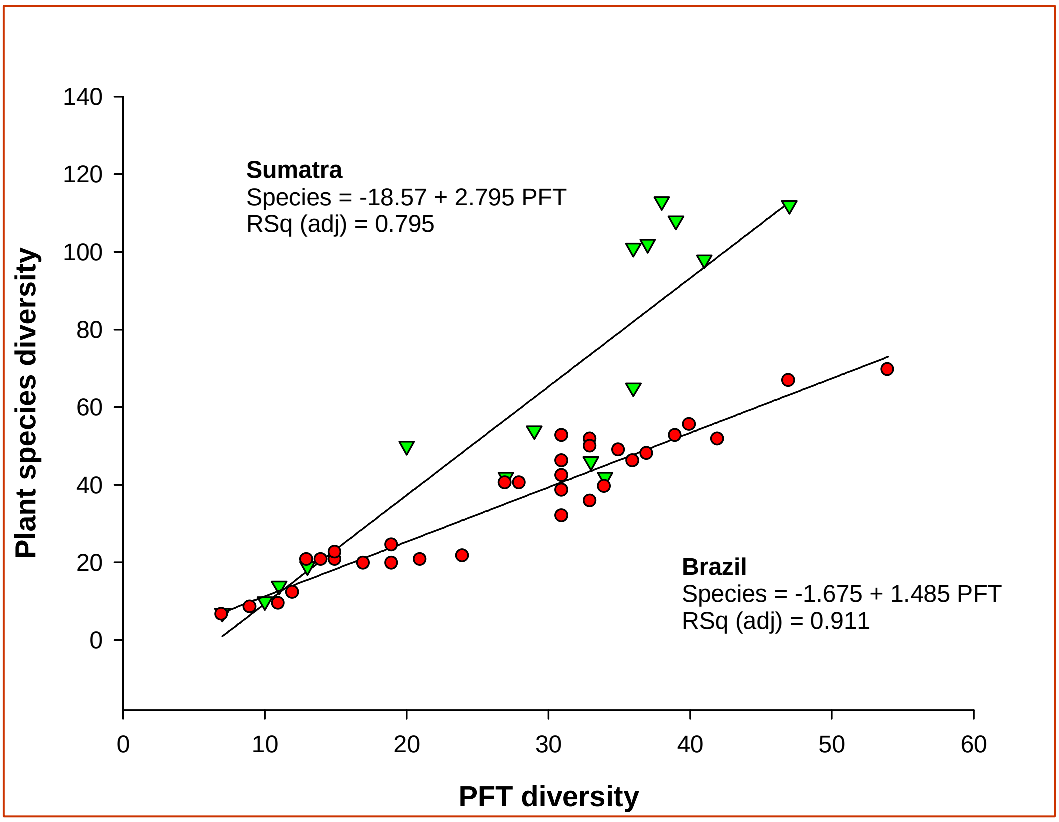

Figure 1. PFTs predict species richness. Although independent, species and PFTs tend to be highly correlated. Response patterns along similar land use gradients can differ between continents

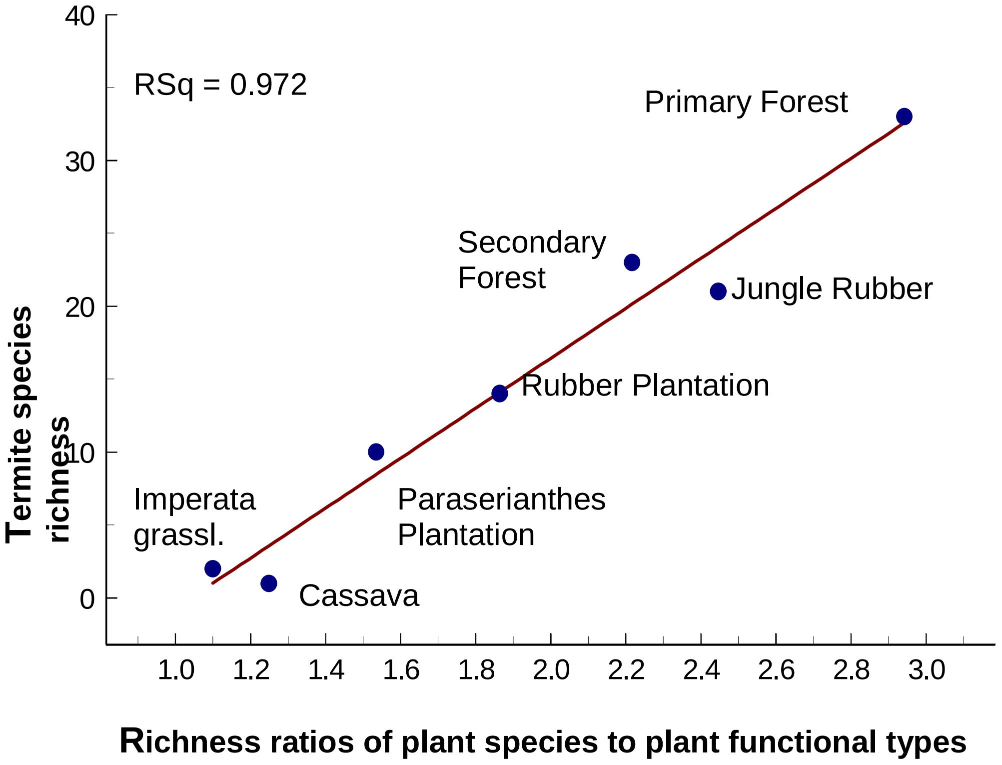

Figure 2. Ratio of plant species richness to plant functional types as an indicator of Termites species richness over 7 land use types : Sumatra, Indonesia

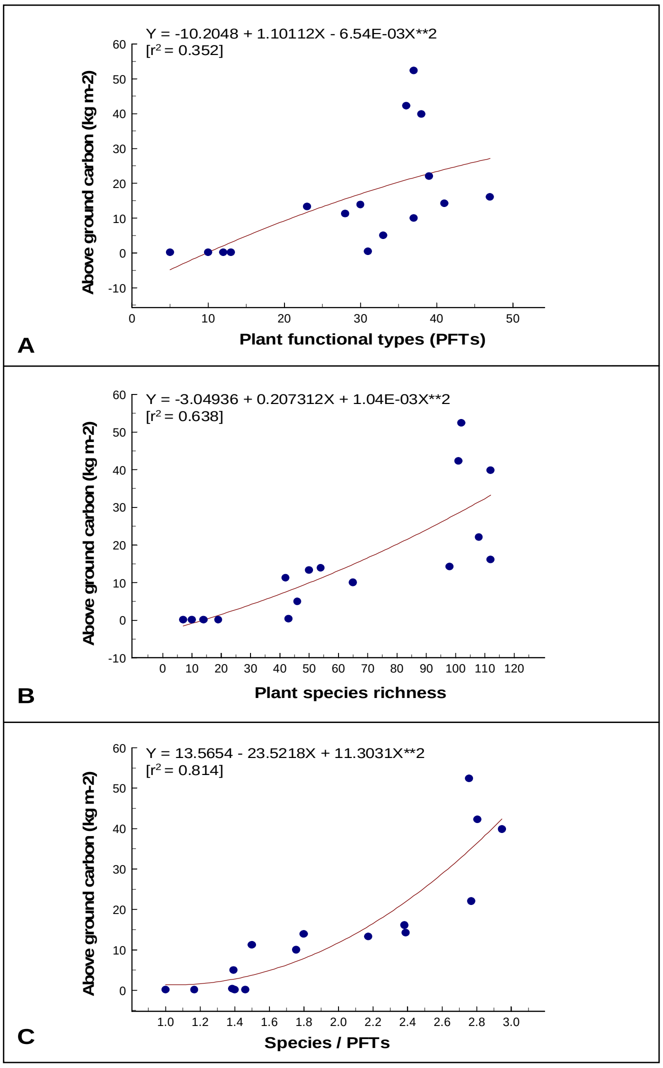

Figure 3. Different predictors for above-ground carbon along a gradient of forested land use types, Jambi, Lowland Sumatra, (A) plant functional type richness, (B) species richness and (C) species / PFT ratios. Each point represents a 40 x 5m transect.

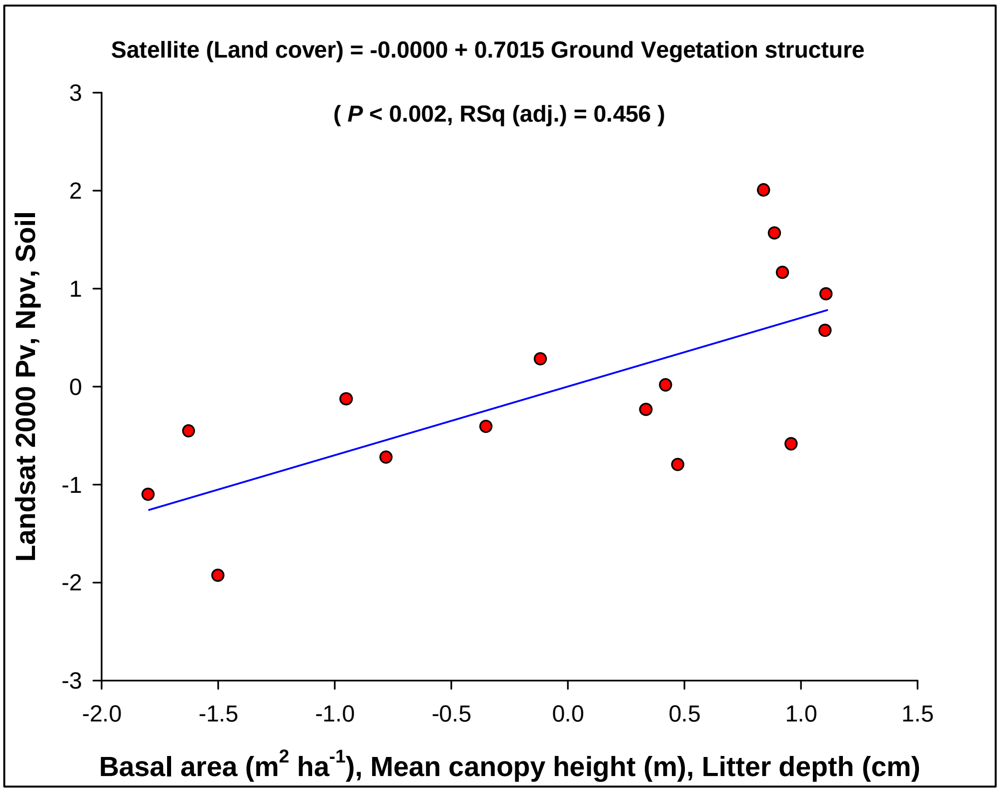

Figure 4. Multidimensional scaling (MDS) expressed as single eigenvector solutions for combined Landsat imagery of land cover (photosynthetic, non-photosynthetic and bare ground (soil)) and combined vegetation structure. Transects (solid squares) occur within one Landsat scene of the central project area of the lower Zambezi basin

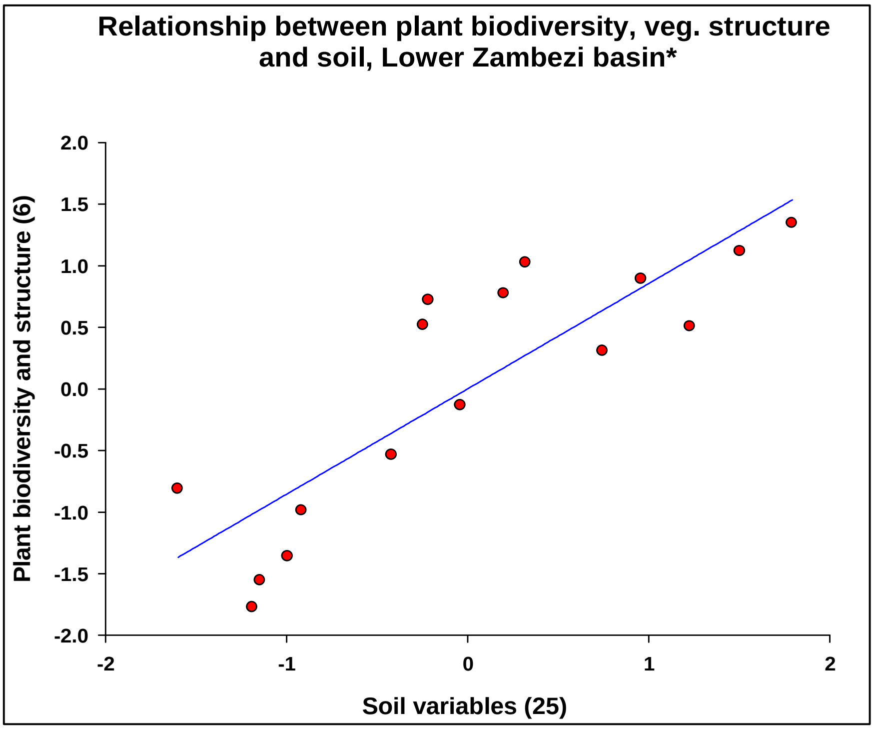

Figure 5. MDS vegetation structure (combined basal area all woody plants (m^2 ha^{-1}), mean canopy height (m), litter depth (cm)) and key soil properties. Transects (solid squares) occur within one Landsat scene of the central project area of the lower Zambezi basin

Best soil predictors are: P (*P* <0.0001), O.M. (*P* <0.002), N (*P* <0.007), Sand% (*P* <0.006), Silt% (*P* < 0.010), Clay% (*P* <0.011).

Best plant predictors are: Crown cover woody plants (*P* <0.0001), Basal area all woody plants (*P* <0.0001), Mean canopy height (*P* <0.002), Species richness (*P* <0.0.017), PFT richness (*P* <0.023) Transects (solid squares) occur within one Landsat scene of the central project area of the lower Zambezi basin.

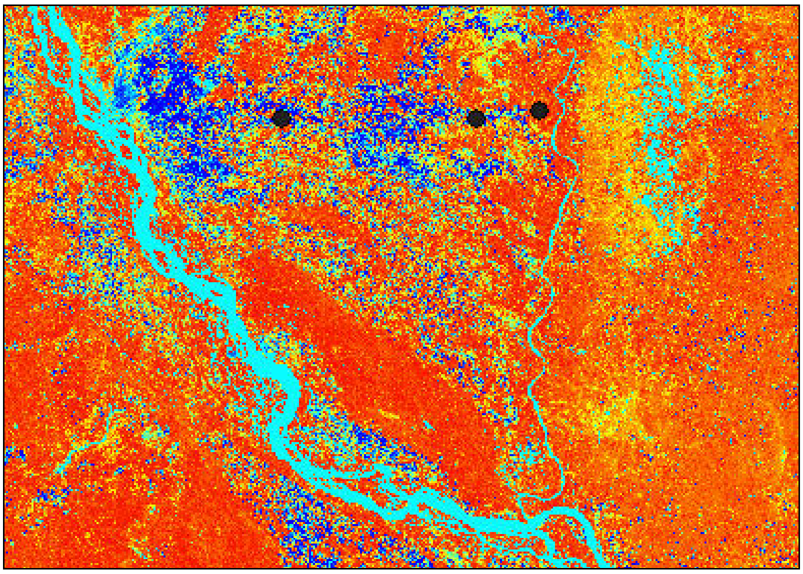

Figure 6. High soil fertility values (7.5-10.00) mapped against derived photosynthetic and non-photosynthetic land cover values from Landsat at 30m grid resolution. Black circles indicate sites with high SFG values. Location at confluence of Shire and Zambezi rivers, Lower Zambezi valley, Mozambique (red = highest similarity, grading through orange, yellow, green, blue, lowest)