A Field Manual for Rapid Vegetation Classification and Survey for general purposes

[Including instructions for the use of a rapid survey proforma and 'VegClass© 2.00 computer software]

by

A.N. Gillison

Center for International Forestry Research*

* P.O. Box 6596 JKPWB
Jakarta 10065
Indonesia
Email: andy.gillison@austarnet.com.au

Swiss Agency for Development and Cooperation

CBM

CBM 14 Feb. 2006

Contents

Section I: Introduction to the Field Proforma

1. Background

There is no universally accepted method for vegetation classification. Many different methods have been developed to meet a variety of very general to very specific needs. In broad terms the reason why we need to classify vegetation is to convey useful information for management and science about different aspects of the natural, living resource. This can involve information about vegetation itself or else may involve various aspects of plant features that can be used for example, to indicate animal habitat or potential productivity of a site (Vanclay *et al.* 1996) or its aesthetic or cultural values. Historically, in the western world, vegetation descriptors were used to communicate visual mind pictures of plant assemblages at varying spatial scales. This necessarily involved simple, easily recognisable elements of structure and physiognomy (appearance) and, where necessary, information about the dominant plant 'species'. This essentially static pictorial view of vegetation has changed as humans have become increasingly concerned with the socioeconomic as well as cultural and aesthetic values of remaining natural resources and the need to understand more about the way in which plants respond to environment. This understanding is necessary in order to provide the baseline information needed to create acceptable options for more sustainable management. Because information about vegetation dynamics is usually very complicated, simple methods of investigation have proved difficult to develop. Our capacity to deal with this problem has improved with access to powerful, portable computers that can assist in reducing large amounts of complex information to more manageable units. For such procedures classification methods need to be cost efficient, logical and repeatable as well as being easy use to produce interpretable results that can be readily applied by managers.

The purpose of this manual is to introduce vegetation classification and survey to persons with limited botanical or ecological experience. The kinds of people for whom this manual is designed, range from natural resource managers and planners and those engaged in policy development to research workers, teachers and students. It is designed specifically to introduce the 'VegClass'[1] Windows©-based software that forms the core of the manual and to describe how the software can be used to describe and classify vegetation for a range of purposes. The reader may access related figures, tables and detailed explanations of terms and concepts used here by double-clicking on highlighted text. This second edition of the manual incorporates many suggestions from users and a number of programming refinements. As more information comes to hand, for subsequent editions, more detailed, scientific rationale about the theory and practice of vegetation classification and survey and case studies, will be progressively included in cross-referenced appendices. The reader is introduced to the key elements of a rapid vegetation field survey proforma and then to a tutorial on the use of the VegClass packages itself. Recently published case studies of actual field surveys are included to help illustrate how the data can be examined via standard methods of exploratory data analysis. Although statistical software is not included in the package, the user will find a useful array of VegClass tools for preparing data for statistical analysis. These summarise site physical, vegetation structural and plant species and plant functional data. The software also contains a facility to produce graphs and is capable of producing recently developed, ecological measures of stand diversity based on plant functional

[1] VegClass is a Windows© -based software package developed by CIFOR with assistance from ACIAR and the Swiss Agency for Development and Cooperation. The software is designed to assist with compilation and analysis of data recorded by a rapid vegetation proforma.

attributes[2]. Tabulated data can be readily exported to industry-standard relational databases and spreadsheet packages such as Microsoft Excel© and Microsoft Access©. These allow the transfer of data directly to statistical and exploratory data analysis software. Section II contains a step-by-step introduction to data entry coupled with an in-built error-checking protocol that will help introduce the new user to the methods used to compile, tabulate and analyse the data. Section III provides access to a real-world data set as well as illustrations of how variables used in VegClass can be applied to biodiversity assessment including spatial data analysis.

Note: *In this document, underlined text in blue highlight indicates a linked image. To view the image click on the underlined text. To return to the main text click on the white arrow in the green circle at the very bottom of the page.*

2. Concepts and methods

Whereas the more traditional methods of vegetation classification involve 'static' descriptors that simply provide a more or less visual 'snapshot' of the appearance of vegetation, the advent of computers, especially portable laptops, has made it possible to use certain 'dynamic' plant features that can be used to indicate how plant individuals adapt to changes in the environment. In this manual recently developed algorithms are used to compute numeric 'distances' between individuals within and between stands. These are based on assumed numerical relationships between plant functional elements used to characterise each individual (Gillison and Carpenter, 1997; Gillison, 2002). Most vegetation classification methods (e.g. Küchler, 1949; Fosberg, 1970; IUCN, 1973; Shimwell, 1972; Mueller-Dombois, 1974; Walter, 1979) are designed either for very broad, geographical purposes or else specific kinds of vegetation such as rain forest (Webb *et al.*, 1976). Both approaches present problems for management purposes. Whereas the former tends to be too general, the latter classification method is designed purely for mature rain forest and does not apply to successional stages of rain forest or for non-rain forest vegetation. As real-world management usually embraces a dynamic gradient of land use intensity overlaid on a mosaic of vegetation types at varying successional stages, a more comprehensive and more dynamic approach to vegetation classification is needed.

The VegClass method is based on a minimum set of plant functional attributes or elements that can be applied to any terrestrial, dry-land vegetation and in a limited way, to aquatic, seasonally aquatic and shallow, marine benthic[3] vegetation. The need to provide a simple, generic approach has meant a trade-off between using simple, easy-to-recogise, vegetation features and more difficult-to-detect, descriptors such as phenology[4], breeding systems or methods of seed dispersal, germination and establishment (Westoby et al., 2002; Cornelissen *et al*. 2003). The main aim of VegClass is to provide a core set of attributes for general use to which the user may add other descriptors for specific purposes and scales as required. Apart from providing basic resource information, this method provides a common platform for investigators to compare certain basic information even though they may collect additional discipline-specific data (e.g. micro-scale habitat features or data related to a specific food source). Because VegClass contains adaptive morphological as well as taxonomic attributes it tends to be more sensitive to changes in environment than more traditional classification

---

[2] Plant Functional Attributes or PFAs are essentially morphological features of a plant individual that reflect adaptations to environment.

[3] Benthos refers to plants and animals living on the bottom of the sea or a lake.

[4] Study of periodicity in plants such as flowering and fruiting at a certain time of the year.

methods. This means it can be used to discriminate more readily between for example, successional stages in a rain forest compared with methods employing less sensitive 'static' or non-adaptive features. Because the method is 'generic', it can be used to compare vegetation in a uniform way between any two or more localities in the world where, for example, species names may differ but where vegetation response to environmental change is similar.

Classification methods[5] based primarily on vegetation structure (e.g. mean canopy height, canopy cover percent) take no account of changes in the spatial and temporal distribution of chlorophyll that is responsible for photosynthesis (the 'power house' of the plant). Yet plant organs containing chlorophyll are remarkably sensitive to local and regional changes in light, water and nutrients. VegClass provides a user-friendly protocol using more sensitive response-based features that is likely to be of greater use in monitoring finer scale changes in vegetation reponse to environment than methods based primarily on non-photosynthetic structures. Most classification methods incorporate plant species as additional descriptors. Where classifications are used to assess biodiversity this is highly significant as there the species is the key variable. A major problem with using species alone is that as the same species become less frequent with increasing distance from site, meaningful comparisons also become progressively difficult. In order to capture the broad range of vegetation descriptors and response characteristics, the present method includes vegetation structure[6], as well as vascular plant species[7] and plant functional types or PFTs [8].

3. Purpose and scale

As with any application in vegetation science, methods must be tailored to suit purpose and scale. For this reason, sampling approaches to wide-ranging surveys of global tropical forests will almost certainly differ from intensive sampling of an alpine meadow. Whereas in the latter, a plant-by-plant survey may use species and sub-species as part of a detailed investigation of meadow dynamics, because of the high level of species complexity and difficulties with identification, the former may apply remote sensing techniques for the purpose of detecting rates of forest retreat on a square kilometre basis. The survey method described in the present manual is designed for general purposes than can include both a tropical forest and an alpine meadow. In this respect it combines variables that can be applied at varying spatial and environmental scales for different purposes. Whereas vegetation structure may be critical to animal habitat assessment and to remote sensing, other vegetation features include vascular plant species (where these can be identified) that may reveal local (but not regional) sensitivities to environmental variability and habitat. These are all relevant to conservation planning and management. Other significant variables are PFTs that include fine scale leaf features through to larger scale life form.
The relative scale of ecophysiological response (Fig. 1) of these plant functional features can be compared with vegetation parameters used in other classification systems. This concept of a scaled functional response has been developed further using plant functional attributes (see below) where the focus is to identify plant attributes that

[5] Various approaches used to place vegetation assemblages in specific categories based typically on structure and dominant plant species.
[6] Major features such as canopy height, basal area, canopy cover. Tends not to include physiognomic features – a confusing term that more commonly includes finer structures such as leaves.
[7] Refers to plants with vascular conducting tissues that include ferns and higher plants; excludes bryophytes (mosses and liverworts).
[8] Combinations of plant functional elements (e.g. leaf size class, life form, above-ground rooting systems) according to a specific rule set (see Gillison and Carpenter, 1997; Gillison, 2002).

can be show to vary directly with environmental gradients (Fig 2). such as light, moisture and nutrients.

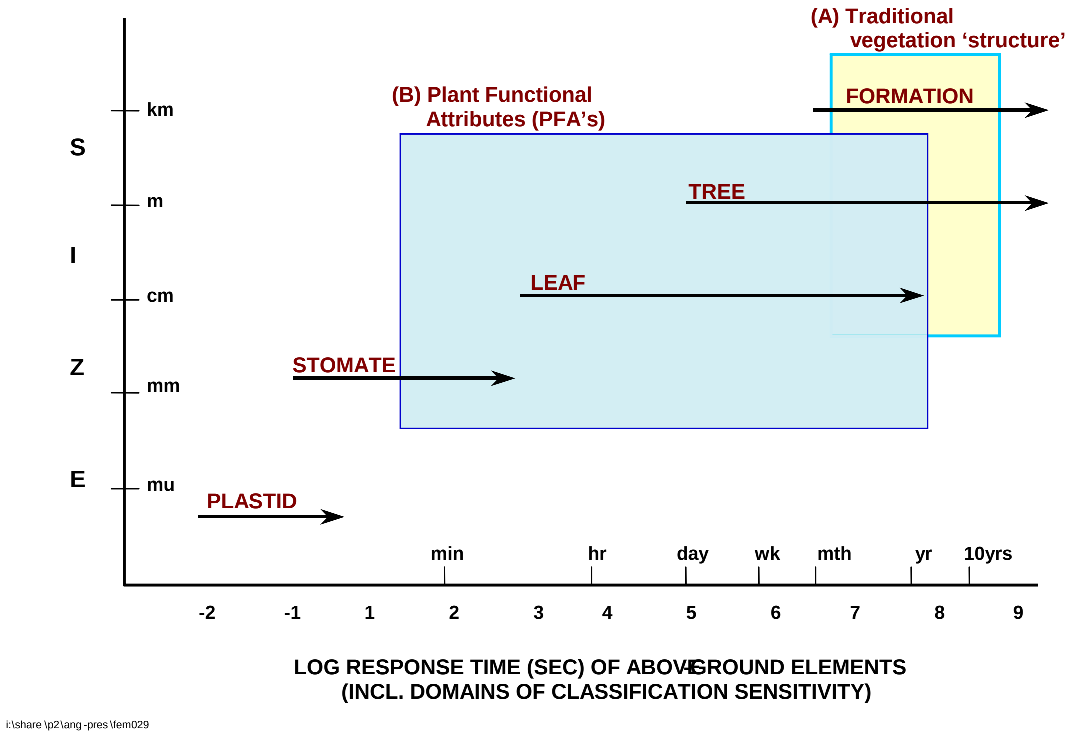


Figure 1

4. Survey design and sample plot location

The method of survey should be consistent with the scale and purpose of the operation. This, in turn will influence the type of data recorded and the subsequent type of classification and analysis. To effectively sample a 10 ha plot may require considerable time, money and logistic support in order to collect detailed information about population structure and dynamics – should that be the purpose. But the degree to which that information can be effectively extrapolated will depend on how well it represents the nature of the surrounding landscape. If the purpose is to capture as much information as possible about the nature and extent of plant and animal species distribution then a greater number of much smaller plots located along a representative environmental gradient is likely to be more efficient. If, on the other hand the purpose is to estimate some vegetation feature such as merchantable volume or number of tree species per hectare then some form of random design has to be included.

For general purposes of natural resource survey the use of gradsects is usually more convenient as well as being more efficient than sites located according to a statistical design that requires purely random or purely systematic sampling. The placement of gradsects relies on a combination of user knowledge and intuition about which environmental factors are most likely to influence the distribution of biota. Survey design that includes a hierarchy of progressively finer scale gradients can significantly improve the chances of locating biota and increases the probability of locating rarities (Gillison and Brewer, 1985; Wessels *et al.*, 1998).

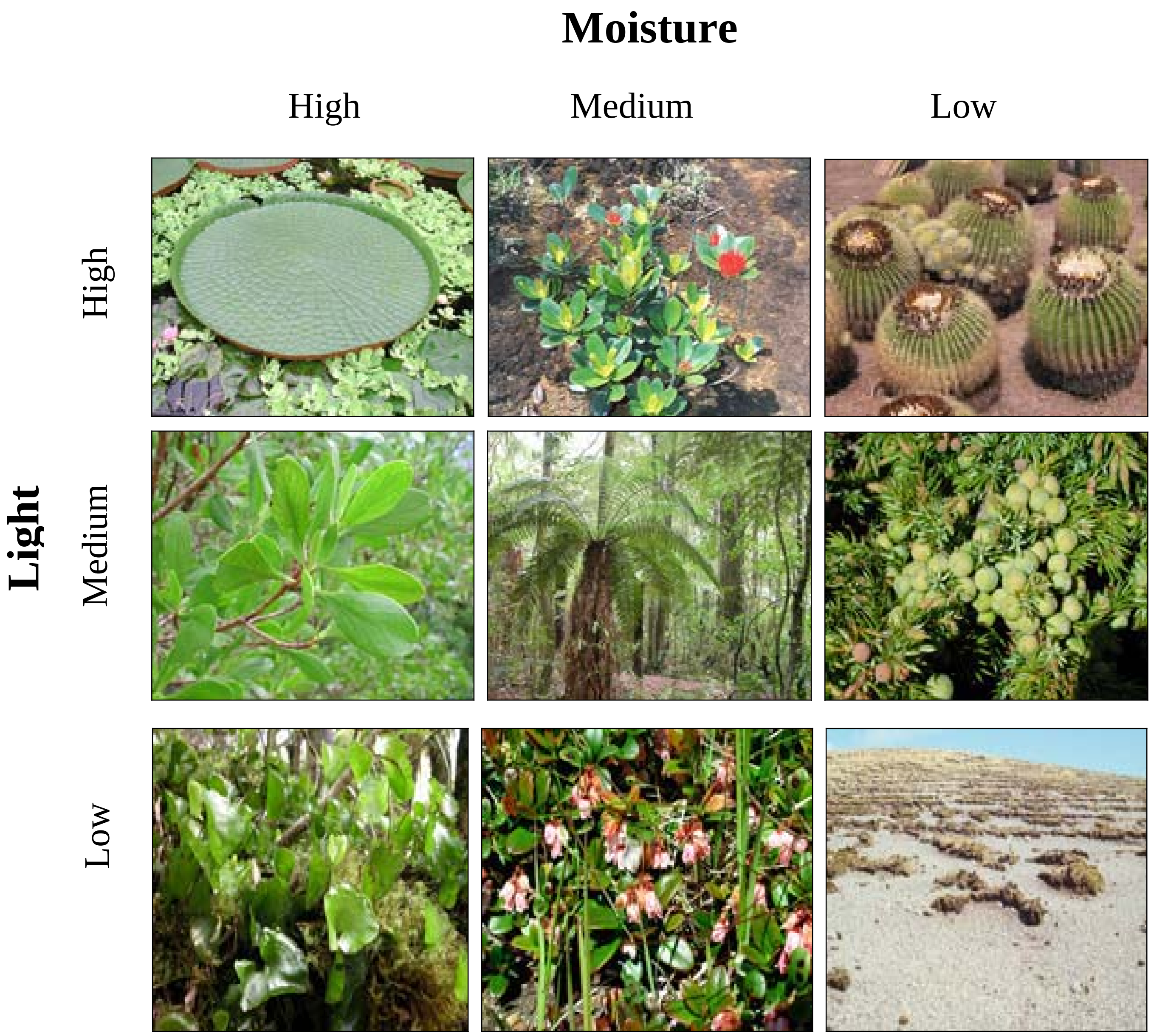


Fig 2 Indicative range of Plant Functional Types along light and moisture gradients

The procedure is to first locate an 'ideal' set of sample points according to all available data (digitised or hard copy, topographic maps, vegetation cover, aerial photographs and other remotely sensed imagery, human demography, parent rock types, soils, climate, road systems etc.) and then to modify these to suit available logistic support. The criteria for plot location will depend very much on purpose and scale of the survey. If the survey is designed to record information for biodiversity then plots should be stratified along land use intensity gradients as well as gradients of the underlying natural resource such as soil nutrient availability, rock types, drainage systems and land use. On site, a transect is usually subjectively located to represent the key characteristics of the vegetation unit under study. This requires ground reconnaissance in combination with aerial photographs or, where facilities are available, an over-flight with fixed wing or helicopter support before and after initial plot selection to ensure representativeness.

For most purposes so-called 'replication' for subsequent statistical analysis is impractical, with pseudo-replicates being acquired at best. As a general principle, paired plots (preferably including drainage run-on, run-off) are a minimum requirement.

4.2 Locating a sample plot on the ground

When using the VegClass proforma approach, once a representative location is decided, a transect (plot) is usually located along any visible topographic contour. The reason for selecting a contour is that this tends to reduce secondary effects due to composite effects of slope and elevation and, as a result, may be more sensitive to the detection of animal habitat, especially those habitats that are cryptic or small scale, e.g. stream banks and ridge tops. In addition it is less physically demanding to record along a contour than by traversing up and down very steep slopes. Depending on available time, parallel transects can be positioned to accommodate local drainage patterns and soil catenary sequences[9], for example from ridge to upper, mid and lower slopes to gully and stream beds where the last are accessible. For surveys where time is very short and where only a few plots can be selected, an upper slope loation will on many occasions help integrate elements of ridge and lower slope. Much depends on the local ‘grain' of the landscape. The relative value of slope and aspect data between sites may be confounded by shadow effects from nearby mountains. Access is an important consideration if the plot is to be re-visited in the future. Equally important is appropriate labeling of a plot, bearing in mind land ownership sensitivities and aesthetic concerns. When a series of plots is laid out in an area it is useful to photograph the location as well as to construct a map showing spatially-referenced[10] key access points as well as the general direction and layout of plots.

For multi-taxa, biodiversity baseline studies the vegetation surveyor must consider the needs of other disciplines. For example bird sampling will require plot locations that facilitate efficient aural and visual sampling of birds often with widely differing spatio-temporal distributions. At much finer scale, insects such as Collembola and termites are much more localised and can be fairly easily co-located with the vegetation plot. Because terrestrial animals depend on vegetation for survival, for most multi-taxa inventories it is logical to regard the vegetation plot as the focal sample point for all or most taxa. For surveys of birds, herpetofauna and large mammals it is common practice for the researchers concerned to locate sample points well beyond the confines of the vegetation plot. Provided the vegetation plots have been efficiently located along a gradsect, survey data from other biota can still be related to the plant data for spatial modelling purposes. This is significant as vegetation is usually the key indicator of animal habitat. The sampling approach requires all survey data to be accurately spatially-referenced (see Section III). In locating sample sites consideration must be given to range distributions of key species of concern to management. Many animal species known to inhabit humid closed forests for example, may range into other vegetation types. Restricted sampling of species ranges (Table 1) is likely to lead to very misleading outcomes for management.

---

[9] Characteristic sequence of soil profiles usually along a topographic sequence – e.g. ridge, slope, gully.
[10] Referenced according to latitude and longitude using degrees, minutes and seconds or decimal degrees (and in the present case, elevation).

Table 1. Restricted sampling can give misleading results. These are examples of range distributions of some key plant and animal taxa: Mae Chaem watershed, Northern Thailand. Sampling within only 900-1100 m would generate a truncated distribution model

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

4.3 Sample plot size

There is probably no more seriously contested topic among natural resource surveyors and ecologists than the question of sample plot size. Much depends on what is being sampled – for example samples of tree species richness in tropical forests will usually require larger plot sizes than samples of mosses or small ferns and epiphytes. Watershed studies may require one large plot or a series of contiguous plots along drainage gradients. For VegClass the issue is largely irrelevant as the data may be entered using whichever plot size is considered appropriate. One of the usual ways to check for sample representativeness is to progressively add sample quadrats until a cumulative species:area or PFT:area curve provides an acceptable asymptote. Even so, the way in which the graph axes are scaled can influence recognition of an acceptable asymptote. To generate such curves the present version of VegClass is can be set to a predetermined number of quadrats or plots depending on user needs (Section II).

For general purposes it has been found that a 40x5m (200 m^2) transect is adequate (Gillison, 1981, 1988, 2000, 2001a,b). A number of studies (Gillison, 2004) show that various families of asymptotic curves (Fig 3) can indicate whether additional plots are needed.

Experience in a range of countries has shown that observer fatigue increases markedly if plot sizes larger than 40 x 5m are used in complex vegetation – a factor likely to be compounded in rough terrain. This is because above 40 x 5m, in complex forest, the transect needs to be marked out with pegs or stakes. In the present method the transect is laid out along a contour (if one exists) using a 50m tape. Two marker sticks each 2.5m long are placed either side of the tape at progressive intervals of 5m. Even in the most dense rain forest it is usually possible for an observer to see the ends of the marker from the tape centreline. Beyond such distance it becomes progressively difficult and at 3-4 m ground markers usually need to be put in place - a procedure that greatly increases observer fatigue and commonly leads to over and under measurement of plant individuals. The distance of 40m has been shown to useful over a wide range of vegetation types from alpine pastures, and Mediterranean – type heathlands to 60m tall, complex, dipterocarp-dominated rain forests. The transect size has also been applied in sampling seagrass beds (Gillison, unpubl. data). In heavily dissected terrain it is relatively easy to locate a 40x5m plot along contours from ridge to various positions downslope. Such emplacement improves chances of recording and identifying cryptic animal habitat rather than, for example, a 1ha or 10 ha plot where such habitats may be subsumed within the general forest structure and variation in terrain. Before recording takes place the ends of the plot are tagged with conspicuously coloured flagging tape and the site number and date written on the flagging tape. Unless there is a good reason for leaving the tape in place for future re-measurement, it is good environmental practice to remove the tape at the conclusion of data recording.

Other transect sizes: While a 200m^2 transect may be appropriate for a tropical rain forest or a savanna, transect size and quadrat number may need to be varied to suit the scale and purpose of a particular study. In arctic tundra for example, a 40x5m transect can be used to profile overall vegetation characteristics. But for fine scale studies in such conditions, quadrat size may need to be less that 1m^2 and quadrat number varied to accommodate variation in plant assemblages due to topographic micro-relief . The VegClass program will operate irrespective of transect size and contains a facility to vary quadrat number (Section II).

5. Equipment

For most vegetation surveys equipment is minimal. Basic requirements are:

- Global Positioning System[11] preferably with minimum accuracy of ± 50m
- Binoculars (8x40 or 10x40),
- Height-measuring instruments (direct optical range-finder, Abney level[12], clinometer[13] etc.),
- Optical prism[14] for basal area estimates (Bitterlich technique[15])

[11] A hand-held computer that interrogates signals from orbiting or geo-stationary satellites to compute the observer's position on the earth's surface in terms of latitude, longitude and elevation.

[12] A hand level used used in conjunction with a graduated circle to estimate tree heights by means of trigonometric functions.

[13] Similar to an Abney level; uses a compact level and sighting tube with a usually oil-damped, suspended disc graduated in degrees to determiine angle of view e.g. as a measure of slope.

[14] A glass prism or optical wedge ground with high precision to a mathematical formula. When positioned at a set distance from the observer, images of tree stems can be viewed as an image that becomes increasingly horizontally displaced with distance. Overlaps count as a 'hit' and completely displaced images count as a 'miss'. Used to estimate basal area according to the Bitterlich principle. Prisms are

- Prismatic compass[16]
- Aneroid (preferably digital) altimeter[17] with minimum accuracy of ± 10m
- One, 50m metal or fibre-glass tape,
- Secateurs (scissors for cutting plants)
- Camera (preferably digital,[18])
- Other equipment as needed for plant and soil collections.

For collecting plant voucher specimens in tall forests, a wide variety of techniques exists from shot guns and rifles to cross-bows or catapults that can be used to fire a weight attached to a light line over a high branch. By attaching a heavier line to the other end this should be sufficiently strong enough to break the branch when pulled.

6. The field proforma recording structure

The VegClass field recording sheet or *proforma* contains five basic sections:

- Site physical features
- Vegetation structure
- Vegetation profile
- Vascular plant species
- Plant functional types

The proforma is designed to acquire the minimum amount of data (Table 2) necessary for most general vegetation classification purposes in the shortest possible time. The layout of the *proforma* and that of the VegClass software package contain similar data entry boxes and categories so that the connection between the two is obvious to the user. The layout of the field proforma is designed for ease of input and later transfer to the VegClass software. It consists of two primary pages; the first page (Fig 4)covers site physical features, site history, vegetation structure and a vegetation profile sketch drawn to scale. The second and succeeding pages (Table 3) are set up for entry of all vascular plant species and PFTs.

---

supplied with different magnification factors. A magnification fact of 2x means that a count of ten 'hits' can be used to calculate basal area as 2 x 10 = 20 m^2 .

[15] A remarkably robust mathematical, formula devised by an Austrian mathematician Bitterlich

[16] A magnetic compass, usually with a graduated circular face with movement damped by an oil bath; graduations viewed laterally via a lens or prismatic viewfinder.

[17] Instrument used to estimate elevation.

[18] A camera that records images in digital format usually via a charge-coupled device (CCD). Images recorded at 2 megapixel resolution or higher are to be preferred. Once recorded, the data can be transferred to a computer for editing and adding to a photographic database.

Table 2. List of data variables recorded for each 40x5m transect

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. (GPS)	Alpha-numeric
	Longitude deg.min.sec. (GPS)	Alpha-numeric
	Elevation (m.a.s.l.) (aneroid or GPS)	Numeric
	Aspect (compass. deg.) (perpendicular to plot)	Numeric
	Slope percent (perpendicular to plot)	Numeric
	Soil depth (cm)	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
	Crown cover percent (woody)	Numeric#
	Crown cover percent (non-woody)	Numeric#
	Cover-abundance (Domin) - bryophytes	Numeric
	Cover-abundance woody plants <1.5m 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	Family	Text*
	Genus	Text*
	Species	Text*
	Botanical authority	Text*
	If exotic (binary, presence-absence) #	Numeric
Plant Functional Type	Plant functional elements combined according to published rule set.	Text*
Quadrat listing	Unique taxa and PFTs per quadrat (for each of 8 (5x5m) quadrats) #	Numeric
Photograph	Hard copy and digital image #	JPEG

* Where identified, usually with voucher specimens, used directly in numerical analysis; # Not available for CBM sites pre-1998. All data are compiled in VegClass using the same field structure.

6.1 Site physical features

This includes the plot number, identity of the observers and plot location described according to local road access and key reference points.

Geo-coordinates for latitude and longitude

Geo-coordinates are acquired using a Global Positioning System (GPS) in either degrees, minutes and seconds or decimal degrees. The accuracy of the GPS coordinates will vary with the quality of the instrument. Most current brands will give a location with an error of ± 50m under normal conditions and this tends to be adequate for most survey purposes. For sub-metre resolution a reference base station[19] is needed. A digital or analogue aneroid barometer is desirable for recording elevation (m) as most GPS systems give highly variable estimates of elevation. While the new generation of GPS devices is very accurate and user-friendly, careful instruction is needed to ensure they are correctly used. GPSs work best in open environments with unimpeded access to satellite signals. When sampling in closed forest GPS efficiency can be severely restricted depending on the nature of the canopy. In such circumstances it can be useful to locate a nearby area where the canopy is less dense. By leaving the GPS switched on in that location a reading may sometimes be obtained within ten or fifteen minutes. In the event that a reading cannot be obtained it is sometimes possible to take a reading on an nearby by road or road junction and then either estimate the plot location by pacing or measuring tape from the road point to the site, remembering to take a forward compass bearing.

Slope

Slope is measured with a clinometer in percent (not degrees). In certain brands of clinometers (e.g. Suunto®) an internal scale provides both degrees and percentages. In recording it is important not to confuse the two. The reading is taken by the observer focussing on the eyeline of a person of similar height, positioned at a representative point down-slope.

Aspect

Aspect is recorded using a prismatic compass and is taken at right angles to the main plot axis and toward the outward aspect of any slope. For plots on flat land, slope is of course a zero measure. Terrain position can be difficult to estimate depending on the 'grain' of the landscape. In rapid surveys where access to a representative range of terrain units is limited, ridge, slope and gully locations should be recorded where possible. At a minimum it has been found useful to record vegetation in mid or upper slope terrain positions as these tend to integrate overlaps from ridge and stream line. (see plot location).

Soil

Soil type : Description will vary according to locality and circumstance. The recommended classification is the USDA Soil Taxonomy. While this classification is useful it requires prior knowledge of certain basic physico-chemical features that may not be readily available. Soil textural classes may be estimated in the field using standard pedological techniques (e.g. McDonald and Isbell, 1984) but this is likely to vary with observer experience.

---

[19] A portable instrument with higher precision than a normal hand-held GPS. Used as a reference point tocompute the position of an outfield GPS with greater accuracy. On May 1 2000 the USA Senate approved a bill that removed a deliberate error-generating signal from many satellites thereby reducing the need for base stations.

Soil depth : In a rapid survey soil depth (cm) estimation can be problematic as it may require a soil auger but a useful and common method is to examine nearby stream banks and roadsides where the profile is exposed. Examination of rooting depth of trees in such conditions also provides some insight into soil physical and drainage characteristics together with parent rock type. This information can be useful where rooting depth is needed as a parameter in estimating soil water balance[20] where this is needed.

6.2 Vegetation structure

This includes estimates of :

- *Mean canopy height*
- *Canopy cover percent*
- *Basal area (m^2 ha^{-1})*
- *Furcation index*
- *Cover-abundance of woody plants <2m tall*
- *Cover-abundance of bryophytes*
- *Litter depth*

Mean canopy height (m)

Estimated by a clinometer or optical or laser rangefinder or by the 'broken stick'[21] method. This can be a highly variable measure particularly in tall complex rain forests >50m high. It is best determined by estimating the tallest and smallest canopy units in the 40x 5m plot and using these as reference points for estimating a mean height. The degree of error will depend on the height and structural complexity of the vegetation and observer conditions at the time. A very tall, closed canopy, complex, dipterocarp vine forest in Borneo is far more difficult to estimate than a very tall, simply structured, conifer-broadleaf forest in British Columbia. The angle of view from the eye of a ground-based observer is subject to a relatively large error term particularly when coupled with highly variable canopy height in, for example, tropical rain forest. For this reason, mean canopy height may account for very little variance within one homogeneous forest type. The variable usually takes on greater predictive value when compared between different vegetation types along an environmental gradient.

Canopy cover percent

---

[20] Water balance, an expression of the hydrologic cycle for an area of the land surface in terms of conservation of mass. In a simple form the water balance may be expressed as

$$S = P - Q - E - G,$$

where S is the change of water storage in the area over a given time period, P is the precipitation input during that time period, Q is the stream discharge from the area, E is the total of evaporation and transpiration to the atmosphere from the area, and G is the subsurface outflow. Most hydrologic studies are concerned with evaluating one or more terms of the water balance equation. Because of the difficulties in quantifying the movement of water across the boundaries of an area under study, the water balance equation is most easily applied to an area draining to a particular measurement point on a stream channel. (Source: *Encyclopedia Britannica*, 1999)

[21] Here the observer extends a stick (e.g. 30cm long) out at arm's length and adjusts his or her position to or from a tree until the top and bottom of the stick are seen to coincide with the top and bottom of the tree. At that point the base of the stick is carefully pivoted at right angles at the base of the tree until it is horizontal with ground level. Another observer then measures out the distance from the base of the tree to the point where the "top" of the stick coincides with the main observer's eye. The distance so measured is thus equal to the "height" of the tree. Care must be taken to ensure a 90 deg. angle from the tree base.

Canopy cover is usually estimated as the total projected canopy cover[22] of all plants as a percentage of total ground area. Tree crowns and other plant canopies are considered opaque for this purpose (*cf*. Specht, 1981). A problem with this single estimate is that for ecological purposes, a 90% canopy cover in a grassland plot does not equate with a 90% forest tree cover. For this reason the proforma makes provision for:

- total canopy cover %
- canopy cover % of woody plants and
- canopy cover % of non-woody plants.

This provides a means of discriminating between woody and non-woody plant assemblages.

Basal area
This is estimated using the Bitterlich principle (see Equipment) and is independent of the plot size as it uses an infinite-radius approach. Where 40 x 5m transects are used, measurements are taken at both ends of the plot and in the middle. An optical prism is used to record 'hits' indicated where the image of a tree stem is not totally displaced. All woody stems are recorded regardless of stem size. Individual stems are recorded for multi-stemmed trees Estimates are taken for all woody stems depending on the magnification factor of the prism used. For example 10 'hits' with a factor of 1 indicates 10 m^2 ha^{-1} basal area; a factor 2 = 2x10 etc. Because glass prisms are expensive, small, fragile and easy to lose, a useful alternative is to calibrate an observer's thumbnail against a series of measurements acquired using different prisms or, preferably, a relascope. The multiplication factor needed for an observer's thumbnail can then be obtained. This factor will vary with thumb size. Another alternative method is to use a small metal disc with a 1 cm square notch cut into one side. The notch serves as a 'gunsight' that is used to record 'hits' in a similar way to the thumbnail. The disc is attached to a piece of string, the other end of which is placed in the observer's mouth. Although his ensures the same distance is applied in every case the technique tends not to be as efficient overall as the 'thumbnail' technique. By this means a radial count can be obtained using the same Bitterlich principle but with greater facility. Experience suggests the thumbnail method is surprisingly robust. In even the most densely wooded and complex vegetation where the observer may have to make allowances for 'hidden' stems. In most cases three radial counts can be taken in under three minutes by an experienced observer. The basal area counts are automatically averaged when entered into the computer using the VegClass© software.

Furcation index
Certain structural descriptors tend to be categorical rather than continuous. For example whereas height can be measured in metres, categories of architecture may be described according to form. Two such categories are 'tree' and 'shrub'. A woody plant may be described according to one or the other; there is no current means of expressing a gradient

[22] The area projected on the ground by a canopy as if from the sun shining directly above. The total canopy cover percent is estimated as the percentage of total projected (non-overlapping) canopy area relative to the ground surface. Canopies are considered opaque (i.e. not transmitting any light). An open forest for example might have 65% total cover of which 45% is made of of woody tree crowns and 20% grass cover. Under this method complete cover cannot exceed 100%. (see also Specht, 1981). Because canopy cover is sometimes highly variable, it is best estimated by eye after a careful reconnaissance of the site and should not necessarily be restricted to the 40 x 5m plot but should represent vegetation in the immediate vicinity. This is consistent with other 'plotless' measures of basal area and furcation index. The estimate is crude at best and will vary with observer experience. Other, more sophisticated methods such as hemispherical phtographs or concave reflecting devices such as spherical canopy densiometers or optical canopy densitometers using canopy intercept pattern are difficult to use for comparative purposes in low woody vegetation e.g. heath, or short grasslands (or benthic environments!).

between them in a readily measureable way. This can create confusion especially where there are differences of opinion between observers as to what constitutes a 'shrub' and a 'tree'. Typical definitions are: for a shrub - a "woody plant that branches at or near the ground" and a tree " a woody plant above two metres tall". The reality is there are woody plants <2m tall that do not branch near the ground (i.e. not multi-stemmed), and many woody plants much taller than 2m that are multi-stemmed (e.g. some 30m tall, Australian eucalypts). To avoid this dilemma and to use a metric that allows a comparative measure of primary woody plant architecture a furcation index (Fig. 5) has been devised. Furcation index or FI (Gillison, 1988), is the distance from the apex to the first break point or fork in the main stem of the linear axis of a woody stem expressed as a percentage of total height. Thus an unforked pine tree would have a FI of zero, a mango tree may have an FI of 50% and a mallee eucalypt with multi-stems arising from the base could have a FI of 100%. FI is assessed from a point in the centre of a plot and recorded for the nearest twenty canopy trees in an outward spiral from the centre. When entered in the VegClass software package the software automatically computes the mean and coefficient of variation percent around the mean.

The utility of this feature lies in the way the primary architecture of the main stem is influenced by the fate of the apical meristem. Many plants that are continually subjected to damage through insects, fire, drought or hurricane winds for example, exhibit recurrent branching from break-points on the main stem with resulting high FI values. Desertic plants and heath plants also exhibit typically high FI. Tropical rain forests in the hurricane belt of the south-west Pacific frequently suffer damage and this is reflected in a high cv% . Thus an inventory that includes FI can provide a measure of site history from FI values. In extreme environments with high winds, or abrading wind-blown, ice or sand, FI tends to be very high or very low the reason being that in such environments a stem that is forked at 50% is likely to be more vulnerable for mechanical reasons than if it has an FI of zero or 100%. The predictive value of FI may not be high within a single vegetation type but can be a useful diagnostic of environmental influence especially at regional level. The measure is easy to record with high repeatability between observers. FI has been shown to have value in estimating site productivity potential potential in mixed species stands in tropical forests of far North Queensland when used with several other plant functional attributes (Vanclay *et al.*, 1997).

Cover-abundance of woody plants <2m tall

The incidence of woody plants either below-canopy or in open, low, woody formations, expressed as a 'cover-abundance ' term according to a Domin cover-abundance scale (Table 4). In assessing cover-abundance a radial rather than 'within-plot' estimate is taken to be consistent with estimates of basal area, furcation index etc. In certain cases, additional woody plant strata may be observed at or near ground level, especially towards thermal environmental extremes and are often applied in regional classifications. In many cases however such strata, while visible in some areas, become increasingly difficult to measure with vegetation change along thermal gradients. Experience suggests that the occurrence of ground layers of woody plants such as *Empetrum nigrum* and *Vaccinium uliginosum* is closely associated with other measures of vegetation structure (canopy cover% and mean canopy height) and the composition of PFTs.

Cover-abundance of bryophytes

This measure allows account to be taken of the non-vascular component of vegetation that include the lower plants such as liverworts and mosses. Whereas it would be extremely time-consuming to record individual mosses, the Domin cover-abundance approach (Table 4) gives a crude approximation of spatial cover. It differs from the horizontal estimate of woody plants as bryophyes frequently occupy both vertical and horizontal space. In some cases they may score close to maximum value ± 9 typically in so-called 'elfin' or 'moss' forest in tropical montane regions. Seasonal conditions will tend to influence the count in the same way that deciduousness is associated with seasonal extremes of light and moisture. Care must be taken not to confuse bryophytes with filmy ferns (Hymenophyllaceae) that are also sensitive to seasonal influence.

Presence or absence of lichens can be important vegetation descriptors, especially in high latitudes and high elevations in the tropics. Fruticose lichens in boreal forests and tundra for example are significant food resources for animals such as reindeer (P. Krestov pers. com.) and constitute an important ecosystem element. A facility for recording Domin cover-abundcane of fruticose lichens will be considered in the next version of VegClass.

Table 4. DOMIN cover-abundance scale is an arbitrary ranking system that has been found useful in rapid survey

Cover-abundance	**Scale**
Cover about 100%	10
Cover > 75%	9
Cover 50-75%	8
Cover 33-50%	7
Cover 25-33%	6
Abundant, cover about 20%	5
Abundant, cover about 5%	4
Scattered, cover small	3
Very scattered, cover small	2
Scarce, cover small	1
*Isolated, cover small	X
Note: X is usually excluded for numerical analysis	

Litter depth
Litter refers to the fallen dead or dying plant material (leaves, stems etc.) that cover the transect floor. Litter may occur as a complete carpet or, more frequently, in scattered patches. A ruler or graduated stick is driven through the litter until it reaches the mineral soil and a depth reading taken. Average readings should be taken to include bare soil as well as areas covered by litter. So-called 'duff' layers may occur in cool, moist, acid conditions, typically in tropical fagaceous montane forests dominated for example by *Castanopsis* spp.. This may cause difficulties as they can contain many live root mats up to 15cm deep mixed with other plant material. Sometimes litter can be difficult to tell apart

from living plant material such as mosses. High mountain and high latitude forests may present this problem to varying degrees as can so-called 'quaking bogs' commonly dominated by *Sphagnum* spp. The general rule is to record litter only where the material is dead or dying.

6.3 Vegetation profile

A rapid sketch of the vegetation profile along the transect can be very useful for subsequent interpretation of results and for checking of site structural features. The observer does not need to be a first class artist but simply records a representational sketch (Fig. 4) of the main features of the vegetation. The spatial positioning of plants does not need to be highly accurate. Drawing vegetation structural characteristics in first-hand enables certain features to be emphasised e.g. the architectural form of some tree species.

6.4 Plant species

All vascular plant species are recorded in the transect. These include all higher plants as well as ferns and filmy ferns. They do not include bryophytes (mosses, liverworts) that are recorded as a measure of cover-abundance. Only those individuals are recorded that are either sexually mature or are capable of vegetative regeneration. Exceptions are woody plants more than 2m tall that are included only if there are no representatives already in the canopy. Seedlings are not included. Identification of all species should be obtained where possible. For this purpose voucher specimens[23] should be taken including all sterile (non-flowering or fruiting material) and referred to a herbarium for subsequent identification. Botanical assistance should be sought in the field wherever possible. Where this is not available, specimens may be collected in a plastic bag, tagged with pencilled plot reference number and after pressing overnight, packed tightly between newspaper in plastic bag and saturated with not less than 70 % alcohol. Preserved in this fashion, specimens will keep for up to three months in a tropical climate. The VegClass menu provides for the entry of Family, Genus, Species name, including botanical authority, and local name as well as automatically compiling a 4+4 genus+species code.

In many cases, for example, in tropical forests, species may be unidentifiable in the field or even in the herbarium. Under such circumstances they can be given a 'morphospecies'[24] name provided that it is taxonomically distinguishable from others in the plot. A problem with using morphospecies is that with increasing numbers of plots in a survey it becomes difficult to maintain a systematic working list that is not subject to error. It is generally useful to stick fragments of all species and/or morphospecies in an exercise book with the plot reference and specimen number in addition to making a formal collection. These can be referred to during the survey and cross-referenced. If the 'species' BS23/16 (Transect BS23, specimen number 16) occurs in separate plots it should be referred to by the same code. 'Field' herbaria can be very useful as a reference during and after large surveys. These are constructed by attaching fragments of voucher specimens to a 8x5" or similar index card with site information attached and stored in filling index cabinets. Another approach is to make xerox photo-copies of the specimen direct. These can be used easily in the field without fear of destroying the original specimen. It should be kept in mind that most herbaria are understandingly reluctant to store sterile plant material in valuable space that can be occupied by flowering and fruiting specimens. This makes it even more important to maintain a reference collection elsewhere. Where unusual specimens are collected that may also be fragile or perishable it is a good idea to make a photograph. Although purchasing film may seem expensive it is usually a small expense when total

---

[23] Specimens collected in the field for later identification in the herbarium. Many voucher specimens may be sterile (non-flowering or fruiting) and therefore unilkely to be retained following identification. One way around this is to make a photo-copy of the specimen and its identification and site cross-reference.

[24] A field name given to an otherwise unidentifiable specimen. e.g. “large hairy leaf 1”

survey costs are considered. These days digital photographic records may be preferred and have the added advantage that they can be field-checked.

Only presence data are recorded. For most surveys, time constraints prevent the recording of species abundances (numbers of species per individual). Although for some transects the recording of individuals may seem feasible, there will be occasions when it is not, for example, when there is a preponderance of epiphytes[25] in the canopy. Because uniformity is mandatory to facilitate the comparison of data between all plots, abundances are excluded. This is not to say that for specific purposes (species diversity measures, or faunal habitat) abundances should not be included. It is worth keeping in mind that for most surveys presence/absence data will provide most of the information needed especially when coupled with structure and PFTs.

6.5 Plant Functional Types

As mentioned earlier, PFTs are specific combinations of plant functional elements or PFEs. A minimum set of 35 PFEs (Table 5) is used to construct PFTs according to a specific rule set or grammar. The rationale and explanation for this can be found in Gillison and Carpenter (1997) and the table of PFAs examined in the 'VCreadme' file. Only one change has been made - 'Leaf Type' to 'Morphotype'. In the present treatment a 'leaf' is a 'functional' leaf (i.e. is an organ, not necessarily a botanical leaf, that is capable of photosynthesis - such as green bark). There are two potentially useful data outcomes that arise from using both the discrete, unconnected, or 'atomised' attributes themselves (e.g. leaf size class MI (microphyll) and their combinations (e.g. **mi**crophyll, **la**teral, **do**rsiventral, **ph**anerophyte - mi-la-do-ph). In the first case the relative number of times a PFA occurs in a plot gives some idea of the frequency of that specific variable as an adaptive response. But this gives no indication of the aggregate role of a variable. For example two different individuals may occur with mi but in different combinations (mi-ve-do-ph and mi-la-do-ph). Thus the proforma has the capacity to record information on adaptive response at two levels of coordination. PFTs and PFEs may be recorded either on a presence-absence basis or (preferably) as species-weighted variables. (i.e. if the PFE 'mi' is recorded for six species in a plot then it scores six, and similarly for a PFT). When first introduced to the recording procedures outlined here the observer may feel observations are unusually difficult. Experience in a variety of vegetation types with novices in different countries suggest that these difficulties are quickly overcome. Disadvantages encountered in some areas tend to be outweighed by advantages in others.

Recording procedures are described for each of the following attribute classes:

- ***Leaf size class***
- ***Leaf inclination***
- ***Leaf chlorotype***
- ***Leaf morphotype***

Leaf size class

Nine classes range from 'nr' (no repeating unit) and from the smallest 'picophyll' to the largest 'megaphyll'. Select the most commonly repeating unit. In certain cases these will be the leaflets of compound leaves or the pinnae of ferns or the branchlets of certain succulent plants such as some Euphorbiaceae. For some deeply lobed leaves (e.g. *Amorphophallus, Artocarpus incisa, Carica papaya*) the entire leaf is taken into account unless the lobes are touching or almost touching the main vein.

[25] Traditionally plants that use other plants such as trees for support (e.g. many orchids). In VegClass the epiphytic descriptor is also attached to plant parasites if they are supported on the aerial parts of plants.

The classes used here are those originally constructed according to a logarithmic scale by Raunkiaer (1934). Based on field experience and frequency data, this scale has been modified by the addition of the 'Notophyll' (no) size class introduced by Webb and Tracey (1976) for rain forests and two other sizes, 'Platyphyll' (pl) and 'Picophyll' (pi) (Gillison, 1981, 1988). Because leaf size classes tend to vary within a plant from new to old leaves and with degree of exposure to light, it is necessary to select an arbitrary location on the plant to seek uniformity. Only one leaf size class is recorded per plant. A leaf of average size is selected from the 'shoulder' of the plant so that leaves of mid-range maturity are estimated rather than very old (e.g. shade) or very young (sun) leaves. The 'shoulder' site tends to carry leaves that are the most photosynthetically active and responsive to incoming light. In every case, whether tree or herb, the chosen leaf should be the 'most repeating unit' on the plant. In some cases where no repeating unit is detectable as in a barrel cactus, the 'nr' (non-repeating) element will apply. In others such as some lianes with highly variable leaves or where leaves are hidden within in a complex forest canopy an arbitrary choice may be difficult. It is inevitable that for very tall trees in complex forests where much the canopy is hidden from view, sighting leaves can be a problem. This can usually be avoided by the use of binoculars (see equipment, above) to locate and identify a canopy leaf. Where there are no easy means of collecting a remote canopy leaf, a ground search will usually reveal the presence of the species or PFT in question. Local informants can be very useful in identifying the appropriate parent individual.

A commonly asked question is "how do you locate a leaf if the plant is deciduous?". Despite almost complete leaf fall, in almost every case it is possible to locate a remnant leaf either on the stem or on the ground or in a crevice or, in extreme cases, by searching outside the plot boundaries or by examination of representative herbarium specimens where these are available. Where conditions permit, catapults can be used to fire a weight and string over a selected branch or a rifle or shotgun used to obtain fragments where this is permitted. The size of the leaf can be estimated by comparing it with the leaf size class template (Fig. 6). For convenience an ellipse has been selected as the most central shape. To estimate size the actual total leaf area on one side should be compared with the total leaf area of the ellipse. Long, thin grass leaves for example, can be folded and made to fit inside one the ellipses to approximate the right size class. leaves. With very little practice an observer can be trained to recognise a leaf size class without referring directly to the template. Examples of different leaf size classes are illustrated can be accessed though the following hyperlinks:

- Picophyll (pi)
- Leptophyll (le)
- Nanophyll (na)
- Microphyll (mi)
- Notophyll (no)
- Mesophyll (me)
- Platyphyll (pl)
- Macrophyll (ma)
- Megaphyll (mg)

Table 5. Plant Functional Attributes and Elements

Attribute	Element	Description	
[Photosynthetic envelope]			
Leaf size	nr	no repeating leaf units	
	pi	picophyll	< 2mm^2
	le	leptophyll	2 - 25
	na	nanophyll	25 - 225
	mi	microphyll	225 - 2025
	no	notophyll	2025 - 4500
	me	mesophyll	4500 - 18200
	pl	platyphyll	18200 - 36400
	ma	macrophyll	36400 - 18 x 10^4
	mg	megaphyll	> 18 x 10^4
Leaf inclination	ve	vertical	>30^o above horizontal
	la	lateral	±30^o to horizontal
	pe	pendulous	>30^o below horizontal
	co	composite	
Leaf chlorotype	do	dorsiventral	
	is	isobilateral or isocentric	
	de	deciduous	
	ct	cortic	(photosynthetic stem)
	ac	achlorophyllous	(without chlorophyll)
Lf. morphotype	ro	rosulate or rosette	
	so	solid 3-D	
	su	succulent	
	pv	parallel-veined	
	fi	filicoid (fern)	(Pteridophytes)
	ca	carnivorous	(e.g. *Nepenthes*)
[Supporting vascular structure]			
Life form	ph	phanerophyte	
	ch	chamaephyte	
	hc	hemicryptophyte	
	cr	cryptophyte	
	th	therophyte	
	li	liane	
Root type	ad	adventitious	
	ae	aerating	(e.g. pneumatophore)
	ep	epiphytic	
	hy	hydrophytic	
	pa	parasitic	

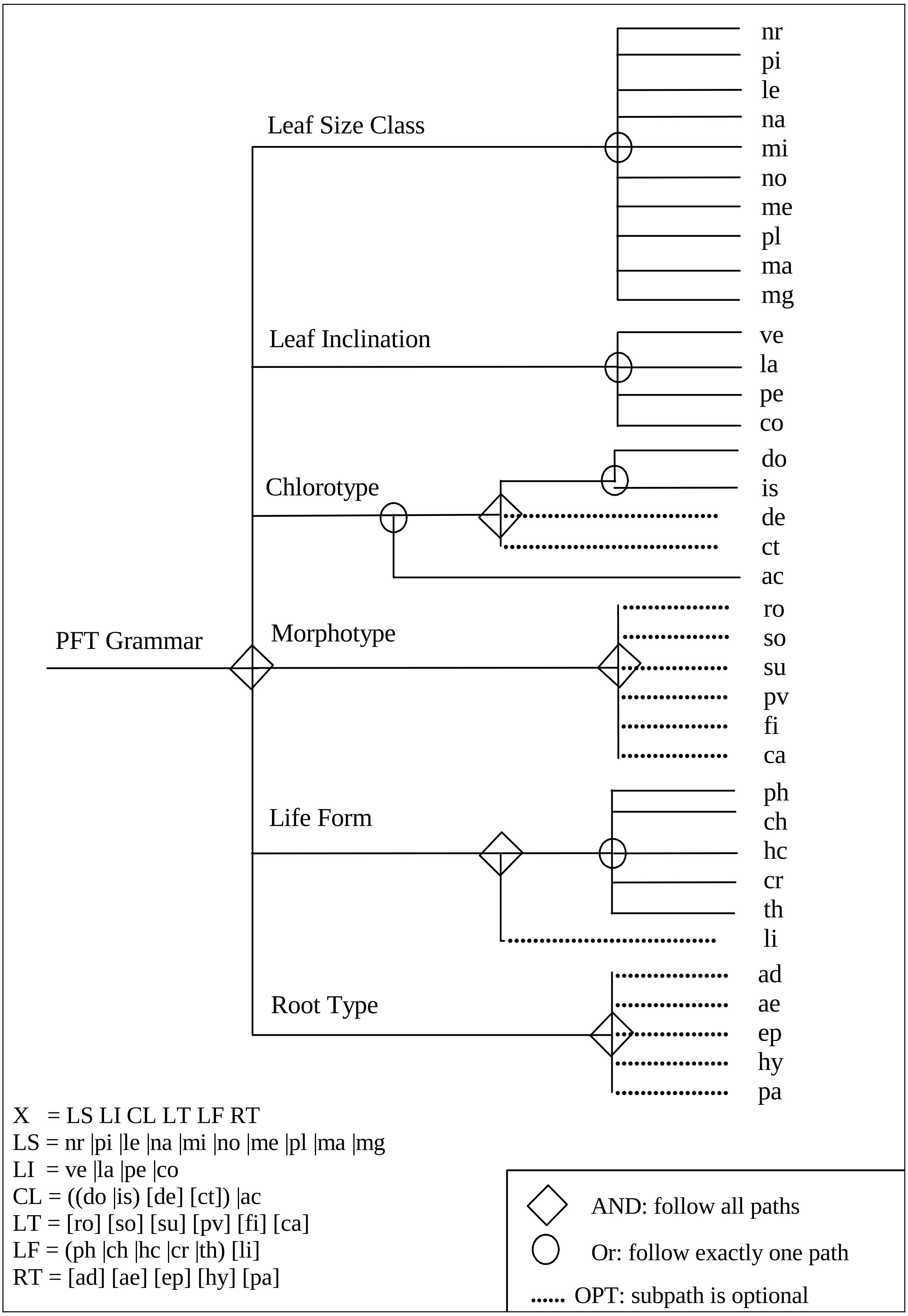


Figure 5. Grammar and rule set for compiling Plant Functional Types. Using this method, an individual of the seasonally deciduous sub-tropical tree *Dipterocarpus tuberculatus* might be classified as **ma**crophyll-**do**rsiventral-**co**mposite-**de**ciduous-**ph**anerophyte with a resulting PFT ma-do-co-de-ph.

Because the larger size classes cannot be accommodated on a proforma page, multipliers are used. These should be examined carefully when estimating size. Where it is difficult to decide between one size class and another is useful to try a number of

Leaf inclination

This is the most difficult of all attributes to measure as estimation depends on the viewing perspective – which can be problematical for example, in 50m tall tropical forest. Basically the measure is designed to indicate whether a leaf is seeking or avoiding sunlight. Leaves have many ways of dealing with this. Most have relatively fixed positions but others may have specialised cells that allow a leaf to respond to the sun's position (helionasty[26]). The inclination class selected is that where in the opinion of the observer, the leaf position would be during the period of the noon-day summer sun. Where wilting occurs as in some so-called 'pioneer' tropical forest species such some *Macaranga* or *Mallotus* spp. compensation for this should be estimated. There are four classes to chose from. Only one is selected. Variation in leaf inclination on a plant can be confusing and this can be made worse the longer one looks at a plant. For this reason the observer is advised to select the leaf inclination class based on the first, quick impression – trust your eyes. Where there is clear and obvious variation across more than one class on the one plant then the 'composite' class is chosen. Although identifying a leaf inclination class can be frustrating, the real value of this variable rarely becomes apparent until plots have been compared along an obvious environmental gradient such as soil nutrient availability or rainfall seasonality. It is then that differences between rather than within plots become more obvious and inclination begins to take on some predictive value. Empirical studies from satellite images suggest combinations of leaf size class and inclination may be correlated with reflectance values (pers. obs.). There are four categories that are illustrated through a range of examples (Fig. 16).

- **Vertical** (**ve**)
  The leaf inclination is >30º above horizontal. The observer should note that even where a leaf blade may appear to be laterally inclined, the sides of the leaf may be angled in an upward "V" shape (>30º) so that the net result is a vertical inclination (e.g. *Cornus suecica* –see illustrated example Fig. 16). Very small leaves such as those in compound leguminous trees (e.g. *Albizia*, *Delonix*, *Parkia*, *Prosopis*) usually require close attention to see if the leaflets on the shoulder of the crown are >30º as inspection of the lower shade leaflets commonly indicate lateral inclination.

- **Lateral** (**la**)
  The leaf inclination is plus or minus >30º, taking into account leaf blade angles either side of the mid-rib.

- **Pendulous** (**pe**)
  The leaf inclination is >30º below horizontal. In certain cases leaf blades may possess a "V" such that it appears vertical but the entire leaf can be inclined downwards. In such cases where the leaf is >30º from the petiole[27] it is regarded as pendulous.

- **Composite** (**co**)
  The plant individual has leaves at a variety of inclinations beyond any one class. Under conditions where there are difficulties in deciding any one inclination class (ve, la, pe) then the default class is composite.

---

[26] The ability of a plant leaf to maintain maximum exposure to the sun by tracking the daily solar march.

[27] Leaf-stalk

Chlorotype
One of the key differences between the present system of functional classification and that of Raunkiaer is the inclusion here of photosynthetic organs and tissues. Whereas Raunkiaer's life forms classify plants according to relatively unchanging attributes related to the position of the perennating bud, very little attention has been given to attributes that are more sensitive to environmental change such as the photosynthetic apparatus, other than general indicators of deciduousness. The distribution of chlorophyll tissue can vary dramatically in time and space. Features that describe this variation are potentially useful in describing the adaptive response to local and often fine-scale changes in light, water and nutrients. Five elements are used here:

- Dorsiventral
- Isobilateral or isocentric
- Deciduous
- Cortic
- Achlorophyllous

- **Dorsiventral** (**do**)
  With chlorophyll mainly on the upper side of a flat leaf. If there is doubt about whether a leaf is dorsiventral or not, a good indicator is to run the fingers down both sides of the leaf – this will usually detect whether there is a groove on the dorsal or upper surface and whether there is a ridge protruding on the lower or ventral surface (terms sometime used for the upper and lower leaf surfaces are 'adaxial' and 'abaxial' respectively).

- **Isobilateral** (**is**)
  With chlorophyll equally distributed on both sides of the leaf (e.g many *Eucalyptus* species) or else equally around the surface of a solid leaf that may be circular in cross-section (**isocentric**) (e.g *Euphorbia tirucalli* and many cacti)

- **Deciduous** (**de**)
  This term is applied to plants that lose all their leaves either completely or almost completely at one or more times during a year. Indications are often given if the plant belongs to a family well known for deciduousness (Fagaceae, Moraceae, Sterculiaceae). Local knowledge can be valuable in determining if an individual that is in full leaf at the time of survey can be deciduous.

- **Cortic** (**ct**)
  Where chlorophyll is contained in the cortex (ct) of the main stem – the bark, either on the exterior or just under the outer bark (the sub-rhytidome[28]), it records a positive value for ct. Care must be exercised when examining a stem for evidence of 'ct'. A broad, sharp-bladed knife should be used to scrape (without making a direct cut) the surface of the bark at right angles to the stem. Various shades of green or yellow-green may be seen in some species. The cortic condition is recorded positive only if chlorophyll is conspicuous either as a complete layer or as discontinuous stripes (as in some families such as Bombacaceae, Malvaceae or Sterculiaceae). Upper stems and branches are ignored in estimating this variable. As many single-stemmed and almost all multistemmed woody plants <2m tall (both shrubby chamaephytes and phanerophytes) contain chlorophyll as do most woody lianes, the

[28] Living tissue below the outer bark layer (phloem) that is a frequent site for photosynthesis, common in very seasonal environments.

variable is recorded only for woody plants >2m tall where its presence or absence defines the PFT.

- **Achlorophyllous** (**ac**)
  Without chlorophyll. Certain plants such as saprophytes obtain organic matter directly from the breakdown of dead and decaying tissues of plants and animals. These plants may not require photosynthesis and for that reason do not possess chlorophyll. Certain parasites e.g. *Cuscuta* may be partly chlorophyllous. According to the rule set it is logical that with no chlorophyll, the attributes do, is, de, ct, do not apply.

Morphotype

Morphotype covers a miscellany of attributes that describe features such as method of leaf attachment and insertion and other specialised morphological characteristics:

- Rosulate (ro)
- Solid 3-dimensional (so)
- Succulent (su)
- Parallel-veined (pv)
- Filicoid (fi)
- Carnivorous (ca)

- **Rosulate** (**ro**)
  Leaf attachment or insertion is similar to the way petals are arranged on a rose. The condition is a result of a reduction in internode distance between leaves so that the leaves appear in a tight cluster towards the end of the branch or stem. Good examples of this are *Agave*, *Cyathea*, *Pandanus* and many palms and cryptophytic herbs. There is an increase in the proportion of plants with rosulate leaves in extreme environments (sea shore, upland, exposed environments, peat swamps, salt flats, ultramafic substrates etc.). In some families such as Sapotaceae, certain species of rain forest trees may exhibit partial rosette form but usually with the internode visible. As the feature is designed to reflect mainly extreme conditions, as a rule the term 'rosulate'(ro) is restricted to plants where the internode is so compressed that it is not visible. It is a common feature of many rosette-type plants with their perennating organs protected below ground (cryptophyte life form (cr))

- **Solid 3-dimensional** (**so**)
  In certain plants in families such as Cactaceae, Casuarinaceae, Chenopodiaceae and many succulent Euphorbiaceae and Orchidaceae the 'botanical' leaf may be either vestigial or reduced to a green stem that is often circular in cross-section (*Casuarina equisetifolia*, *Euphorbia tirucalli*) or greatly thickened (*Opuntia inermis*). In such circumstances the entire plant may be a functional 'leaf' (e.g. the Saguaro cactus). Most solid 3-d leaves are isobilateral (is) rather than dorsiventral (do). This auto-correlation or 'logical dependency' of (is) and (so) is unavoidable in the present classification.

- **Succulent** (**su**)
  Estimates of succulence are crude at best and may vary between observers. Nevertheless it has been shown to be a useful indicator of extreme conditions. The condition is usually described when sap is readily expressed when the leaf or stem is squeezed between thumb and forefinger. Many Araceae (*Alocasia*, *Xanthosoma*) are typically succulent as are many Cactaceae. Suculence is usually a response to

one of two extreme conditionsof moisture availability – either an aquatic or a desertic environment. Plants in the latter environment commonly exhibit crassulacean acid metabolism (CAM) – a specialised carboxylation pathway in photosynthesis. While combining the two types together in the present version of VegClass may be confusing from an adaptive viewpoint, the association of other PFTs is usually sufficient to discriminate between these extremes of moisture availability. Although the presence of many succulent epiphytes in the canopy of tropical rain forests may suggest a response to a moist environment, in fact this can be a region with frequent periods of extreme dryness that is typified by the presence of many 'desert' or CAM species e.g. Bromeliaceae and Orchidaceae.

- **Parallel veined** (**pv**)
  Leaf venation can be characterised in many ways, some of which may indicate an adaptive response to environment. The most useful venation found so far is the parallel condition found in many monocotylodons and some 'grass-like' (graminoid) dicotyledons. For most purposes the feature is restricted to graminoid leaves where the primary leaf veins run parallel to the main axis of the leaf. Certain dicotyledons such as Melastomataceae that exhibit pseudo parallel venation are excluded.

- **Filicoid** (**fi**)
  This term is used to describe the leaf type found in the fern or Pteridophyte family. It includes all ferns with the exception of the filmy ferns (Hymenophyllaceae) that may be only seasonally abundant or difficult to detect due to their sometimes cryptic habitat.

- **Carnivorous** (**ca**)
  In extreme environments where nutrients are limiting – such as acidic peat swamps and bog fringes, some plants have developed a means of capturing and digesting small animals (mostly insects). This is achieved by a remarkable evolution of leaf structures found in such genera as *Darlingia*, *Drosera*, *Sarracenia* and *Nepenthes*. In certain cases the occurrence of the so-called 'pitcher' in the pitcher plant *Nepenthes* may be facultative – meaning the plant may switch on or off the development of the leaf specialisation depending on availability of nutrients. For this reason the observer need to ensure that pitchers are actually seen when recording this feature. From a functional viewpoint such plants can access nutrients, from both mineral soil and animal sources (Schulze, *et al.*, 1997).

Life–form
'Life form' refers to the functional aspect of a plant and should not be confused with 'growth form' that refers to specific growth structures such as 'palm' 'shrub' etc. The Danish ecologist Raunkiaer (1934) devised a method of characterising plants according to the position of the perennating bud (organ) during the most unfavourable season. Because the method reflects functional or response-based features of plants to changing environment it has been found useful in characterising plants worldwide and has been the most successful method of vegetation classification developed thus far. It has the added advantage of being independent of species. Other, species-based methods such as the phytosociological approach developed by Braun-Blanquet of the so-called Zűrich-Montpellier (*cf*. Mueller-Dombois, 1974) school may be locally useful where the flora is well known but lack comparative efficiency between regions where taxa differ in otherwise similar environments or in taxonomically complex environments where identification is difficult. Raunkiaer based his classification on five major life forms:

- Phanerophytes
- Chamaephytes
- Hemicryptophytes
- Cryptophytes
- Therophytes (annuals)

He further extended these according to whether they were deciduous, shrubby, succulent, hydrophytic, (living in aquatic environments) and so on. Although the Raunkiaer system continues to be used, extensions of the method into finer categories (e.g. Mueller-Dombois, 1974) suffer from practical limitations. Despite its advantages over most vegetation classification systems, the Raunkiaer method is not without some significant problems. For example, there are gradations between most of his forms even when modified using finer scale descriptors. Many woody 'tree'species >30m tall may occur as 'suffruticose' (shrubby or multi-stemmed) phanerophytes that can be confused with multi-stemmed 'shrub'chamaephytes. Certain tropical woody plants such as *Fagraea* spp. can occur as 10m tall epiphytes. In addition, while giant woody lianas (*Entada* spp.) also qualify as phanerophyte, in the Sahel, *Entada africana* exhibits remarkable, composite features of a phanerophyte and chamaephyte and cryptophyte. For these reasons the VegClass approach uses a modification of Raunkiaer (*cf.* Gillison, 1988) to accommodate as far as possible, variation in tropical (as well as temperate) plants. I have taken some liberties with partitioning some of his forms arbitrarily into woody *vs*. non-woody and whether there is a tendency for graminoid forms to predominate in certain cases. This has been done to improve the utility of the method (see below). While purists may argue quite reasonably that this degrades the formal Raunkiaerean classification I would argue the modifications used here are more likely to ensure the maintenance of Raunkiaer's concept into the twentyfirst century, especially if it reduces ambiguity and improves the understanding and acceptance of response-based classifications. Field experience in many countries (Gillison, 1999) has shown that the use of the Raunkiaer life form 'shell' as a basis for adding photosynthetic (PFE) structures complements rather than detracts from the life form system.

- **Phanerophytes** (**ph**)

Usuall woody plants with perennating buds above ground. For VegClass these are restricted to perennial plants >2m tall. While this includes most tree species, it also includes multi-stemmed, so-called 'shrubs' as in many Myrtaceae, provided they conform to the height class. In the present classification, a phanerophyte may also occur as a woody liane.

- **Chamaephytes** (**ch**)

Usually woody plants with perennating buds on branches at or near the ground. For VegClass these are restricted to plants <2m tall. As with phanerophytes, the classification avoids confusion with the the ambiguous terms 'tree' and 'shrub'. While most chamaephytes tend to be multi-stemmed, in the present classification they can also include single-stemmed (monopodial) woody plants.

- **Hemicryptophytes** (**hc**)

Plants with perennating buds at ground level. With or without stolons or rhizomes. Examples are: *Alpinia caerulea*, *Asplenium nidus*, *Cyrtoccocum patens*, *Heliconia bihai*, *Imperata cylindrica*, *Mimosa pudica*, *Pouzolzia zeylanica*, *Pteris ensiliformis*. For plants where there may be difficulty in deciding between chamaephyte and hemicryptophyte, preference is given to hemicryptophyte where the individual is graminoid (grasslike) or non-woody.

- **Cryptophytes** (**cr**)

Plants with perennating organs below-ground. Examples are: *Alocasia longiloba, Cochlospermum tinctorium, Dioscorea alata, Stephania japonica, Curcuma domestica*. Many cryptophytes e.g. *Dioscorea* are lianoid, while others such as *Stephania japonica* may be woody, approaching phanerophytes.

- **Therophytes**

These are annuals where the individual exists as a seed during the most unfavourable season. Examples are: *Ageratum conyzoides, Crassocephalum crepidioides, Erigeron sumatrensis, Isachne globosa*. In many cases local knowledge must be relied upon to determine whether a species is a true annual and not bi- or tri- ennial as is the case in some grass species.

- **Liane modification of life forms**

As outlined above, many tropical plant species can occur in a variety of forms, some which may take on a liane or vine-like form. The present system allows any of the primary Raunkiaer forms to be modified by the '*lianoid*' term where this is applicable. Some chamaephytic species such as the tropical *Mussaenda scratchleyi* often occur in the savanna as a woody multi-stemmed form but change to a liane if the forest encroaches over them.

Above-ground root types

- Adventitious (ad)
- Aerating (ae)
- Epiphytic (ep)
- Hydrophytic (hy)
- Parasitic (pa)

A key modification of the Raunkiaer system is the addition of above-ground root modifiers of any of the perennial life forms. For example, a root parasite such as *Santalum macgregorii* may occur as either a facultative phanerophyte or chamaephyte, in which case the PFT might be mi-co-do-ph-pa. Another example could be a mistletoe (e.g. *Amyema* sp.) that could be mi-pe-do-ch-ep-pa (refer PFT descriptors, Table 4).

- **Adventitious** (ad)

Typically, roots growing from an above-ground stem such as *Ficus virens* (Curtain fig) or in many *Garcinia* or *Myristica* or *Pandanus* or *Rhizophora* species. Often indicators of moist and sometime anaerobic environments.

- **Aerating** (ae)

Roots that persist above-ground, mainly in ever-wet or seasonal wet environments, sometimes known as pneumatophores. These are especially common in mangroves as in *Avicennia marina* and many Rhizophoraceae. Other examples, also in swampy conditions are *Sonneratia alba* and *Terminalia brassii* (salt and freswater, respectively).

- **Epiphytic** (ep)

By their very nature, plants that are supported by other plants have epiphytic root systems. Typical among these are many members of the Orchidaceae and Bromeliaceae. In the tropics many species that are generally regarded as terrestrial may also occur as epiphytes (e.g. *Alocasia, Alpinia, Nepenthes, Rhododenron, Ficus, Pinus*). The present classification includes climbing epiphytes that may also be rooted temporarily or permanently in the ground such as *Epipremnum pinnatum*. This is a departure from the more conventional definition of epiphyte that requires all parts of the plant to be supported by the host.

Lithophytic root types (plants growing on bare or almost bare rock surfaces) are not classified here as epiphytes, the rock substrate being treated as 'ground' based.

- **Hydrophytic** (hy)

Although Raunkiaer restricted this to a life form class, it is used here as a simplistic category to account for the myriad of functional types that occur in aqueous environments. To adequately account for these additional types would require a significant extension of the present system and make it unnecessarily ponderous. For that reason the term 'hydrophytic' is applied to all circumstances where there is an obvious modification of the above-substrate root to a waterworld. Examples are: *Azolla, Ipomoea aquatica, Nelumbium, Nymphaea, Pistia, Victoria*.

- **Parasitic** (pa)

As explained above, certain plants can occur with parasitic root systems above-ground, when they are usually supported by aerial parts of the host, in which case they also quality as an epitphyte for the purposes of this classification. Examples are mostly members of the Loranthaceae and Viscaceae and sometimes Cuscutaceae (*Cuscuta* spp.) and Lauraceae (*Cassytha* spp.). An exception to this 'above-ground' rule is the inclusion of the (pa) descriptor where the individual is either a confirmed or suspected parasite such as *Balanophora, Exocarpos, Rafflesia* and *Santalum* although with below-ground root system.

7. Other data

Photographs

Where possible ensures a representative photograph is taken. The use of high-resolution (megapixel) digital cameras is recommended, especially one that can provide a 10-15 second 'video' of the transect in both horizontal and vertical directions.

Soil samples for laboratory analysis

It is always desirable to collect and analyse soils where logistic support permits. In rapid surveys it is frequently difficult to acquire and transport large numbers of samples. For most purposes a minimum 400g wet weight of soil is needed for laboratory analysis. Ideally the soil profile should be sampled at 0-5, 5-15, 15-25, 25-50 and 50-100cm depth or at representative zones representing changes in structure and colour. For colour a Munsell soil colour chart is used. Because soil colour data are difficult to analyse for many comparative purposes and because the acquisition of such data are time consuming, careful thought should be given as to whether accurate recording of soil colour is necessary. In very rapid surveys soil collected in the 0-15cm layer will give a minimum amount of useful information without additional sampling as it is here most nutrients occur. It is useful to sample at three equidistant points in the plot and then combine the samples in one bag. A representative 400 g can then be extracted and the sample stored in a porous container such as a cloth bag or a heavy duty plastic bag with small holes. Site tags should be included in each bag with the site name, number and date and preferably written in pencil or a waterproof marker.

Characterisation of soil drainage is desirable but experience suggests repeatability and accuracy depend largely on observer experience. For this reasondrainage has been excluded in preference to a more detailed pedological and laboratory analysis based on field samples.

Botanical specimens

Wherever possible the services of a botanist with local field experience should be sought. Voucher specimens for each species or 'morpho-species'should be tagged and cross-referenced with the plot. An unidentified specimen that may be the fifteenth sequential collection could be labeled 'Plotname/indet15' with date.

8. Tips for recording data in the field

- A preliminary inspection of the transect should be carried out so that the observer is familiar with the key structural and site physical features. This is important. Although in complex vegetation this may take up to fifteen minutes, it is time well spent. In the time available become familiar with the area to be sampled to ensure the plot is as representative as possible and that the ends of the transect do not, for example, disappear into a creek or a clearly different vegetation type.

- For recording mean canopy height select the highest and lowest canopy tree in the plot. An accurate measure of these will make it easier to estimate a mean overall height.

- In a team of observers select individual members who have a responsibility for one or two specific sampling procedures – e.g. whether site location and physical description, vegetation structure, plant species or PFTs. This will help maintain uniformity and help to reduce observer error and fatigue.

- Where possible do not record plot data in the rain as this will only lead to inaccuracies. This also prevents good photographs being taken and may make soil collections difficult where these are to be included. Recording in the rain may be difficult to avoid in the middle of a carefully coordianted field survey but consider the options carefully beforehand.

- When making a profile sketch remember this is only representational and not meant to be a highly accurate measurement of the plot. Draw in key features at both ends of the plot and in the middle, then fill in the rest. Use the sketch to emphasise key vegetation features.

- In tropical rain forest the time slot for recording is usually between 0830 and 1600hrs from the equator to about 20 degrees latitude. This is because the low sun angle outside that period leads to silhouetting of tree crowns making observation difficult. In high latitudes similar care should be taken to consider heavy shadow effects when the sun is at low angle.

- Enter the results of each days' recording into a computer using the VegClass software. When a proforma book is complete, make a photocopy. Also ensure electronic data are backed up wherever possible, preferably on a daily basis. Where access to the internet is available it is a good idea to regularly email summary data to a secure location.

- After a plot is recorded, remove any flagging tape other than that needed to relocate the plot if necessary. Keep damage to a minimum; the proforma method is designed to be essentially non-destructive of habitat. The need to slash tree bark for identification purposes can be reduced by using a small knife rather than a parang or machete. Bark wounds can lead to diseased stems.

- GPS recording can be problematic in rain forest, especially after rain. In many cases a reading can be achieved by turning off the 'sleep mode' and placing the instrument on a log under the most open segment of the canopy. Provided satellites are available, a reading can often be obtained within 10-15 minutes. Alternatively a local reading can be taken at a nearby open location and a compass traverse used to fix the plot.

9. Acknowledgements

Much useful feedback was received from training course participants in Mato Grosso, Brazil (Elton Silveira, Paulo Nunes, Alan Rangel, Peter May), WWF Indonesia (Edi Permana, Andjar Rafiastanto, Martin Hardiono, M. Stuewe), WWF-India (Christy Williams, Tariq Aziz, Sujit Bairagi, Mani Babu), ICRAF-ASB Thailand (Pornwilai Saiphotong), Conservation International, Philippines (Perry Ong, Leonard Co) and CIFOR (Nining Liswanti). José María Fernández-Palacios, (Depto. de Ecología, Facultad de Biología. Universidad de La Laguna. Tenerife), Otar Abdaladze (Institute of Botany, Academy of Science, Georgia), Khulegee Dugarjav, Hongor Tsogt and G. Tsedendash (Botanical Institute, Mongolian Academy of Sciences) kindly checked botanical identifications. Pavel Krestov (Institute of Biology & Soil Science, Vladivostok, Russian Federation) provided many useful comments. Close interaction with Guy Carpenter (Clearwater Software) greatly assisted in refining Sections I and II. Markku Kanninen of CIFOR was instrumental in facilitating conceptual development and subsequent financial assistance.

10. References

Austin, M.P. and Heyligers, P.C. (1989). Vegetation survey design for conservation: gradsect sampling of forests in North-eastern New South Wales. *Biological Conservation* **50**, 13-32.

Cornelissen, J.H.C., Lavorel, S., Garnier, E., Diáz, S., Buchmann, N., Gurvich, D.E., Reich, P.B., ter Steege, H., Morgan, H.D., van der Heijden, M.G.A., Pausas, J.G. and Poorter, H. (2003). A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. *Australian Journal of Botany* **51**, 335-380.

FAO. 2005. *Food and Agriculture Organization of the United Nations, Statistical Databases.* (http://apps.fao.org/page/form?collection=Production.Crops.Primary&Domain=Production&servlet=1&language=EN&hostname=apps.fao.org&version=default) Accessed April 2005.

Fosberg, F.R. (1967). A classification of vegetation for general purposes. In: G.F. Peterken (ed.) *'Guide to the Check Sheet for IBP Areas'*, IBP Handbook No. 4, Sect. IBP/CT, pp. 73-120.

Gillison, A.N. and Brewer, K.R.W. (1985). The use of gradient directed transects or gradsects in natural resource surveys. *Journal of Environmental Management* **20**: 103-127

Gillison, A.N. (1981) Towards a functional vegetation classification. In: A.N. Gillison and D.J. Anderson (eds.) *Vegetation Classification in Australia*, pp.30-41.

Commonwealth Scientific and Industrial Research Organization & Australian National University Press, Canberra.

Gillison, A.N. (1988) *A Plant Functional Proforma for Dynamic Vegetation Studies and Natural Resource Surveys.* Tech. Mem. 88/3, Commonwealth Scientific and Industrial Research Organization Div. Water Resources, Canberra.

Gillison, A.N. (2000). Rapid vegetation survey. In: A.N. Gillison (Coord.) Above-ground Biodiversity assessment Working Group Summary Report 1996-99 Impact of different land uses on biodiversity. pp. 25-38. Alternatives to Slash and Burn project. ICRAF, Nairobi.

Gillison, A.N. (2001a). *Vegetation Survey and Habitat Assessment of the Tesso Nilo Forest Complex; Pekanbaru, Riau Province, Sumatra, Indonesia.* Report prepared for WWF-US. (October-November, 2001). http://www.worldwildlife.org/species/attachments/tesso_nilo.pdf

Gillison, A.N. (2001b) *Promoting biodiversity conservation and sustainable use in the frontier forests of Northwestern Mato Grosso: Bioregional assessment, land use and zoning for biodiversity conservation.* Report prepared for UNDP/GEF and PróNatura (August, 2001).

Gillison, A.N. (2002). A generic, computer-assisted method for rapid vegetation classification and survey:tropical and temperate case studies. *Conservation Ecology* **6**: 3. (http://www.ecologyandsociety.org/vol6/iss2/art3/print.pdf).

Gillison, A.N. (2004). *Biodiversity assessment in the North Bank Landscape, N.E. India: a preliminary survey.* Report submitted to WWF-India and Smithsonian Institution National Zoological Park and Conservation Research Center, Va. USA. Center for Biodiversity Management Report No. 02.04 10 January 2004.

Gillison, A.N. and Carpenter, G. (1997). A generic plant functional attribute set and grammar for dynamic vegetation description and analysis. *Functional Ecology* **11**, 775-783.

Gillison, A.N. and Liswanti, N. (2004). Assessing biodiversity at landscape level: the importance of environmental context. In: T.P. Tomich, M. van Noordwijk, and D.E. Thomas (Eds.) *Environmental Services and Land Use Change: Bridging the Gap between Policy and Research in Southeast Asia . Agriculture Ecosystems and Environment* **104**: 75-86.

Gillison A.N., Carpenter, G, and Thomas, M.R. (unpubl.) Plant functional diversity and complexity: two complementary measures of species diversity.

IUCN Secretariat (1973). A working system for classification of world vegetation. IUCN Occasional Paper No. 5. Gland, Switzerland.

Küchler, A.W. (1967). *Vegetation Mapping*, (The Ronald Press Co. : New York).

McDonald, R.C. and Isbell, R.F. (1984) Soil Profile. In: R.C. McDonald, R.F. Isbell, J.G. Speight, J. Walker, J. and M.S.Hopkins (eds.) *Australian Soil and Land Survey. Field Handbook*. pp. 83-126. Inkata press, Melbourne.

Mueller-Dombois, D. (1974). *Aims and Methods of Vegetation Ecology*. Wiley, New York.

Raunkiaer, C. (1934) *The Life Forms of Plants and Statistical Plant Geography*. Clarendon Press, Oxford.

Sandmann, H. and Lertzman, K.P. (2003). Combining high-resolution aerial photography with gradient-directed transects to guide field sampling and forest mapping in mountainous terrain. *Forest Science* **49**: 429-443.

Schulze, W., Schulze, E.D., Pate, J.S. and Gillison, A.N. (1997). The nitrogen supply from soils and insects during growth of the pitcher plants *Nepenthes mirabilis, Cephalotus follicularis* and *Darlingtonia californica*. *Oecologia* 112: 464-471.

Shimwell, D.W. 1972. The description and classification of vegetation. Univ. Washington Press, Seattle.

Specht, R.L. (1981b). Foliage projective cover and standing biomass. In: A.N. Gillison and D.J. Anderson (eds.) *'Vegetation Classification in Australia'*, pp. 10-21. (CSIRO Aust. and Aust. Natl Univ. Press : Canberra).

USGS-NPS. (2003). United States Geological Survey – National Parks Service, Vegetation Mapping Program 5.0 Field methods (http://biology.usgs.gov/npsveg/fieldmethods/sect5.html)

Vanclay, J.K., Gillison, A.N. and Keenan, R.J. (1996). Using plant functional attributes to quantify site productivity and growth patterns in mixed forests. *Forest Ecology and Management* **94**: 149-163.

Walter, H. (1979). *Vegetation of the Earth and Ecological Systems of the Geo-biosphere*. Springer-Verlag, New York Inc. pp. 275.

Webb, L.J., Tracey, G.J. and Williams, W.T. (1976). The value of structural features in tropical forest typology. *Australian Journal of Ecology* **1:** 3-28.

Wessels, K.J., Van Jaarsveld, A.S., Grimbeek, J.D. and Van der Linde, M.J. (1998). An evaluation of the gradsect biological survey method. *Biodiversity and Conservation* **7:** 1093-1121.

Westoby, M., Falster, D., Moles, A.T., Vesk, P.A. and Wright, I. (2002). Plant ecological strategies: some leading dimensions of variation between species. *Annual Review of Ecology and Systematics* **33**:125–59.

Section II: User Notes for VegClass Version 2.00

VegClass: A computer-assisted data-entry and analytical tool for general vegetation classification and analysis

1. Introduction:

The VegClass© software has been developed by Guy Carpenter in association with Andy Gillison, to capture and analyse data acquired via a field proforma originally developed by Gillison (1981, 1988) for generic vegetation survey and classification. The original compilation of this software was supported by CIFOR (Center for International Forestry Research), via funding from the Australian Centre for International Agricultural Research (ACIAR) and the Swiss Agency for Development and Cooperation (SDC). The upgraded Version 2.00 has been developed through the Center for Biodiversity Management (CBM) by Guy Carpenter in association with Andy Gillison with financial support from CIFOR. The program is designed to record a minimum set of site physical, vegetation structural, plant species and Plant Functional Types (PFTs) that together provide a basis for classifying vegetation for general purposes. As described in the accompanying manual, the structure of VegClass follows a field proforma with matching data entry fields for site physical features (VC p1) , including date, observers, location, latitude, longitude, slope, aspect and elevation, soil depth, soil type and terrain position (VC p2). Additionally, vegetation structure (VC p3) includes mean canopy height, canopy cover percent (total cover, cover of woody plants, cover of non-woody plants), furcation index, basal area (m^2 ha^{-1}). All vascular plant species are recorded with provision for Families and Genera, local name and botanical authority together with a 4+4 Genus+species alphanumeric code.

In addition to plant taxa, the proforma includes **Plant Functional Types** (PFTs). Although the rationale for constructing and using PFTs is described in the accompanying manual, because it is a relatively new concept it is summarised here for convenience. The plant functional approach is based on the concept that a minimum set of 35, mostly adaptive, morphological plant attributes can be combined according to a specific rule set or grammar for dynamic vegetation description. The theoretical basis for this is described formally by Gillison and Carpenter (1997).

Using this method a plant individual can be described as a 'coherent' functioning model composed of two primary elements : The photosynthetic envelope and the vascular support system of modified life forms (after Raunkiaer, 1934). Gillison and Carpenter (1997) modified an earlier plant functional attribute set (Gillison 1981, 1988) that described a plant individual as a two-component, functional model (photosynthetic envelope and vascular support system). To the latter were added another category of life form modifiers represented by the above-ground rooting system. The photosynthetic envelope is described according to the most repetitive functional 'leaf' unit using four attribute classes (size, inclination, chlorotype and morphotype). Together these define the spatial and temporal distribution of photosynthetic leaf and stem tissue. The vascular support system is described according to a class of pure Raunkiaerean life forms modifiable by the lianoid form and a class of above-ground rooting systems (see Section I).

A PFT descriptor for the oak *Fagus sylvatica* for example, might be recorded as:**'no-co-do-de-ph'**

Where: '**no**' = **No**tophyll leaf size class
'**co**' = **Co**mposite leaf inclination
'**do**' = **Do**rsiventral leaf with chlorophyll mainly on the upper side.
'**de**' = **De**ciduous leaves
'**ph**' = **Ph**anerophyte or woody plant with perennating buds on a vascular support system > 2m tall.

We emphasise that a PFT describes a plant individual, not a taxon. A species may be represented by multiple PFTs and one PFT may represent multiple species - i.e. the species-PFT transformation is a many-to-many mapping. The method has been found useful for characterising vegetation in a way that reflects its adaptation to environment independently of species. (Gillison, 2001a,b) It can be used to make uniform comparative descriptions of plant assemblages, for example, between geographically remote localities where the species may differ but where environments and adaptive morphologies are similar.

The paper by Gillison and Carpenter (1997) also describes a means of calculating a similarity matrix based on inter-PFT distances and another based on inter-plot distances. **Diversity indices** for (Fisher's α , Shannon-Wiener and Simpson's) can also be generated on demand as can a **Plant Functional Complexity (PFC) index** (Gillison, Carpenter and Thomas, unpublished). The summary data produced via VegClass include ratios of plant species to unique as well as ratios of unique to species.

These measures have been found useful as an indicator of certain faunal assemblages above-ground carbon and certain site physical conditions such as soil bulk density and nutrient availability (Gillison, 2001a,b; Gillison et al. 2003; Jones et al., 2003; Gillison and Liswanti, 2004).

2. Purpose of VegClass:

VegClass has been developed in order to facilitate error-free electronic data entry of potentially complex data sets. The data can be entered directly in the field or in the laboratory from the field proforma. Apart from its value as a module for data entry and summary analyses of data, VegClass is an excellent training tool as it provides an explicit summary of the kinds of site physical and plant taxonomic and functional data needed to support biodiversity assessment. The data can be readily exported to a number of industry standard databases such as Microsoft Excel© and Microsoft Access© and thereby used by a variety of statistical packages. The present documentation is designed to introduce the user quickly to the method of data capture and summary analyses. The VegClass structure (graphic user interface) ensures maximum compatibility with the VegClass proforma. Blank forms (VC p42) are supplied separately to assist in generating field books. The software is designed to be user-friendly and requires only basic familiarity with the Windows® PC operating system. Both the manual and the user notes have been written for people for whom English may not be the primary language. Multiple-language versions are planned.

3. Structure of the Proforma:

The proforma supports three principal components, namely the site physical attributes, the vascular plant species and the PFEs.

4. VegClass specifications:

VegClass is written to run under Windows® 95/98 and NT platforms including Windows® XP. It requires 3 megabytes of hard disk space to install.

5. How to acquire and Install VegClass:

At the time of writing VegClass 2.00 is unavailable on CD-ROM. However the program may be downloaded directly from either the CIFOR website (www.cifor.org) or the CBM website (www.cbmglobe.org). The program is currently available *gratis* from both sources. Instructions for installation are evident when the program is first opened.

6. How to run VegClass:

Once installed, VegClass may be run by selecting Start, then Programs, then by moving the mouse over to the VegClass option on that menu and finally double clicking on the VegClass icon. Alternatively the icon can be placed on the Desk Top task bar. A VegClass splash page (VC p41) will appear briefly.

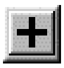
7. How to Enter Data into VegClass:

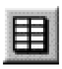
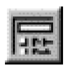
To create a new file, select 'New' from the 'File' menu or use control+N. A new file will be created. If desired, a previously saved file may be edited by using Control+O or selecting Open from the File menu. Recently edited files will appear at the end of the File drop down menu.

The VegClass window is divided into two panes. Adjust the panes using the mouse click-and-drag function to view the forms in full. Each pane may be in proforma view (VC p1) or spreadsheet view (VC p1a). In proforma view, the top window has 3 tabs where data may be entered relating to general **site** description, **vegetation** description and **site** physical attributes.

The lower pane (VC p4) has click-the-box options for describing the plant individual being recorded. By moving the mouse over the boxes, a dialogue box will outline the meaning of the two-letter abbreviation. The boxes are linked to ensure the validity of the entered PFT. Mutually exclusive options are automatically negated, and missing required attributes are automatically added.

The toolbar above the top pane shows the record number. Each plot must be identified with a unique plot ID, which is distinct from the record number. The tool bar may be moved to a vertical orientation or to overlay other panes. It may be hidden by clicking on the x at the top right corner of the bar and retrieved by using the View menu. The forward and reverse triangles allow a user to step between records singly or the double triangles allow a user to move quickly to the first and last records.

When a record is complete, click the  button to append. This saves the data as well as stepping the user forward to a new empty record at the end of the file. If a previously saved record is changed, VegClass will prompt to ensure that this change is correct. Alternatively, clicking on the disk icon, using Control+S or Save on the File menu will also save the document.

To the right of the yellow question mark help button are two buttons which allow a user to view the two panes in either spreadsheet (VC p5)  or proforma (VC p4)  mode. These toggle buttons switch between the viewing modes.

At present, data may only be edited in the proforma mode although the next version will allow direct-edit in spreadsheet format.

The following facilities and options are available for data manipulation:

8. File operations:

Merge file: allows the user to append other *.pfa files.

9. Record manipulation:

Sort: Facilitates direct sorting of site names. An additional facility provides for insertion and deletion of records.

10. Edit preferences:

Three sets of user-configurable preferences (VC p13) can be set. Click on Edit in the main menu to gain access to the preferences. Changes are automatically saved in a vegclass.ini file.

Species Comparisons and Data Entry

This is a particularly useful tool that influences the total number of records counted for a plot. Boxes can be checked to include or exclude:Family, genus, species, species code, local name. A section below the dialogue box allows the user to decide whether to automatically generate a 4+4 genus + species code and whether a PFT is required for every record added to the database (both recommended).

Cache

A core function of PFT analysis is the computation of the degree of difference between plant functional types. Once computed, the differences are stored in a cache where they can be found later to avoid unnecessary recalculation. Under normal circumstances the cache settings should not be changed from their defaults.

Other

The other tab allows the user to adjust the maximum number of quadrats used in the quadrat analyses. The default value is 8. The value entered here determines the number of rows in the quadrat analysis results. While VegClass© normally provides for 8 5x5m quadrats in a 40 x 5m transect, other requirements may dictate extended quadrats.

11. Analysis: (access via single left hand click on 'Analysis')

PFA/PFT tables (VC p6): Options here include

- **Data source:** Current plot or all plots
- **Table columns:** Complete species (VC p14) , PFT or individual PFT attribute elements.
- **Count method:** Species-weighted count (i.e. the number of species per PFT (recommended)); Presence/absence.
- **Totals:** Data totals can be included or excluded using this toggle switch.
- **Extent of table columns:** if *this document* or *all documents* is specified, zero-filled columns will be added for all entries in the current document or in all currently opened documents.

Distance Tables (VC p7):

- **Data source:** Current plot or all plots
- **Distance measure:** distance between PFTs or distance between plots. Algorithms for these measures are described in Gillison and Carpenter, (1997). In addition to the values provided for a distance matrix a log-transform is available
- **Distance matrix:** A matrix can be computed for PFTs or for transects is computed and can be generated as the lower or upper half of a matrix or the entire matrix. These can be exported directly in CSV (comma delimited) format for use in a variety of statistical analyses.

Site summary table (VC p8):

- **Data source:** Current plot or all plots (VC p17)
- **Table columns:** The options include:
  - **Unique species:** (include a column counting unique species in each plot)
  - **Unique PFTs:** (include a column counting unique PFTs in each plot)
  - **Total record count:** Total number of individually recorded species and PFTs.
  - **Species/PFT ratio:** (useful as predictive correlate for other taxa etc.)
  - **Furcation mean and cv%:** (mean and coefficient of variation percent computed automatically from FI counts from 20 nearest-neighbour, canopy individuals). Gives an indication of influence of site physical conditions on woody plant architecture.
  - **Basal area mean:** Mean of three basal area counts.
  - **Complexity measure:** Plant Functional Complexity (PFC) computed as total minimum spanning tree length of all PFTs within a plot (ref: Gillison and Carpenter, 1997). This is not selected by default because it can be a potentially time-consuming computation.
  - **Diversity measures:** Includes Shannon-Wiener, Simpson's and Fisher's α for functional types. (See accompanying manual for explanation).
  - **Proforma vegetation:** All vegetation structural variables.

Quadrat tables (VC p9):

The number of quadrats is set at a default of 8. The default can be user-modified via the 'Edit' tab. Output includes total records, total unique species, total unique PFTs, totals of species/PFT ratios, Fisher's α for species and PFTs and total species records.

12. Graphics:

Various graphic outputs can be generated such as total species against PFTs after a summary table is generated. When a quadrat table summary is generated, clicking once on 'View' opens a dialogue box. Clicking once on 'Graph' generates a default graph (VC p10) of total species against quadrat counts. This may be modified by selecting other variables (VC p12) such as 'Unique species' or 'Unique PFTs' or 'Species/PFT ratios' that can be graphed one against the other. A facility exists for labelling graph points with quadrat row numbers. The graph dimensions can be modified by clicking on 'graph layout' (VC 12b). Graphs can be printed out directly. Table properties (VC p11) can be modified and clicking on 'edit' also provides for options to hide invariant table values as well as rotating table axes.

13. Print:

Various outputs can be printed out directly. Choose 'Print' option under 'File'. These include site and vegetation spreadsheets, PFA/ PFT tables, summary tables, quadrat tables and graphs.

14. Export and import:

Data files are stored as Microsoft Access databases, with a default file name extension of "pfa". These files can be read and modified directly in Microsoft Access©. Site and vegetation spreadsheets, and analysis results can be exported as Comma Separated Value (CSV) files. CSV files can be read by Microsoft Access©, Excel©, Word© and many analytical packages.

15. User feedback:

Constructive feedback on the use of the present version of VegClass will be very welcome. Please email any comments to < andy.gillison@austarnet.com.au >.

16. References:

Gillison, A.N. (1981) Towards a functional vegetation classification. In *Vegetation Classification in Australia* (eds A.N. Gillison & D.J. Anderson), pp.30-41. Commonwealth Scientific and Industrial Research Organization & Australian National University Press, Canberra.

Gillison, A.N. (1988) *A Plant Functional Proforma for Dynamic Vegetation Studies and Natural Resource Surveys.* Tech. Mem. 88/3, Commonwealth Scientific and Industrial Research Organization Div. Water Resources, Canberra.

Gillison, A.N. and Carpenter, G. (1997). A generic plant functional attribute set and grammar for dynamic vegetation description and analysis. *Functional Ecology* **11**, 775-783.

Gillison A.N., Carpenter, G, and Thomas, M.R. (unpubl.) Plant functional diversity and complexity: two complementary measures of species diversity.

Raunkiaer, C. (1934) *The Life Forms of Plants and Statistical Plant Geography*. Clarendon Press, Oxford.

Section III: Sample data and case studies

1. Sample data from WWF survey, Tesso Nilo, Sumatra

An intensive survey of the Tesso Nilo area of Riau Province, Sumatra, Indonesia was undertaken by WWF-Indonesia in late 2001. Full details of the report are available online http://www.eyesontheforest.or.id/doc/tesso%20nilo%20biodiversity.pdf . Although the survey was short and intensive, it provided important documentation that subsequently led to a logging moratorium and ultimately a proposed National Park by the Indonesian Government. In addition, the survey recorded the highest levels of plant diversity for any terrestrial vegetation type using the VegClass system. The data file Sumatra.pfa can be downloaded as well from www.cbmglobe.org. Data from this file should not be modified or used for publication without prior arrangement with WWF-Indonesia or CBM (andy.gillison@austarnet.com.au).

2. Comparative data from global studies using VegClass

The VegClass recording system has been used in more than 1,600 transects worldwide. As such it provides a uniform basis for comparing plant diversity across a wide range of environments. Such data are currently unique as global records of vegetation tend to be produced using non-uniform methods and at different scales. A comparison of data acquired from a selection of closed forests (VC p 43) worldwide illustrates how data may be used for comparative studies at regional and global scale.

3. VegClass and biodiversity indicators

Multi-disciplinary, ecoregional baseline studies along perceived land use intensity gradients in forested landscapes have shown how certain plant-based biodiversity indicators can be used to predict the occurrence of certain faunal groups such as termites (VC p44) (Gillison et. al., 2003; Jones et al. 2003) as well as above-ground carbon (VC p45). While both plant species and PFT richness (number per unit area) are useful predictors, the examples included here illustrate how the ratio of species to PFT richness can also be powerful indicators of biophysical variables.

4. Spatial modelling using VegClass data

All data recorded using the VegClass approach are georeferenced wherever possible. This facilitates the spatial analysis of data in geographic information system (GIS) platforms, especially where there is a management need for estimating the likelihood of species or PFT distributions (VC p46). Spatial analysis of this kind is largely independent of scale and can be tuned to management requirements. The approach is potentially useful for designing baseline surveys and can be used to simulate land use impact on biodiversity where sufficient ground data are available. The DOMAIN potential mapping software (Carpenter et al., 1997) used for these purposes is also available via the CIFOR website (www.cifor.org) and the CBM website (www.cbmglobe.org).

5. References

Carpenter, G., Gillison, A.N. and Winter, J. (1993). DOMAIN:a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity Conservation* **2**: 667-680.

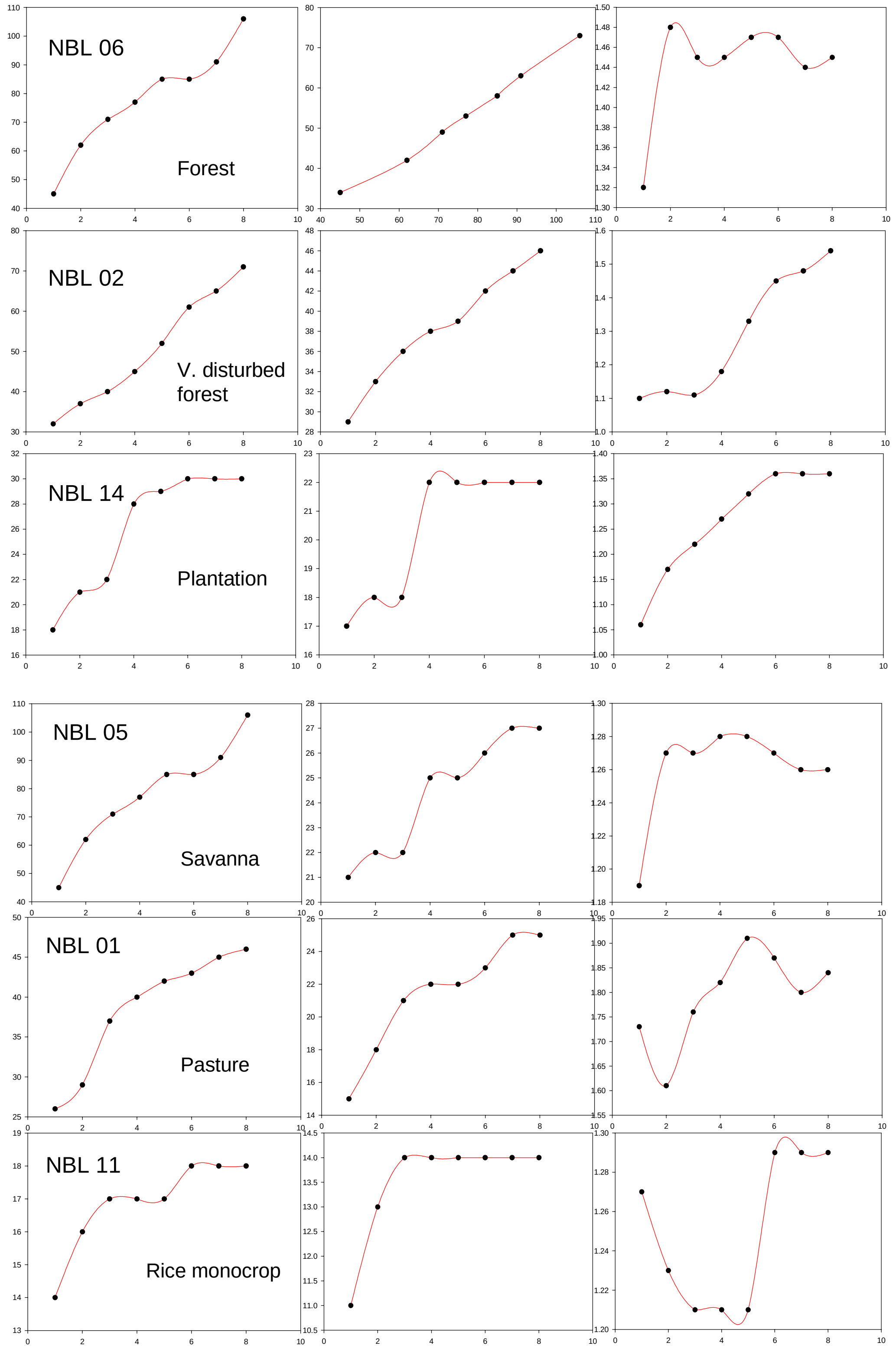
Gillison, A.N., D.T. Jones, F.-X. Susilo and D.E. Bignell. (2003). Vegetation indicates diversity of soil macroinvertebrates: a case study with termites along a land-use intensification gradient in lowland Sumatra. *Organisms, Diversity and Evolution* **3**:111-126.

Jones, D.T., Susilo, F.X., Bignell, D.E., Hardiwinoto, S., Gillison, A.N. and Eggleton, P. (2003). Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *Journal of Applied Ecology*, **40**: 380-391.

Section III Annexes

1. Fig 3

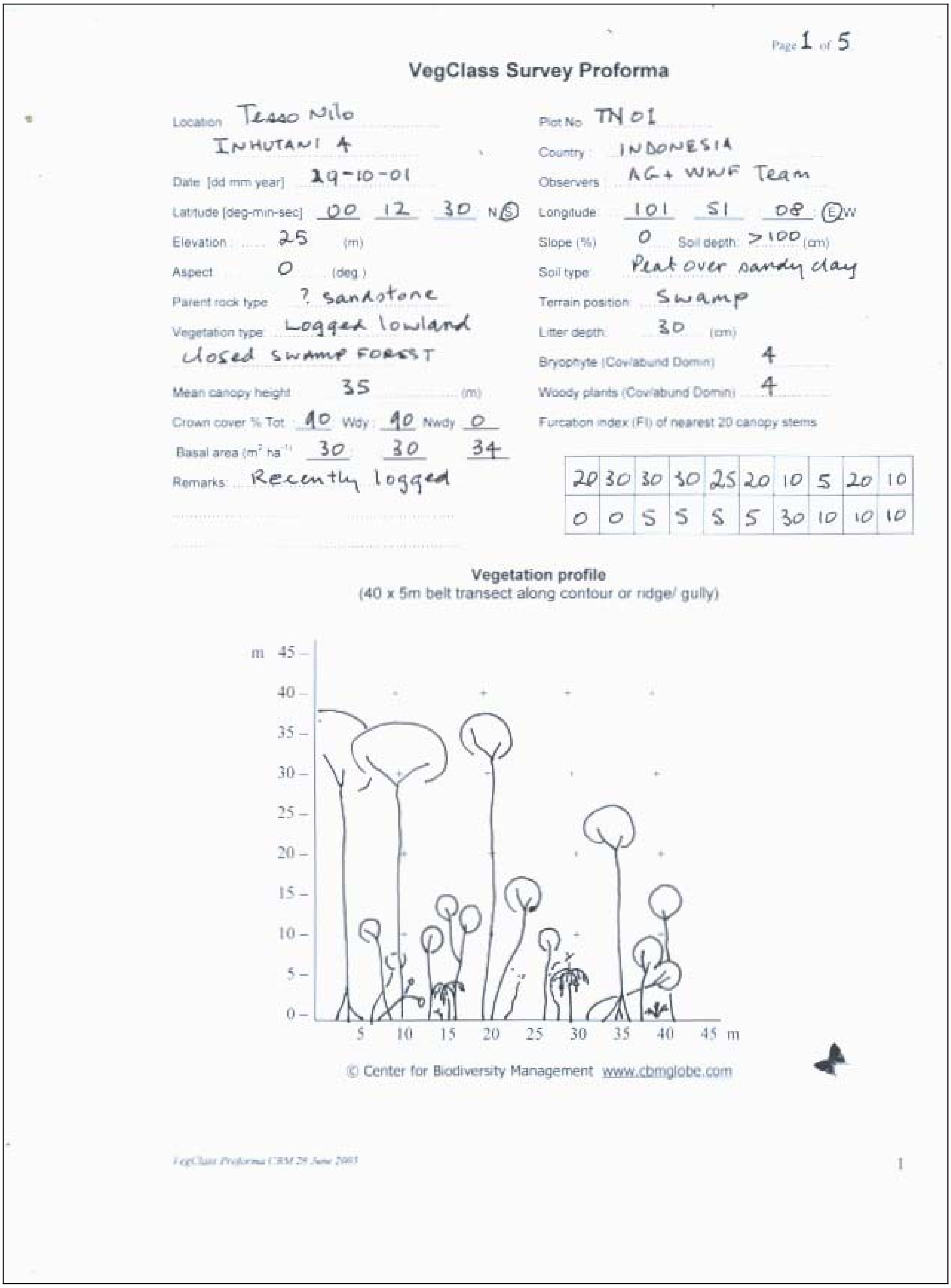
Species **PFTs** **Spp:PFT**



Transects (8 (5x5m quadrats))

Figure 3. Species:area, PFT:area and spp/PFT:area curves for six representative vegetation types in the North Bank Landscape (Assam), India

2. Fig 4. Proforma sheeet 1


Page 1 of 5

VegClass Survey Proforma

Location: Tesso Nilo INHUTANI 4
Plot No: TN 01
Country: INDONESIA
Date [dd mm year]: 29-10-01
Observers: AG + WWF Team
Latitude [deg-min-sec]: 00 12 30 N (S)
Longitude: 101 51 08 (E) W
Elevation: 25 (m)
Slope (%): 0
Soil depth: >100 (cm)
Aspect: 0 (deg.)
Soil type: Peat over sandy clay
Parent rock type: ? sandstone
Terrain position: Swamp
Vegetation type: Logged lowland closed swamp FOREST
Litter depth: 30 (cm)
Bryophyte (Cov/abund Domin): 4
Mean canopy height: 35 (m)
Woody plants (Cov/abund Domin): 4
Crown cover % Tot: 90 Wdy: 90 Nwdy: 0
Furcation index (FI) of nearest 20 canopy stems
Basal area (m^2 ha^{-1}): 30 30 34
Remarks: Recently logged

20	30	30	30	25	20	10	5	20	10
0	0	5	5	5	5	30	10	10	10

Vegetation profile
(40 x 5m belt transect along contour or ridge/ gully)

© Center for Biodiversity Management www.cbmglobe.com

1

PLANT FUNCTIONAL TYPES AND SPECIES

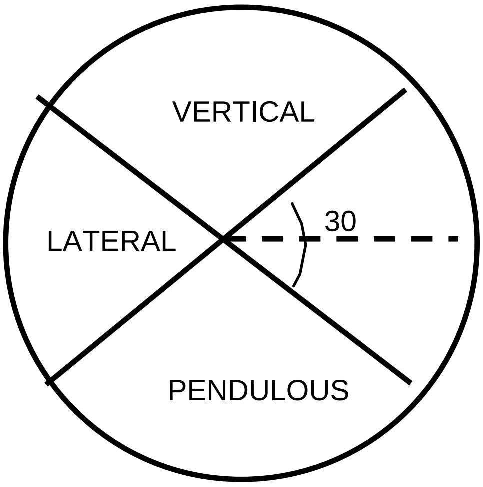
3. Table 3
Sheet B

Plot No…TN01………. Date: …29-10-01……… Observers: …AG + WWF
Team…………………..

Functional elements											Species	W	X
No.	Leaf								Life form	A/Gr Root type			
	Size	Incl	Chlorotype			Morphotype							
1	na	la	do			fi			hc	ad	Lindsaea doryphora (Dennstaed..)		
2	mi	la	do		ct				ph	ad	Macaranga triloba (Euphorb..)		
3	pl	la	do		ct	ro	pv		ph	ad	Pinanga sp. (Arecaceae)		
4	pl	la	do		ct	ro	pv		ph	ad	Nenga pumila var. pachystachya (“)		
5	me	la	do			ro	pv		ph	ad/li	Calamus sp. (Arecaceae)		
6	no	la	do		ct				ph	ad	Xylopia malayana (Annonac..)		
7	pl	la	do		ct				ph		Santiria laevigata (Burserac..)		
8	me	la	do		ct				ph		Knema cinerea (Myristic..)		
9	no	la	do						ch		Barringtonia macrostachya (Lecyth.)		
10	me	co	do						ph	li	Agelaea macrophylla (Connarac..)		
11	me	la	do		ct				ph		Litsea noronhae (Laurac..)		
12	me	la	do						ph	li	Uvaria ovalifolia (Annonac..)		
13	no	co	do			ro		pv	ph	ad/li	Calamus sp2 (Arecaceae)		
14	me	la	do		ct				ph		Mallotus laevigatus (Euphorb..)		
15	pl	la	do						ch		Clerodendron phyllomega (Verben..)		
16	mi	co	do						ph	li	Lasianthus constrictus (Rubiac..)		
17	me	ve	do		ct				ph	ae	Horsfieldia subglobosa (Myristic..)		
18	me	co	do						ph		Pentace floribunda (Tiliac..)		
19	me	co	do		ct				ph		Drypetes subsymmetrica		
20	me	la	do		ct				ph	ad	Xerospermum noronhianum (Sapin.)		
21	no	co	do						ph	li	Phanera stipularis (Fabaceae)		
22	na	la	do			fi			ch		Diplazium esculentum (Aspleniac..)		
23	me	la	do						ph	li	Fissistigma latifolium (Annonac..)		
24	no	la	do						ph	li	Mezzettia havilandii (Annonac..)		
25	no	co	do		ct				ph		Memecylon hullettii (Melastom..)		

W = Weed X = Exotic

4. Fig. 6



Leaf inclination

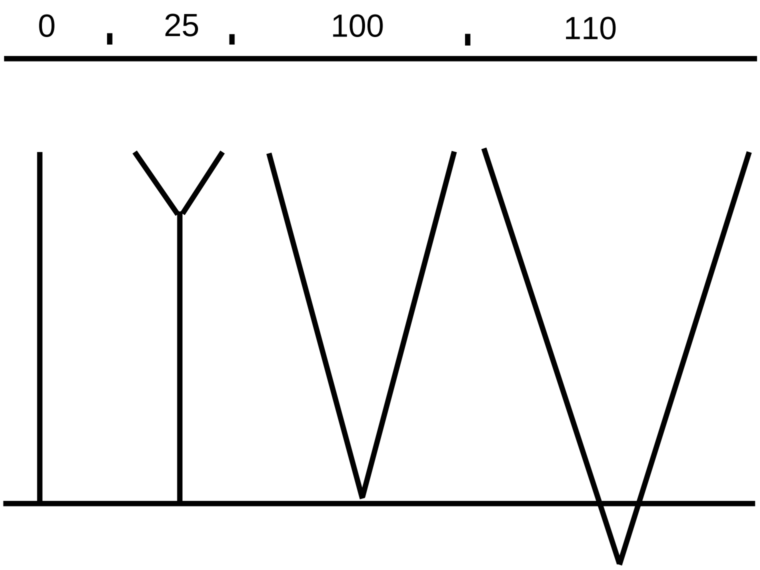
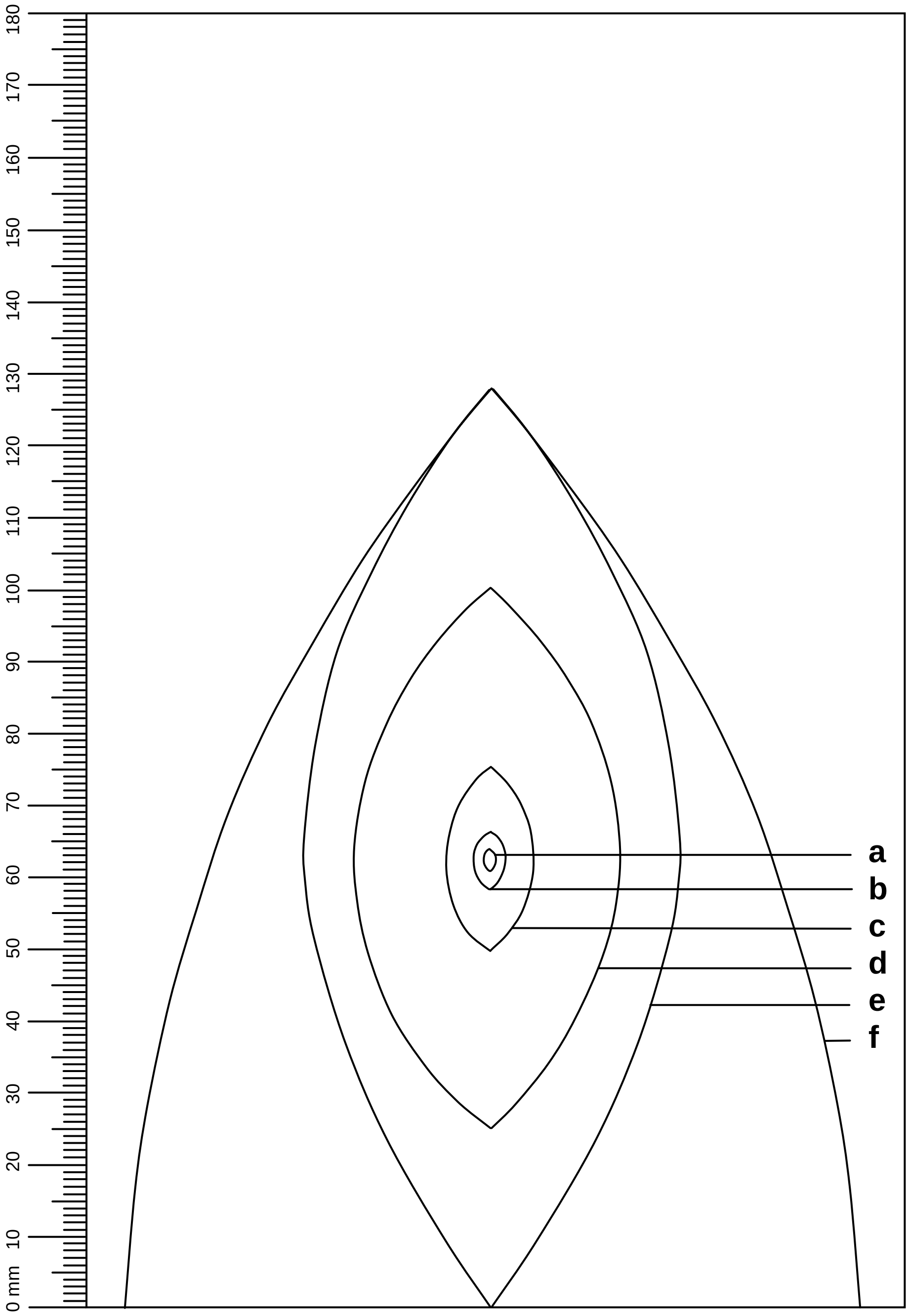


Figure 6. Furcation index (%) examples of continuous range 0 - 110%

5. Fig 7.



Leaf size class	Approximate length of lanceolate leaf (mm)	Approximate area (mm^2)
<a = picophyll	<2	<2
<b = leptophyll	2 - 8	2 - 25
<c = nanophyll	8 - 25	25 - 225
<d = microphyll	25 - 75	225 - 2025
<e = notophyll	75 - 125	2025 - 4500
<f = mesophyll	125 - 250	4500 - 18,200
f to 2xf = platyphyll	250 - 360	18,200 - 36,400
2f to 8x rectangle = macrophyll	360 - 830	36,400 - 18 x 10^4
>8x rectangle = megaphyll	>830	>18 x 10^4

Figure 7. Field book leaf size template

6. Fig 8

Figure 8. Picophyll leaf size class (pi) (< 2 mm^2) (**a**) *Donatia novae-zelandeae* (Donatiaceae), Central Plateau, Tasmania, Australia (**b**) *Tamarix laxa* (Tamaricaceae), central Gobi Desert, Outer Mongolia (**c**) *Selaginella* sp. (Selaginellaceae), E. Kalimantan, Borneo; **Leptophyll leaf size class** (le) (2 – 25 mm^2) (**d**) *Fabiana* sp. (Solanaceae) Pilcaniyeu, Patagonia, Argentina, (**e**) *Saxifraga exarata* (Saxifragaceae), Kazbegi, Central Caucasus, Georgia (**f**) Bell Heather *Erica cinerea* (Ericaceae), Lizard Peninsula, Cornwall U.K.

7. Fig 9.

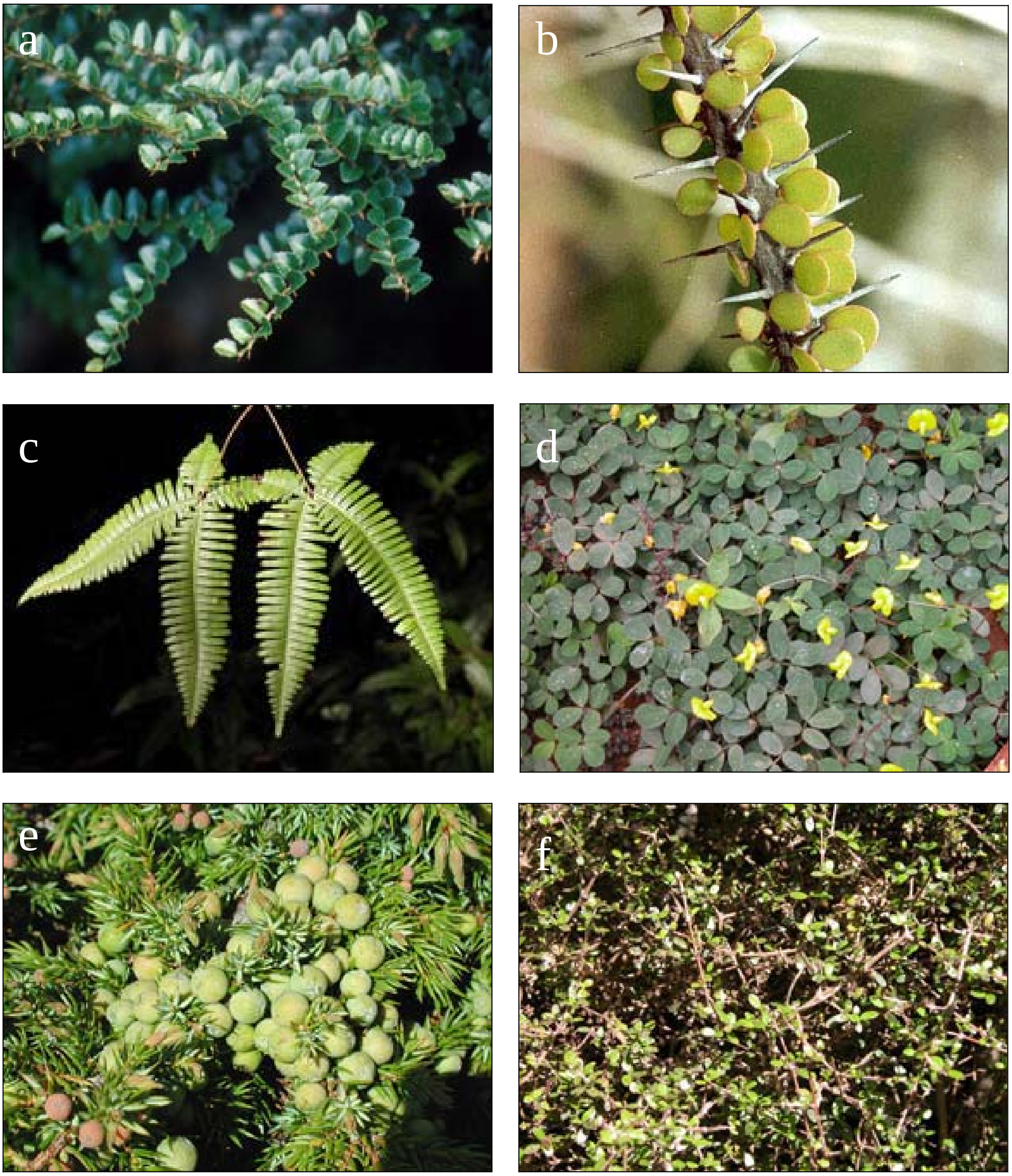


Figure 9. Nanophyll leaf size class (na) (25 – 225 mm^2). (**a**) Myrtle Beech, *Nothofagus cunninghamii* (Fagaceae), Central plateau, Tasmania (**b**) Madagascan Ocotillo *Alluaudia procera* (Didiereaceae), Botanical gardens Antananarivo, Madagascar (**c**) Climbing fern *Dicranopteris linearis* (Gleicheniaceae), Bulolo, Papua new Guinea (note: also **Filicoid** (fi) (**d**) Pinto Peanut *Arachis pintoi* (Fabaceae), Western Amazon basin, Pucallpa, Perú (**e**) Juniper *Juniperus communis* (Cupressaceae), Vestforgay, Lofoten Islands, Norway (**f**) Divaricating *Coprosma* sp. (Rubiaceae), South Otago, New Zealand.

8. Fig. 10

Figure 10. Microphyll leaf size class (mi) (225 – 2025 mm^2) (**a**) Wild strawberry *Fragaria vesca* (Rosaceae) and *Geranium robertianum* (Geraniaceae), Bakuriani, Minor Caucasus, Georgia **(b**) (l > *r*) Willow *Salix phylicifolia* (Salicaceae), Columbine *Aquilegia vulgaris* (Ranunculaceae), Lupin *Lupinus polyphyllus* (Fabaceae) Lofoten islands, Norway (**c**) *Salvinia molesta* (Salviniaceae) S. America (**d**) *Carpobrotus cf.* (Aizoaceae), Cape Province, S. Africa (**d**) *Breynia cernua* (Euphorbiaceae) and (**f**) Bonewood *Macropteranthes leichardtii* (Combretaceae), palaeotropic semi-deciduous 'Monsoon' forest, N. Queensland.

9. Fig. 11

Figure 11. Notophyll leaf size class (no) 2025 – 4500 mm^2 (**a**) Saltbush *Scaevola taccada* (Goodeniaceae), Christmas island, Indian Ocean (**b**) Black Mangrove *Lumnitzera racemosa* (Combretaceae), Morobe, Papua New Guinea (**c**) Birch *Betula pendula* (Betulaceae), Khentii Mts, Mongolia (**d**) *Piper* sp. (Piperaceae), Braulio Carillo NP Costa Rica (**e**) Pencil Bush *Euphorbia cf. tirucalli* (Euphorbiaceae), (S. Africa) Botanical gardens, Barcelona, Spain (**f**) Grey-leaf Sugarbush *Protea laurifolia* (Proteaceae), near Franschhoek, S. Africa.

10. Fig. 12

Figure 12. Mesophyll leaf size class (me) (4500 – 18200 mm^2)**.** (**a**) Hedge Maple *Acer campestre* (Aceraceae), Bakuriani, Minor Caucasus, Georgia (**b**) Chatham Island Forget-Me-Not *Myosotidium hortensis* (Boraginaceae), Chatham Is. Sub-Antartctic New Zealand (**c**) *Costus speciosus* (Zingiberaceae), New Ireland Province, Papua New Guinea. (**d**) Wild Yam *Dioscorea* sp. (Dioscoreaceae), Mae Chaem, Thailand (**e**) *Terminalia sericocarpa* (Combretaceae), Mission Beach, N. Queensland (**f**) *Neoregelia* sp. (Bromeliaceae), (cult.) Brazil.

11. Fig. 13

Figure 13. Platyphyll leaf size class (pl) (18200 – 36400 mm^2). (**a**) *Belucia* sp. (Melastomataceae) Mato Grosso, SW Amazon basin, Brazil (pseudo-parallel veins, non-(pv)) (**b**) *Bromelia balansae* (Bromeliaceae) Alcalinas Canamá , Mato Grosso, SW Amazon basin, Brazil (note: also (pv)) (**c**) *Opuntia* sp. (Cactaceae) Veracruz, Mexico (**d**) *Cecropia hololeuca*, (Cecropiaceae), Juruena, Mato Grosso, Brazil (**e**) *Pterostylis nutans* (Orchidaceae), Yungaburra, Queensland (also (pv)) (**f**) *Rumex scutatus* (Polygonaceae), Kazbegi, Central Caucasus, Georgia.

12. Fig. 14

Figure 14. Macrophyll leaf size class (ma) (36400 - 18 x 10^4). (**a**) *Brocchinia micrantha* (Bromeliaceae), Kaieteur, Guyana (**b**) *Anthurium* spp. (cult). (Araceae) (S. America) (**c**) *Platycerium bifurcatum* (Polypodiaceae), Lamb Range, N. Queensland, Australia (**d**) *Gunnera mexicana* (Gunneraceae), San Carlos de Bariloche, Argentina (**e**) New Zealand Flax *Phormium tenax* (Agavaceae), South Otago, New Zealand (**f**) *Pandanus* sp. (Pandanaceae), Bicobian peninsula, Luzon, Philippines.

13. Fig. 15

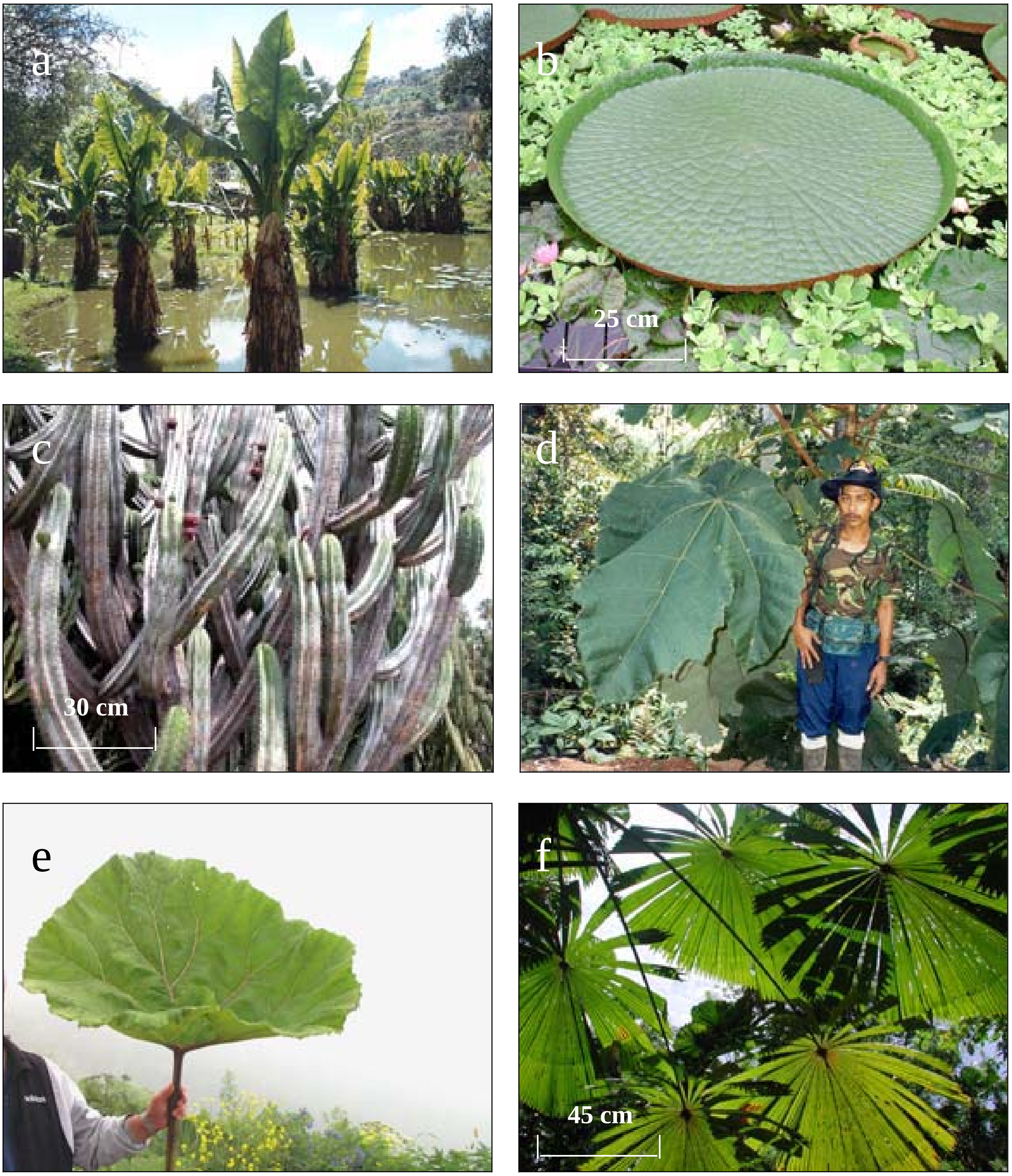


Figure 15. Megaphyll leaf size class (mg) (> 18 x 10^4 mm)**.** (**a**) *Typhonodorum lindleyanum* (Araceae), Antananarivo, Madagascar (**b**) Giant Water Lily *Victoria amazonica* (Nymphaeaceae), Rondônia, Western Amazon basin, Brazil (**c**) *Euphorbia canariensis* (Euphorbiaceae), Guimar, Tenerife, Canary Islands, Spain (also **Succulent** (su). (**d**) *Macaranga gigantea* (Euphorbiaceae), Jambi, Sumatra, Indonesia (**e**) *Petasites albus* (Asteraceae), Minor Caucasus, Georgia (**f**) Fan palm *Licuala ramsayi* (Arecaceae), Kuranda N. Queensland, Australia

14. Fig. 16 Leaf Inclination

Figure 16. Leaf inclination classes: **Lateral** (la) (**a**) *Merremia peltata* (Convolvulaceae), Guadalcanal, Solomon Islands. **Vertical** (ve) (**b**) *Rhizophora apiculata* (Rhizophoraceae), Republic of Belau, Micronesia (**c**) *Cornus suecica* (Cornaceae), Lofoten Islands, Norway. **Composite** (co) (**d**) *Persoonia falcata* (Proteaceae) Mt Surprise, N. Queensland, Australia (**e**) *Pandanus* sp. (Pandanaceae) Bicobian peninsula, Luzon, Philippines Note: also **parallel-veined** graminoid (pv). **Pendulous** (pe) (**f**) Bimble Box *Eucalyptus populnea* (Myrtaceae), Wycanna, S. Queensland.

15. Fig. 17

Figure 17. Chlorotype: Dorsiventral (do) **(a)** *Dillenia* sp. (Dilleniaceae), Mae Chaem, Thailand. (**b**) *Picea orientalis* Pinaceae, Minor Caucasus, Georgia. **Isobilateral** or **isocentric** (is) (**c**) *Acacia* spp. (Fabaceae), (isobilateral), Mt Garnet N. Queensland, Australia (**d**) *Echinocactus grusonii* (Cactaceae), (isocentric), Mexico (cult.) (**e**) *Haloxylon ammodendron* (Chenopodiaceae), (isocentric), Gobi Desert, Outer Mongolia (**f**) *Casuarina equisetifolia* (Casuarinaceae), (isocentric), Mission Beach, N. Queensland. Note: (d,e,f) also **solid** 3-d (so) in cross section.

16. Fig. 18

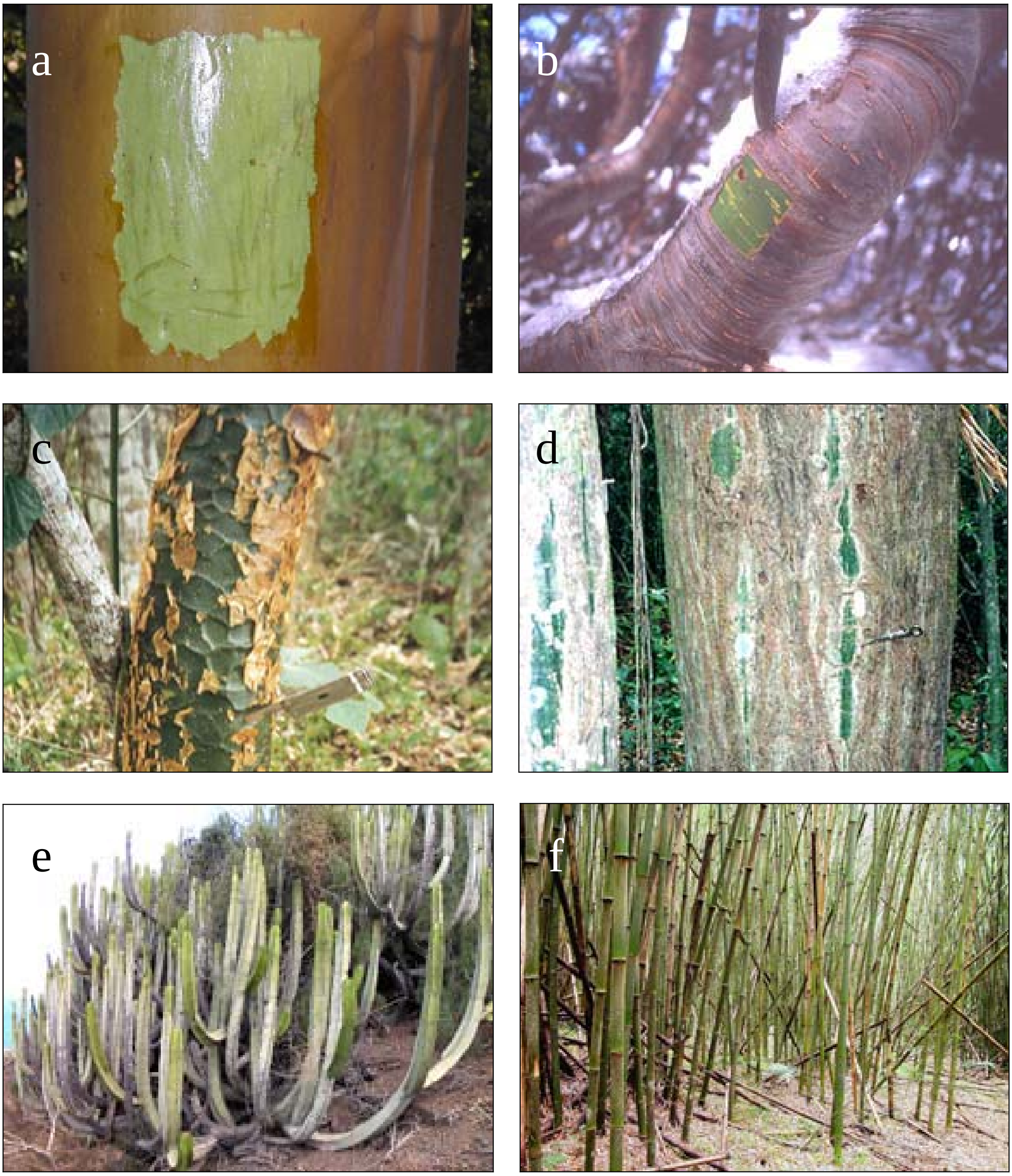


Figure 19. Chlorotype: Cortic (ct) (photosynthetic cortex or green stem) (**a**) Capirona *Calycophyllum spruceanum* Rubiaceae, Jenaro Herrera, Ucayali river, Western Amazon basin, Perú (**b**) *Nothofagus pumilio* Fagaceae Ushuaia, Tierra del Fuego, Argentina (**c**) *Bursera* sp. Burseraceae, Puesto Nuevo. Santa Cruz, Bolivia (**d**) *Chorisia* sp. Bombacaceae, Las Trancas, Bolivia (**e**) *Euphorbia candelabrum* Euphorbiaceae, Guiamar, Tenerife, Canary Islands, Spain (**f**) Subalpine Bamboo *Yushania (Sinarundinaria) alpina* Poaceae, Aberdare NP Kenya.

17. Fig. 19 Root type

Figure 19. Root types: Aerating (ae) (**a**) Pneumatophores on Grey Mangrove *Avicennia marina* (Avicenniaceae), N. Queensland, Australia (**b**) 'Knee root' pneumatophores on Large Leaved Orange Mangrove *Bruguiera gymnorrhiza* (Rhizophoraceae), N. Queensland. **Epiphytic** (ep) (**c**) *Myrmecodia tuberosa 'salomonensis'* (Rubiaceae), Guadalcanal, Solomon Islands, S.W. Pacific (**d**) *Epipremnum pinnatum* (Araceae), Palmerston NP, N. Queensland. **Hydrophytic** (hy) (**e**) Lotus Lily *Nelumbium nelumbo* (Nelumbonaceae), Bali, Indonesia. **Parasitic** (pa) (**f**) *Cuscuta europaea* (Cuscutaceae), parasitising *Polygonum alpestre* (Polygonaceae), Kazbegi region, Central Caucasus, Georgia.

18. Fig. 20 Rosulate

Figure 20. Morphotype: **Rosulate or rosette** (ro) **leaf insertion**. (**a**) Frailejón *Espeletia schultzii* Asteraceae Venezuelan Andes 4,100 m. (**b**) Cycad *Cycas media* Cycadaceae, Atherton Tableland, N. Queensland 700m (**c**) *Lobelia Deckenii sattimae* Campanulaceae, Aberdare N.P. Kenya 3,100m (**d**) *Pandanus* sp. Pandanaceae Sibayak volcano, Sumatra, Indonesia 2,100m (**e**) Dragon tree *Dracaena draco* Agavaceae Tenerife, Canary Islands, Spain 800m (**f**) Golden Houseleek *Greenovia* aurea Crassulaceae Tenerife, Canary islands, Spain 700m.

19. Fig. 21 Carnivorous

Figure 21. Morphotype: Carnivorous (ca) (**a**) Green Pitcher Plant *Sarracenia alata* (Sarraceniaceae) Louisiana, USA (**b**) *Sarracenia purpurea* (Sarraceniaceae), Bruce Peninsula, Ontario, Canada (**c**) Climbing Pitcher Plant *Nepenthes alata* (Nepenthaceae), Luzon, Philippines. Scale cm. (**d**) *Drosera* sp. (Droseraceae), Montagne des Sources, New Caledonia.

20. Fig. 22 Life form 1

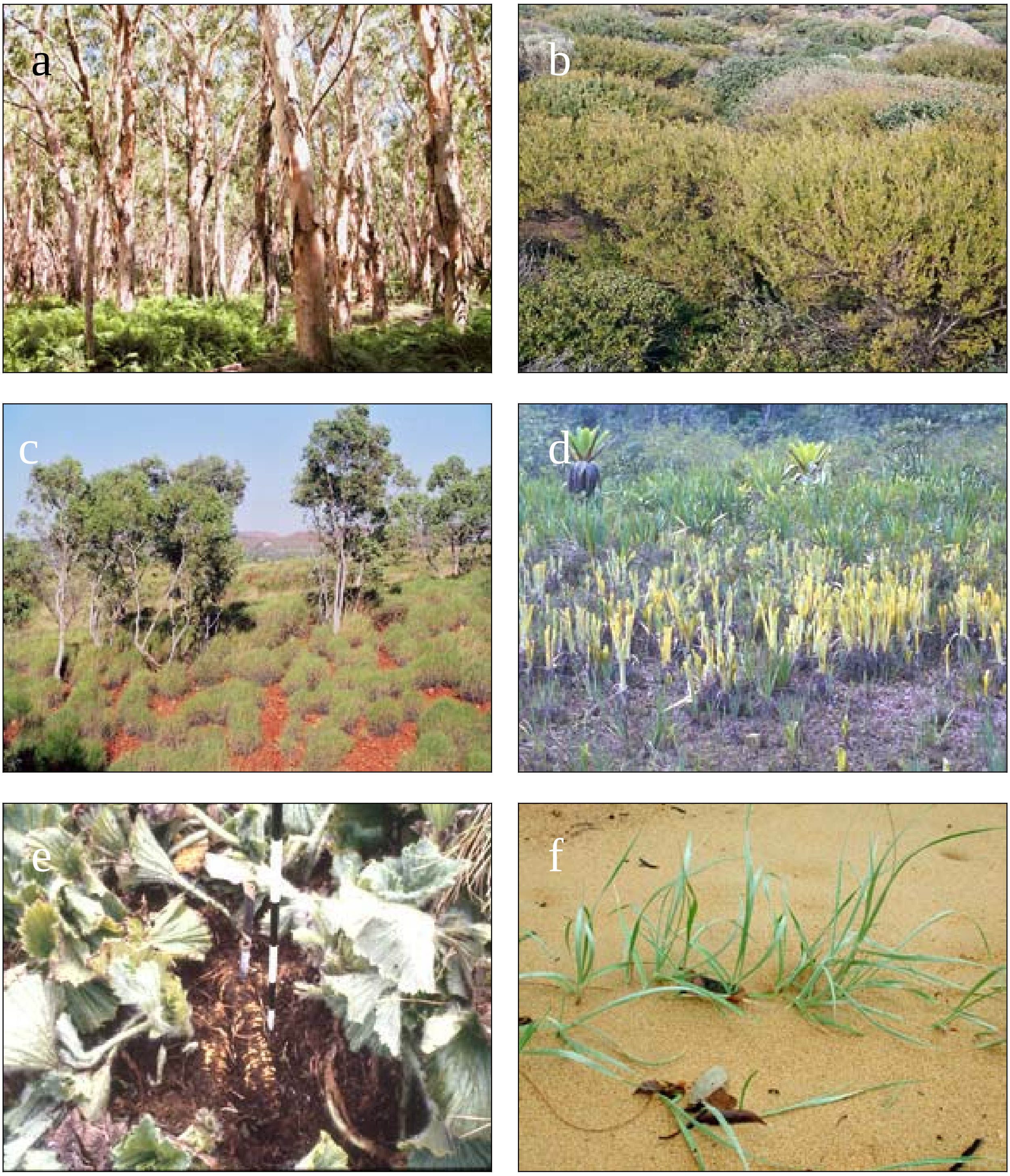


Figure 22. Life forms: Phanerophyte (ph) (**a**) Ti Tree *Melaleuca leucadendra* (Myrtaceae), Mackay, N. Queensland. **Chamaephyte** (ch) (**b**) Mediterranean-type heath, Cape Leeuwin, W. Australia. **Hemicryptphyte** (**c**) Spinifex grassland *Triodia pungens* (Poaceae) (foreground) Mt Isa, Queensland (**d**) Rhizomatous, bromeliad community (Bromeliaceae) (*Brocchinia micrantha*, *B. reducta* (foreground)) Kaieteur, Guyana. (**e**) Rhizomatous *Stilbocarpa polaris* (Araliaceae *cf*. Apiaceae), sub-antarctic Macquarie island, Australia. Scale 10 cm interval (f) Adventitious, Hairy Spinifex *Spinifex hirsuta* (Poaceae), Far Beach, Mackay, Queensland.

21. Fig 23 Life form 2

Figure 23. Cryptophyte (cr) (**a**) Edible Yam, Cryptophytic, seasonally deciduous liane, *Dioscorea* sp. (Dioscoreaceae), Mae Chaem, Thailand. (**b**)Tuberous, ground-flowering *Cochlospermum tinctorium* (Cochlospermaceae), Bamako-Segou, Mali, sub-sahelian W. Africa. **Lianoid** (li) (**c**) Woody liane (also (ph)) assemblage, Iwokrama, Guyana. (**d**) *Canavalia maritima* (Fabaceae), Cape Tribulation, N. Queensland, Australia.

22. Fig. 24 Adventitious

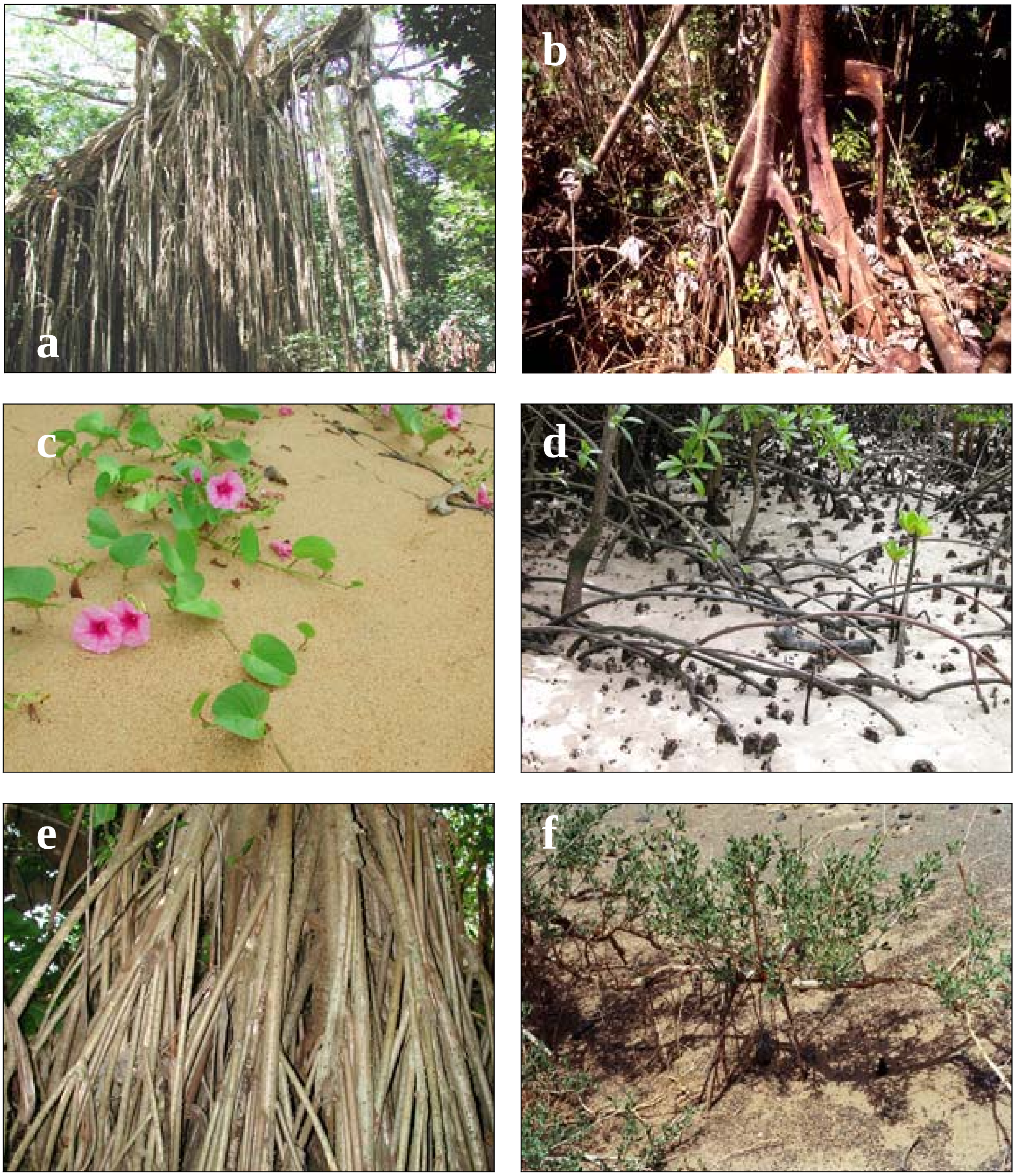
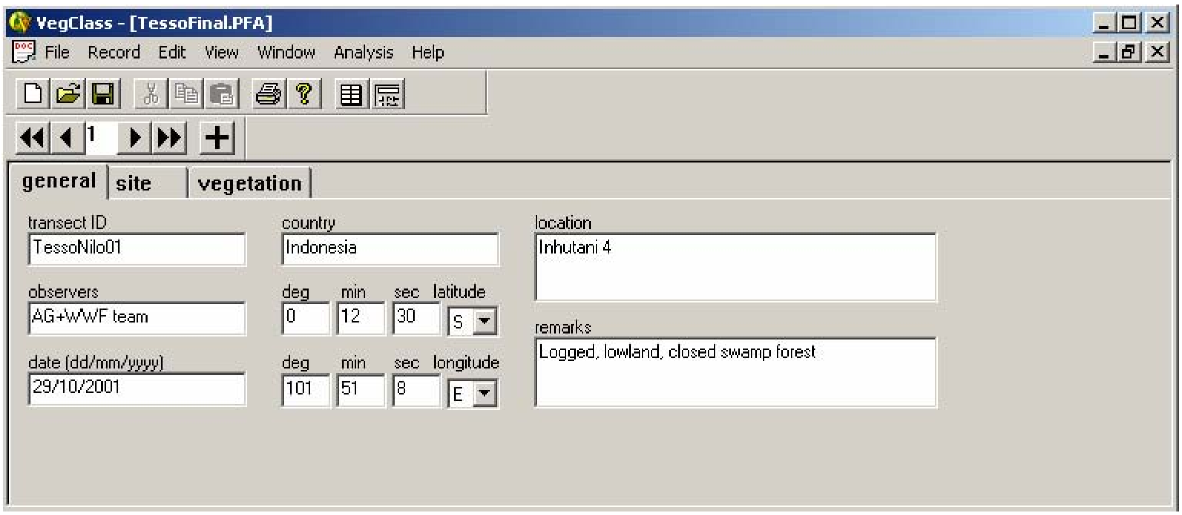
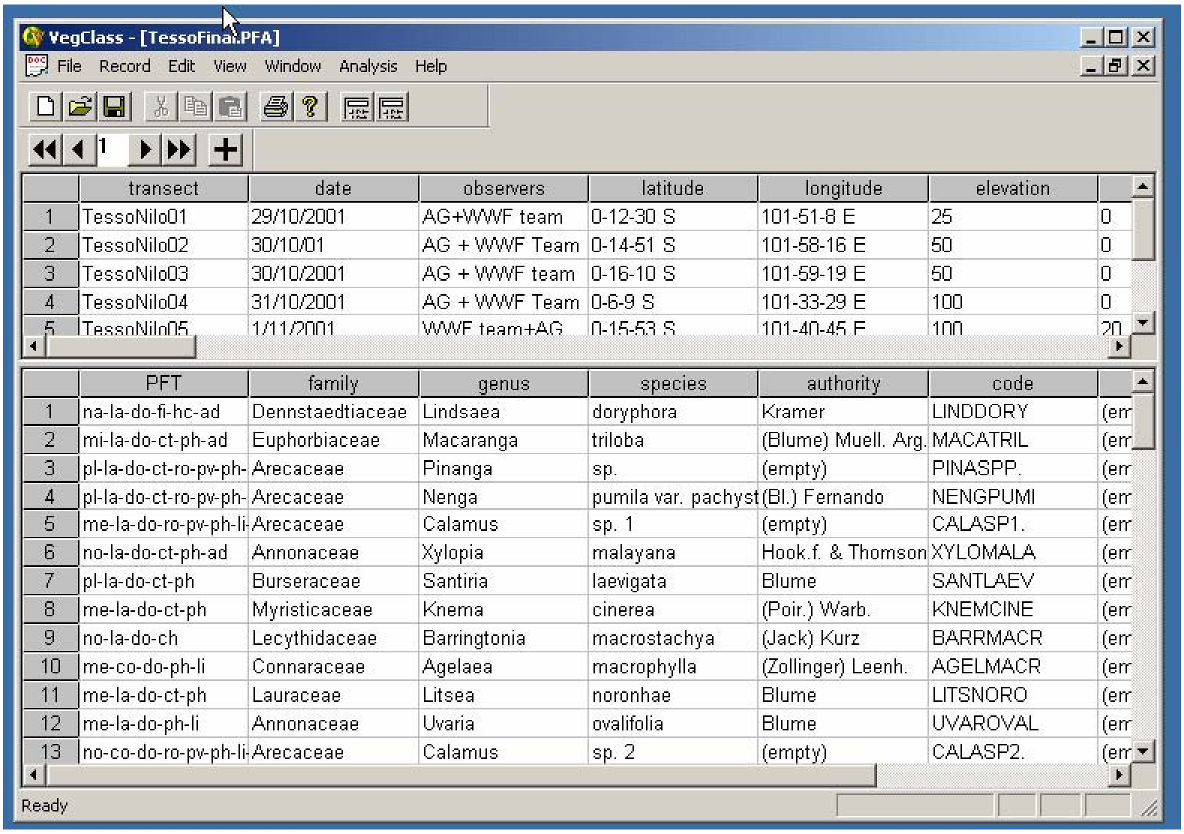


Figure 24. Adventitious rooting systems (ad): (**a**) Strangler fig *Ficus virens* (Moraceae) North Queensland, Australia (**b**) *Cecropia* sp. Cecropiaceae, Petit Saut, Fr. Guiana (**c**) *Ipomoea pes-caprae* (Convolvulaceae) Mackay, North Queensland (**d**) Mangrove *Rhizophora apiculata* (Rhizophoraceae) Mission Beach N. Queensland (**e**) *Pandanus* sp. (Pandanaceae) Rondônia, W. Amazon basin, Brazil (**f**) *Nitraria sibirica* (Nitrariaceae) Gobi desert, Outer Mongolia.

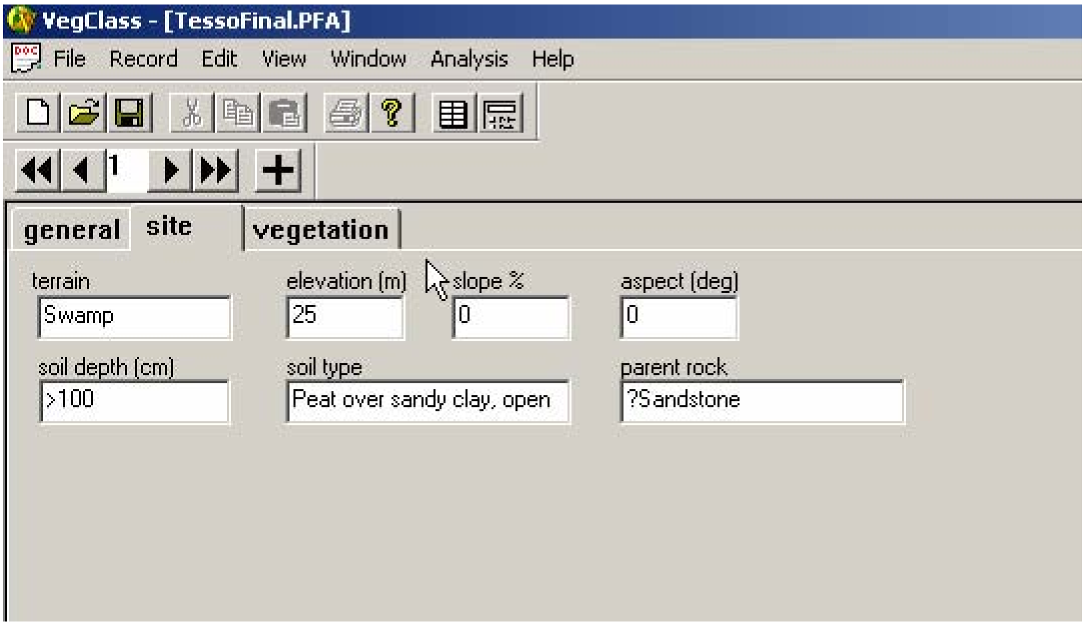
23. VC page 01



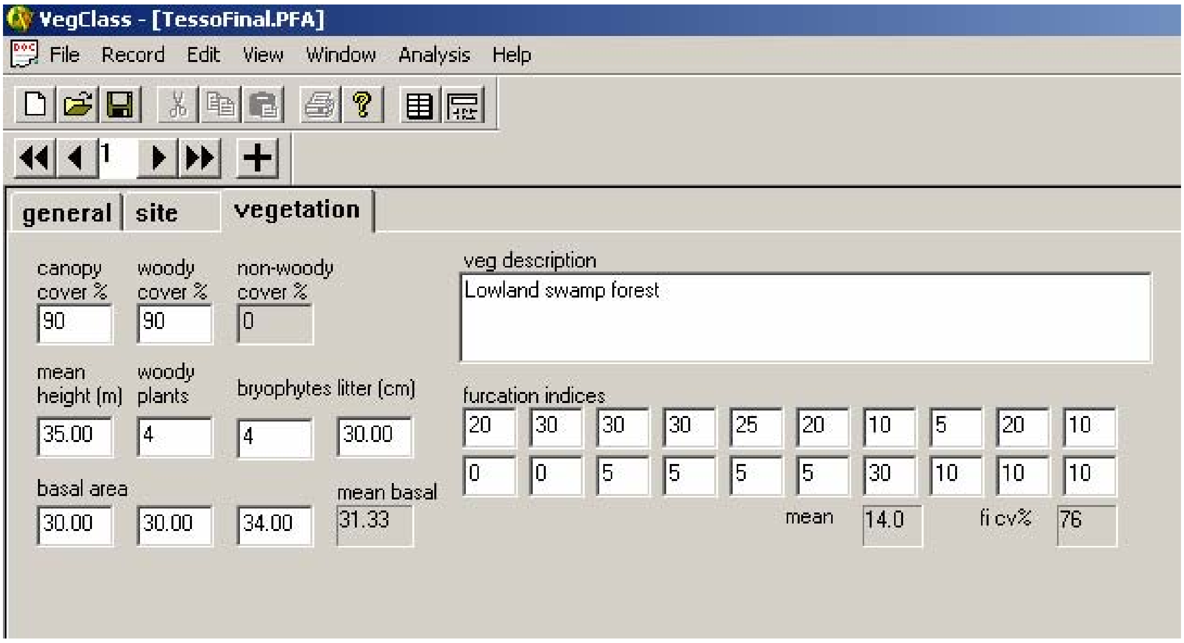
23a. VC page 01a



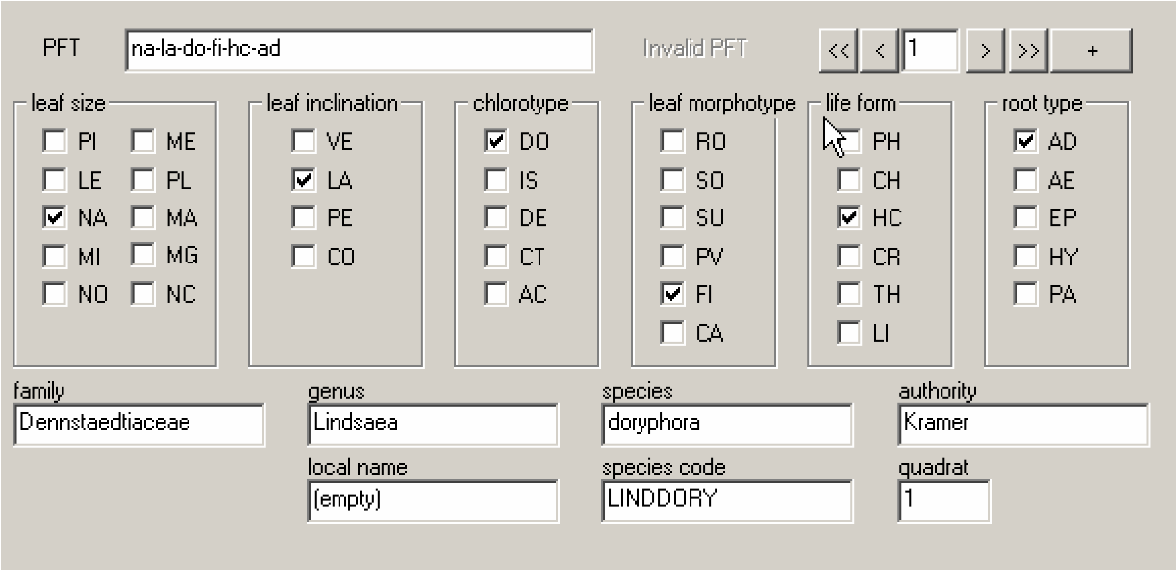
24. VC page 02



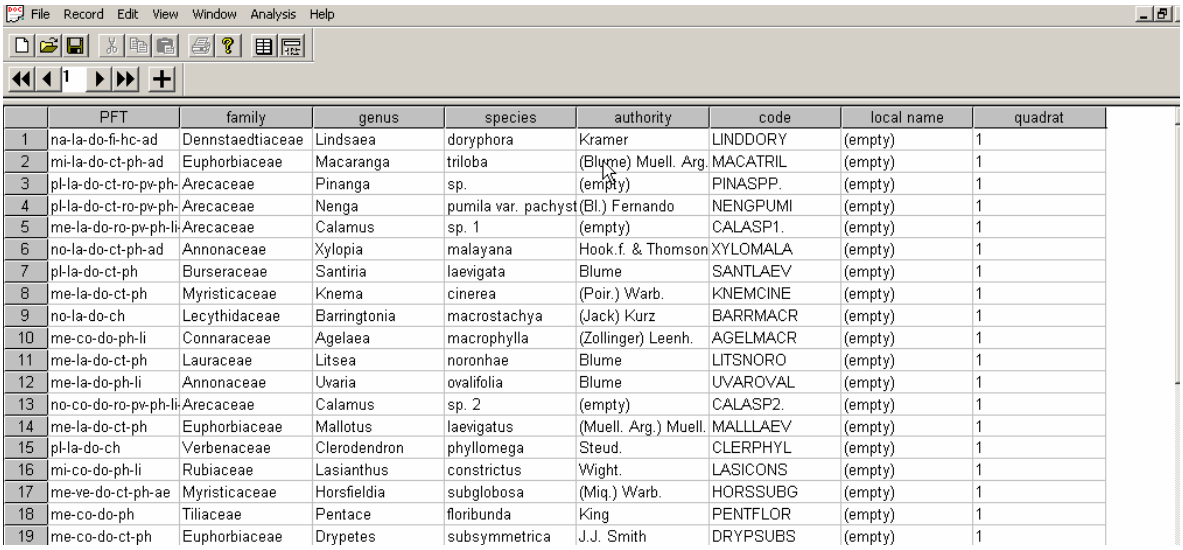
25. VC page 03



26. VC page 04



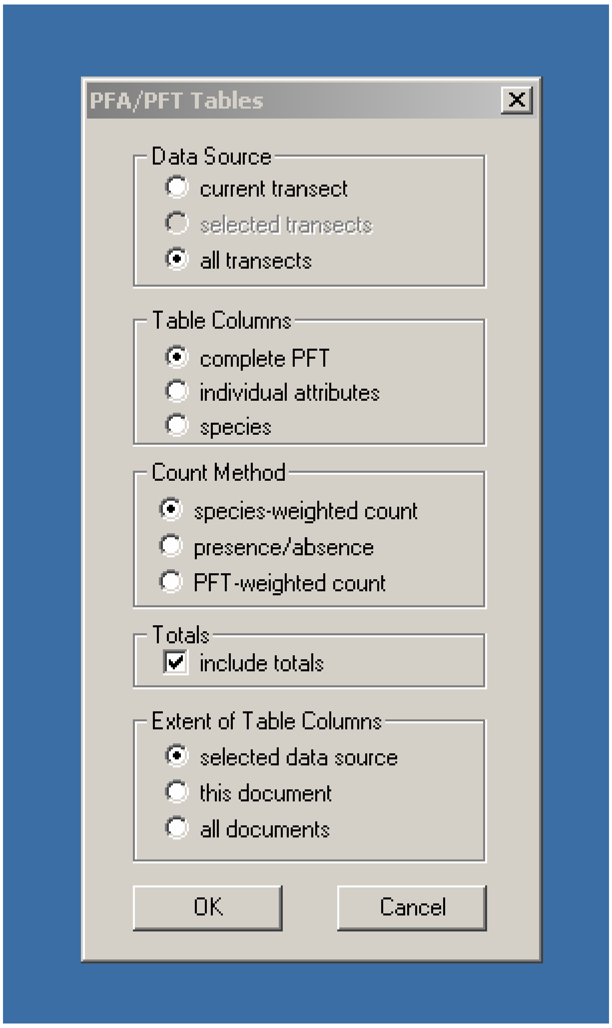
27. VC page 05



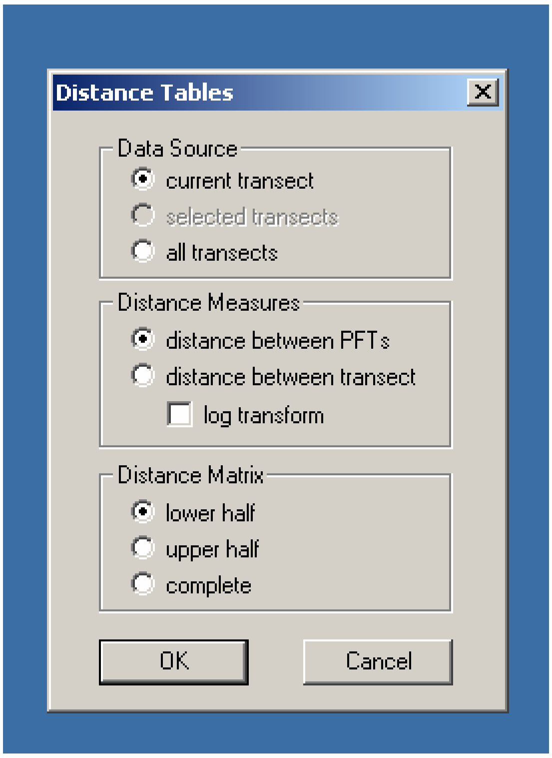
File Record Edit View Window Analysis Help

	PFT	family	genus	species	authority	code	local name	quadrat
1	na-la-do-fi-hc-ad	Dennstaedtiaceae	Lindsaea	doryphora	Kramer	LINDDORY	(empty)	1
2	mi-la-do-ct-ph-ad	Euphorbiaceae	Macaranga	triloba	(Blume) Muell. Arg.	MACATRIL	(empty)	1
3	pl-la-do-ct-ro-pv-ph-	Arecaceae	Pinanga	sp.	(empty)	PINASPP.	(empty)	1
4	pl-la-do-ct-ro-pv-ph-	Arecaceae	Nenga	pumila var. pachyst	(Bl.) Fernando	NENGPUMI	(empty)	1
5	me-la-do-ro-pv-ph-li-	Arecaceae	Calamus	sp. 1	(empty)	CALASP1.	(empty)	1
6	no-la-do-ct-ph-ad	Annonaceae	Xylopia	malayana	Hook.f. & Thomson	XYLOMALA	(empty)	1
7	pl-la-do-ct-ph	Burseraceae	Santiria	laevigata	Blume	SANTLAEV	(empty)	1
8	me-la-do-ct-ph	Myristicaceae	Knema	cinerea	(Poir.) Warb.	KNEMCINE	(empty)	1
9	no-la-do-ch	Lecythidaceae	Barringtonia	macrostachya	(Jack) Kurz	BARRMACR	(empty)	1
10	me-co-do-ph-li	Connaraceae	Agelaea	macrophylla	(Zollinger) Leenh.	AGELMACR	(empty)	1
11	me-la-do-ct-ph	Lauraceae	Litsea	noronhae	Blume	LITSNORO	(empty)	1
12	me-la-do-ph-li	Annonaceae	Uvaria	ovalifolia	Blume	UVAROVAL	(empty)	1
13	no-co-do-ro-pv-ph-li-	Arecaceae	Calamus	sp. 2	(empty)	CALASP2.	(empty)	1
14	me-la-do-ct-ph	Euphorbiaceae	Mallotus	laevigatus	(Muell. Arg.) Muell.	MALLLAEV	(empty)	1
15	pl-la-do-ch	Verbenaceae	Clerodendron	phyllomega	Steud.	CLERPHYL	(empty)	1
16	mi-co-do-ph-li	Rubiaceae	Lasianthus	constrictus	Wight.	LASICONS	(empty)	1
17	me-ve-do-ct-ph-ae	Myristicaceae	Horsfieldia	subglobosa	(Miq.) Warb.	HORSSUBG	(empty)	1
18	me-co-do-ph	Tiliaceae	Pentace	floribunda	King	PENTFLOR	(empty)	1
19	me-co-do-ct-ph	Euphorbiaceae	Drypetes	subsymmetrica	J.J. Smith	DRYPSUBS	(empty)	1

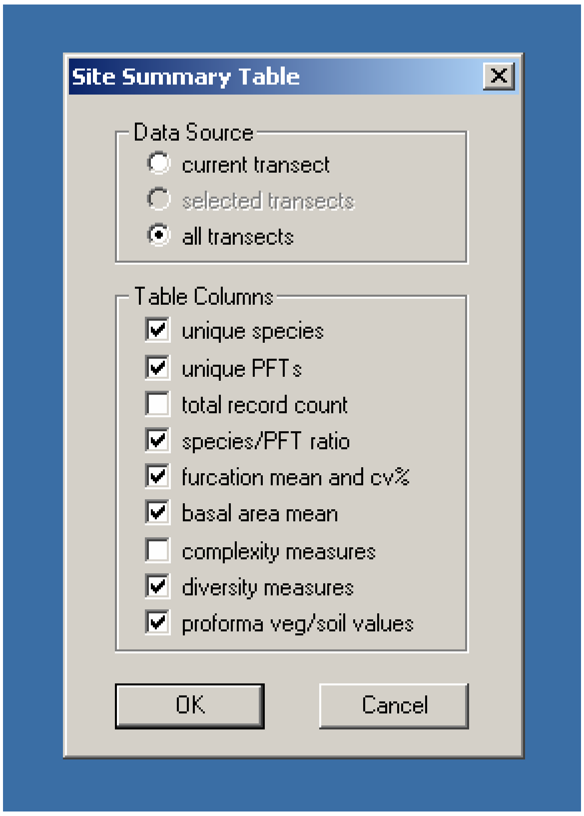
28. VC page 06


PFA/PFT Tables
Data Source
current transect
selected transects
all transects
Table Columns
complete PFT
individual attributes
species
Count Method
species-weighted count
presence/absence
PFT-weighted count
Totals
include totals
Extent of Table Columns
selected data source
this document
all documents
OK
Cancel

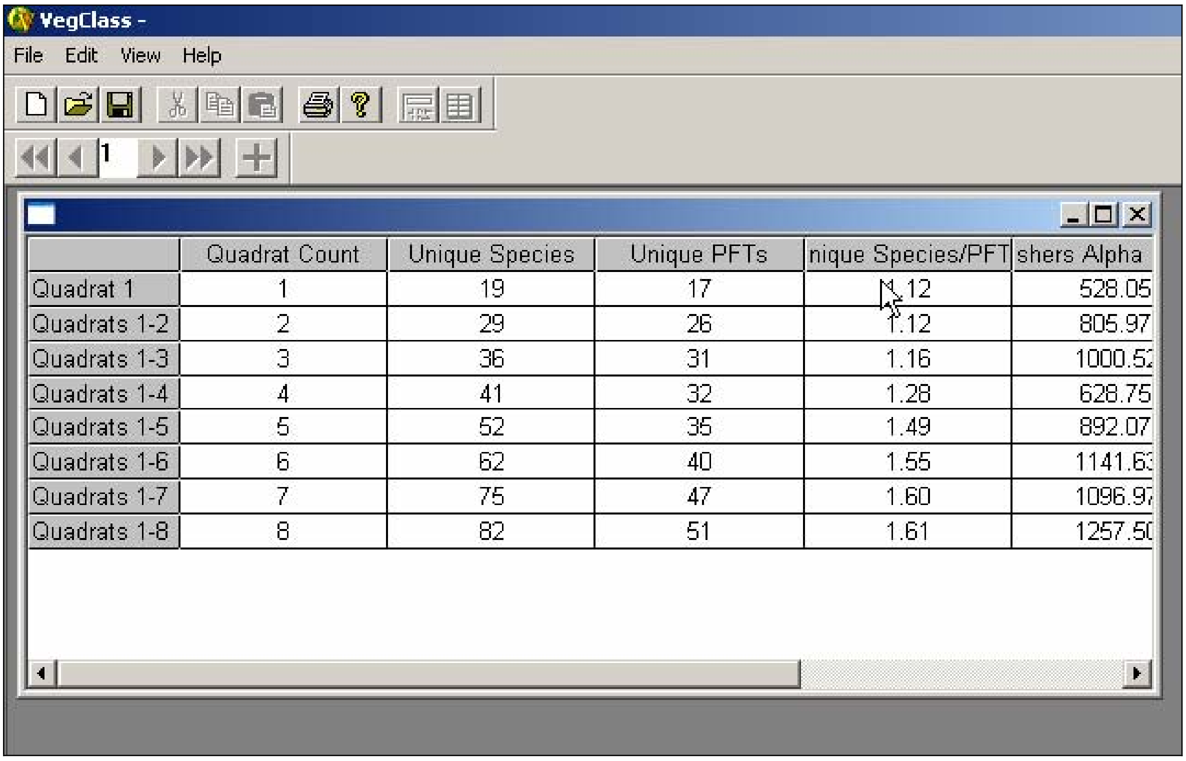
29. VC page 07



30. VC page 08

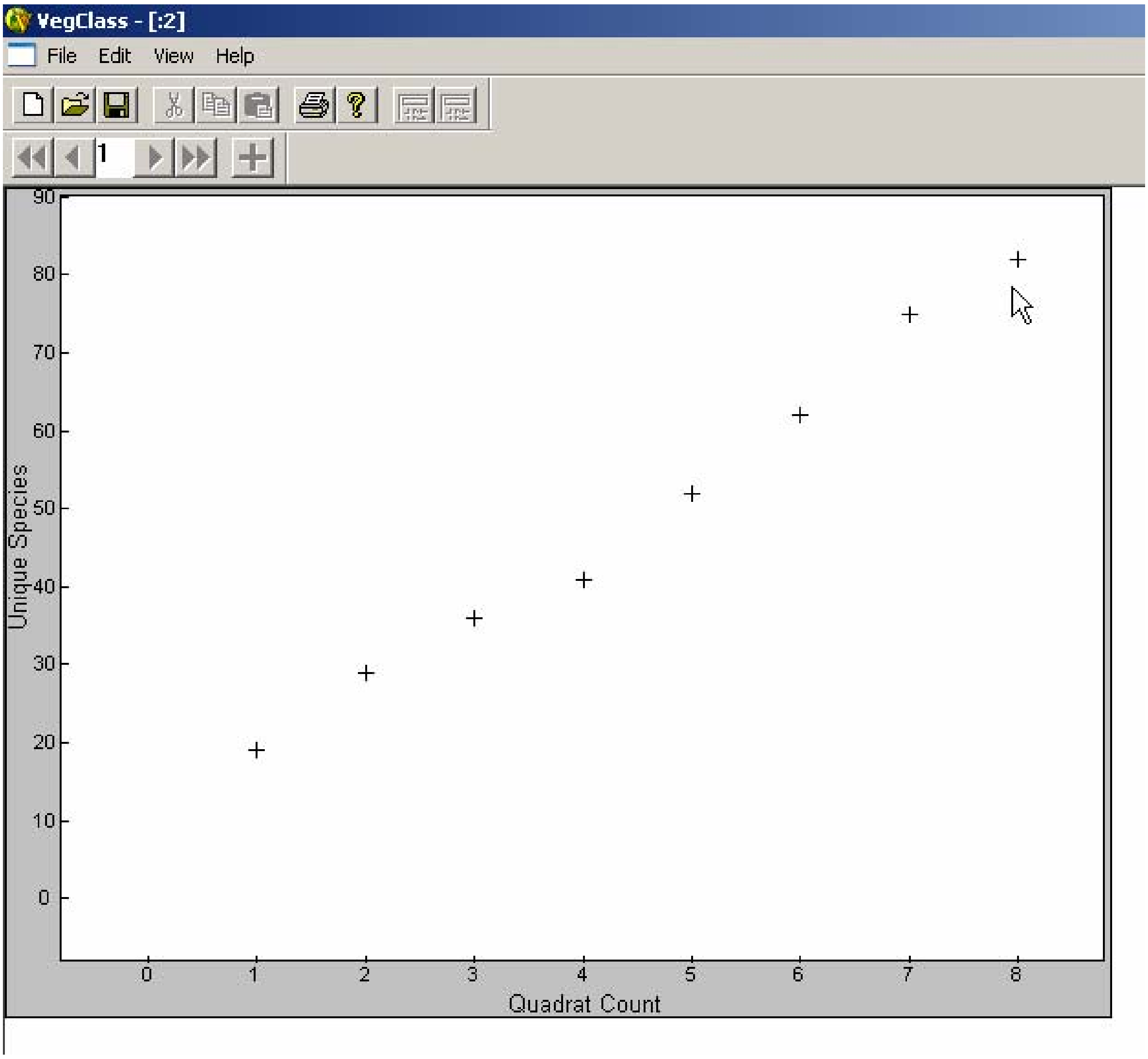


31. VC page 09



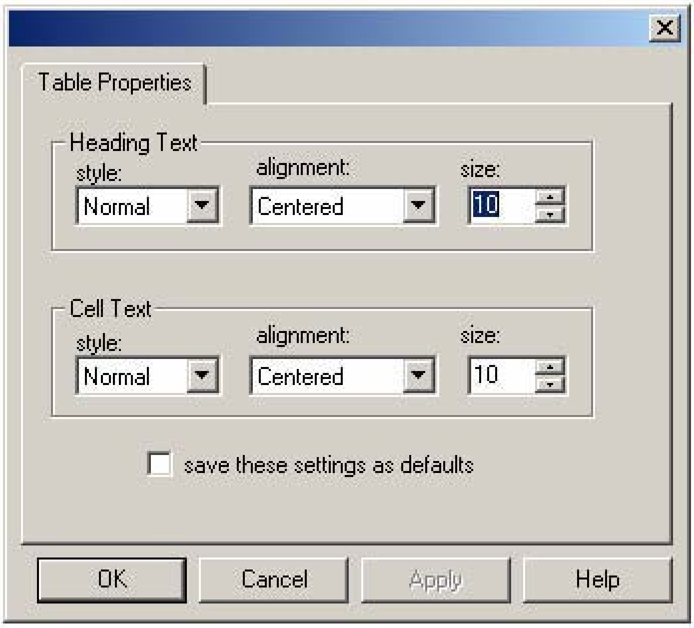
	Quadrat Count	Unique Species	Unique PFTs	nique Species/PFT	shers Alpha
Quadrat 1	1	19	17	1.12	528.05
Quadrats 1-2	2	29	26	1.12	805.97
Quadrats 1-3	3	36	31	1.16	1000.52
Quadrats 1-4	4	41	32	1.28	628.75
Quadrats 1-5	5	52	35	1.49	892.07
Quadrats 1-6	6	62	40	1.55	1141.63
Quadrats 1-7	7	75	47	1.60	1096.97
Quadrats 1-8	8	82	51	1.61	1257.50

32. VC page 10

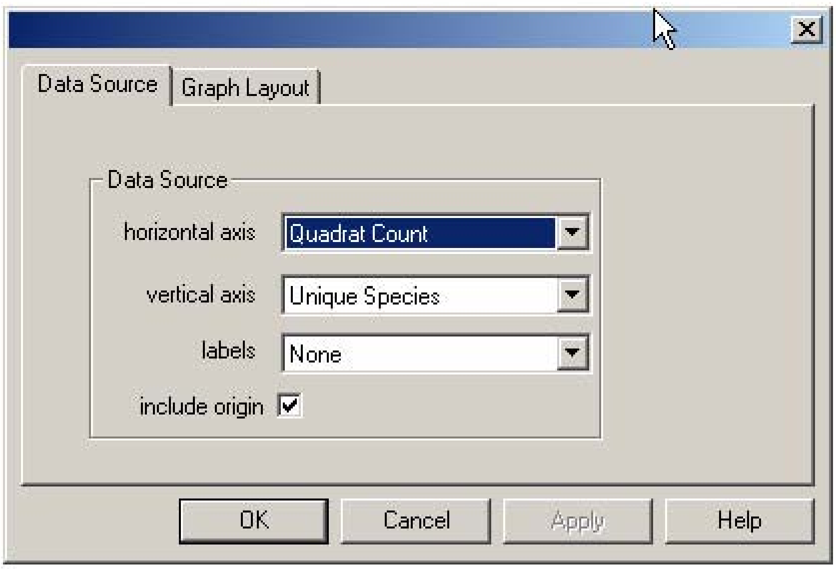


VegClass - [:2]
File Edit View Help
1
90
80
70
60
50
40
30
20
10
0
Unique Species
0
1
2
3
4
5
6
7
8
Quadrat Count

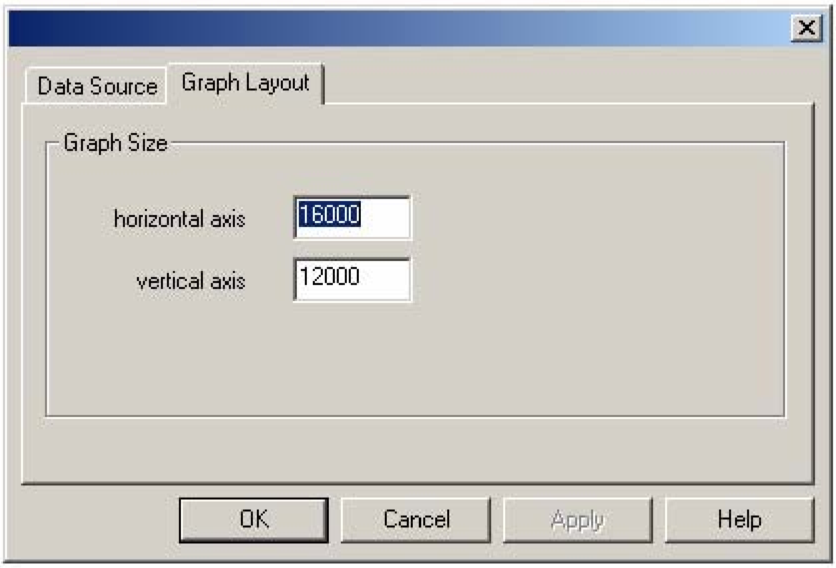
33. VC page 11



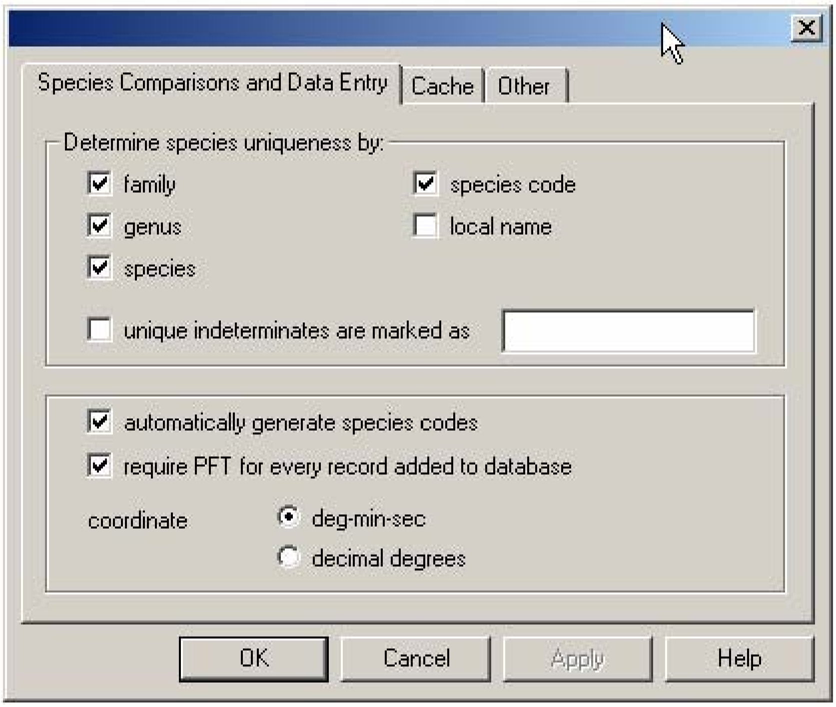
34. VC page 12



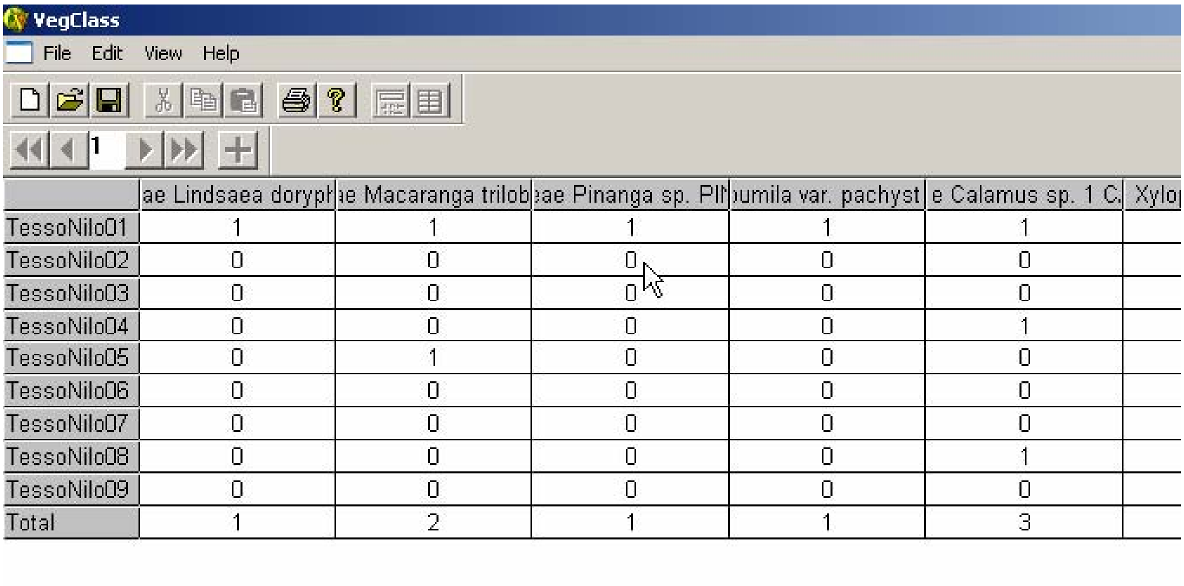
35. VC page 12b



36. VC page 13

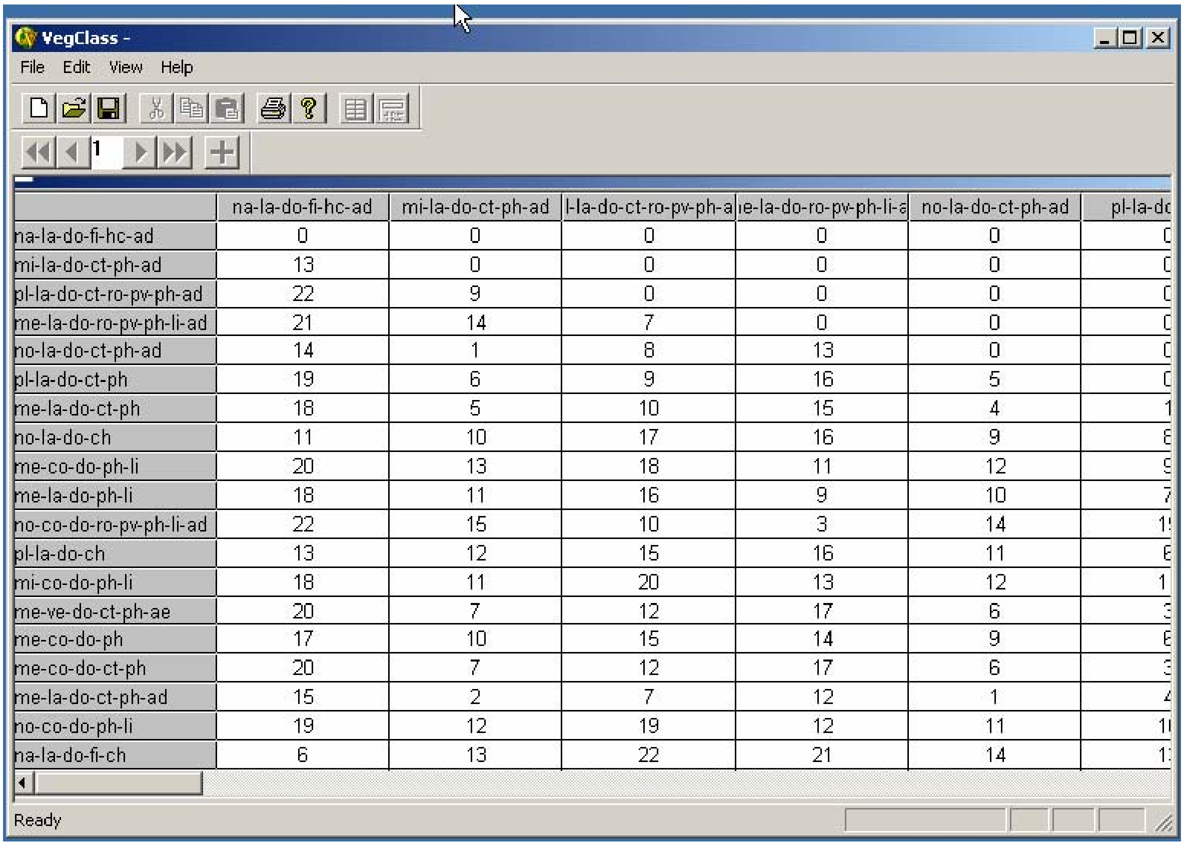


37. VC page 14



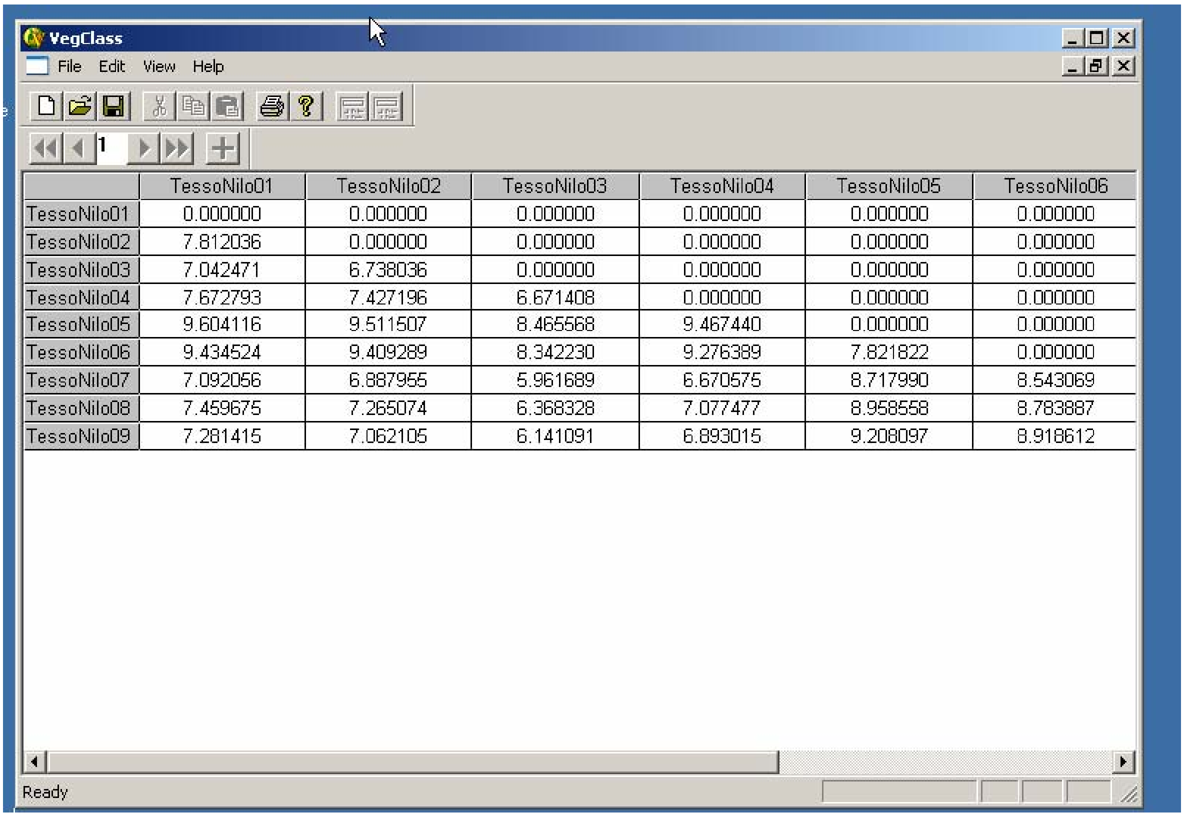
	ae Lindsaea dorypł	ae Macaranga trilob	ae Pinanga sp. Pl	umila var. pachyst	e Calamus sp. 1 C.	Xylo
TessoNilo01	1	1	1	1	1	
TessoNilo02	0	0	0	0	0	
TessoNilo03	0	0	0	0	0	
TessoNilo04	0	0	0	0	1	
TessoNilo05	0	1	0	0	0	
TessoNilo06	0	0	0	0	0	
TessoNilo07	0	0	0	0	0	
TessoNilo08	0	0	0	0	1	
TessoNilo09	0	0	0	0	0	
Total	1	2	1	1	3	

38. VC page 15



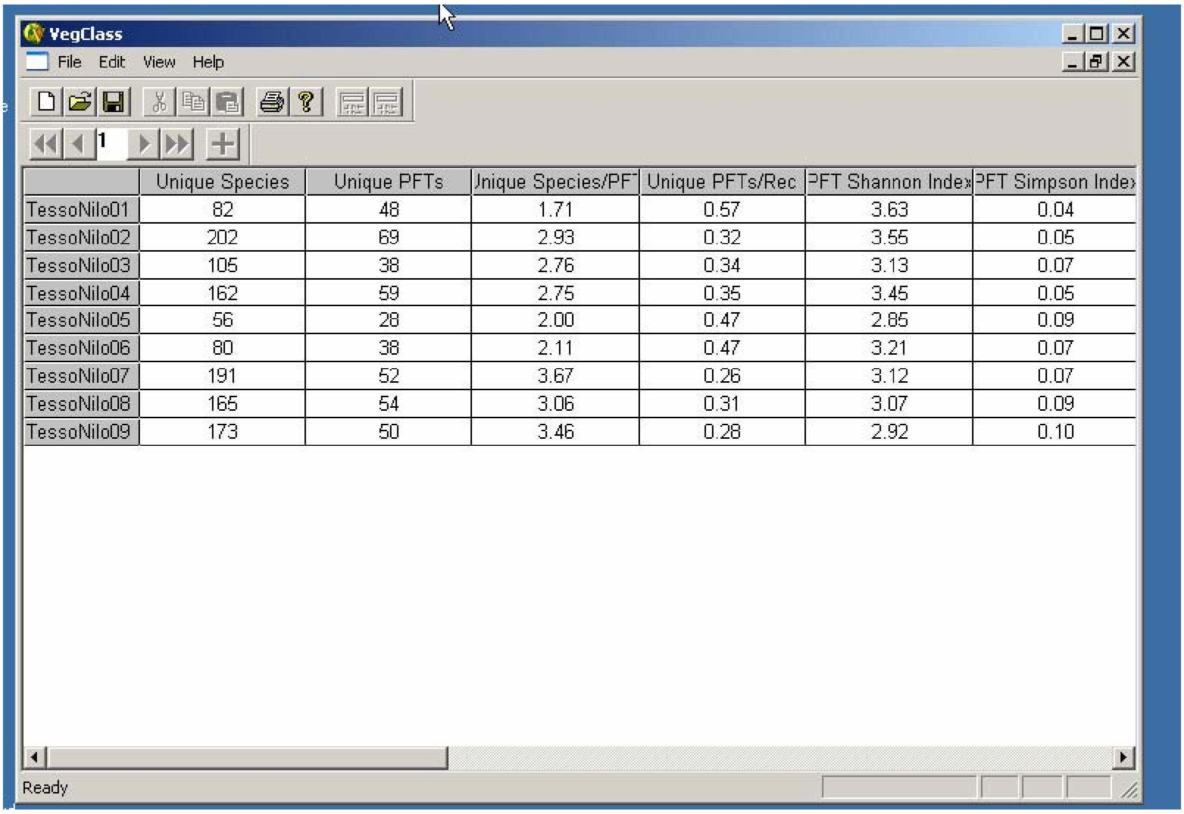
	na-la-do-fi-hc-ad	mi-la-do-ct-ph-ad	l-la-do-ct-ro-pv-ph-a	e-la-do-ro-pv-ph-li-a	no-la-do-ct-ph-ad	pl-la-dc
na-la-do-fi-hc-ad	0	0	0	0	0	0
mi-la-do-ct-ph-ad	13	0	0	0	0	0
pl-la-do-ct-ro-pv-ph-ad	22	9	0	0	0	0
me-la-do-ro-pv-ph-li-ad	21	14	7	0	0	0
no-la-do-ct-ph-ad	14	1	8	13	0	0
pl-la-do-ct-ph	19	6	9	16	5	0
me-la-do-ct-ph	18	5	10	15	4	1
no-la-do-ch	11	10	17	16	9	8
me-co-do-ph-li	20	13	18	11	12	9
me-la-do-ph-li	18	11	16	9	10	7
no-co-do-ro-pv-ph-li-ad	22	15	10	3	14	15
pl-la-do-ch	13	12	15	16	11	6
mi-co-do-ph-li	18	11	20	13	12	1
me-ve-do-ct-ph-ae	20	7	12	17	6	3
me-co-do-ph	17	10	15	14	9	6
me-co-do-ct-ph	20	7	12	17	6	3
me-la-do-ct-ph-ad	15	2	7	12	1	4
no-co-do-ph-li	19	12	19	12	11	1[illegible]
na-la-do-fi-ch	6	13	22	21	14	1[illegible]

39. VC page 16



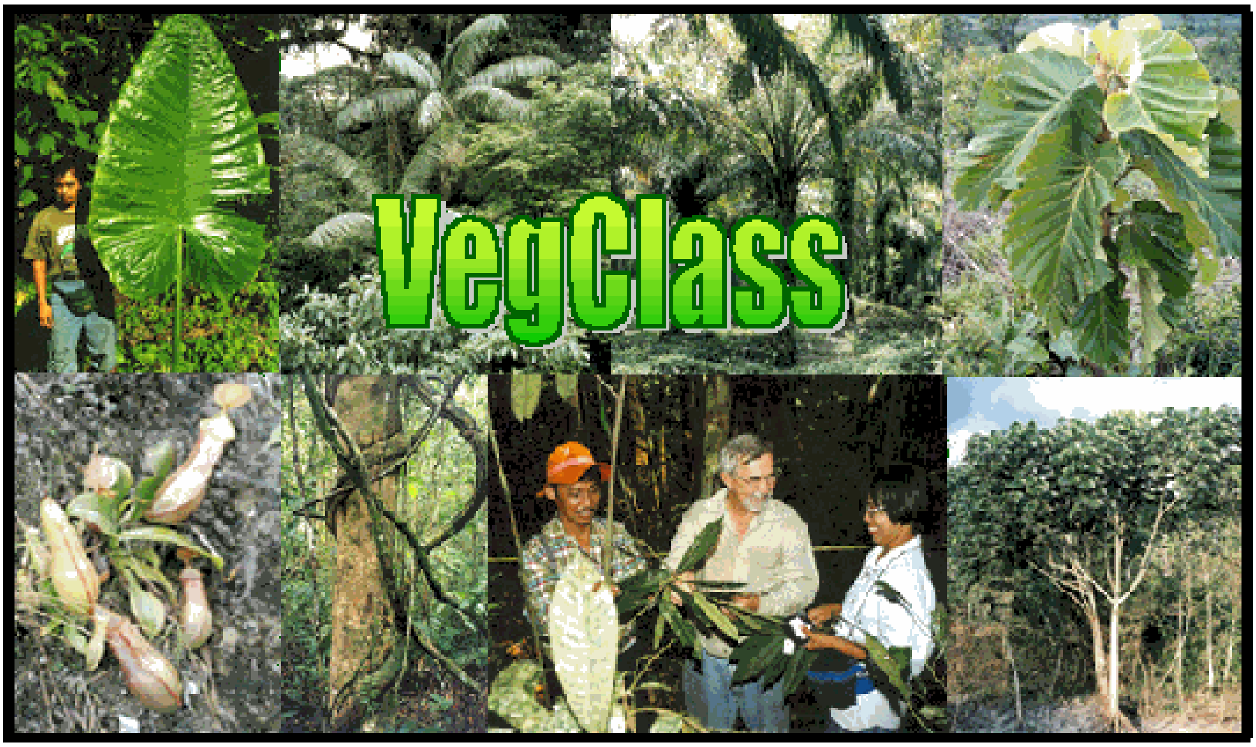
	TessoNilo01	TessoNilo02	TessoNilo03	TessoNilo04	TessoNilo05	TessoNilo06
TessoNilo01	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
TessoNilo02	7.812036	0.000000	0.000000	0.000000	0.000000	0.000000
TessoNilo03	7.042471	6.738036	0.000000	0.000000	0.000000	0.000000
TessoNilo04	7.672793	7.427196	6.671408	0.000000	0.000000	0.000000
TessoNilo05	9.604116	9.511507	8.465568	9.467440	0.000000	0.000000
TessoNilo06	9.434524	9.409289	8.342230	9.276389	7.821822	0.000000
TessoNilo07	7.092056	6.887955	5.961689	6.670575	8.717990	8.543069
TessoNilo08	7.459675	7.265074	6.368328	7.077477	8.958558	8.783887
TessoNilo09	7.281415	7.062105	6.141091	6.893015	9.208097	8.918612

40. VC page 17



	Unique Species	Unique PFTs	Unique Species/PFT	Unique PFTs/Rec	PFT Shannon Index	PFT Simpson Index
TessoNilo01	82	48	1.71	0.57	3.63	0.04
TessoNilo02	202	69	2.93	0.32	3.55	0.05
TessoNilo03	105	38	2.76	0.34	3.13	0.07
TessoNilo04	162	59	2.75	0.35	3.45	0.05
TessoNilo05	56	28	2.00	0.47	2.85	0.09
TessoNilo06	80	38	2.11	0.47	3.21	0.07
TessoNilo07	191	52	3.67	0.26	3.12	0.07
TessoNilo08	165	54	3.06	0.31	3.07	0.09
TessoNilo09	173	50	3.46	0.28	2.92	0.10

41. Splash page



VegClass© splash creen

42. Blank forms

(see following pages)

VegClass Survey Proforma

Location : ……………………………………………

……………………………………………………….

Date: [dd.mm.year] ………………………………

Latitude [deg-min-sec] :______: :______: :______: N_S

Elevation : ………………….. (m)

Aspect: …………………… (deg.)

Parent rock type: …………………………………..

Vegetation type: ……………………………………

……………………………………………………….

Mean canopy height: ………………………….. (m)

Crown cover % Tot. :_____: Wdy : _____: Nwdy :_____:

Basal area (m^2 ha^{-1}) :______: :______: :

______:

Remarks: ………………………………………………

……………………………………………………….

……………………………………………………….

Plot No. …………………..

Country : …………………………………………..

Observers : ………………………………………….

Longitude: …:_______: : _______: :_______: E_W

Slope (%) ………. Soil depth: ……….. (cm)

Soil type: ……………………………………….

Terrain position: ……………………………………

Litter depth: …………… (cm)

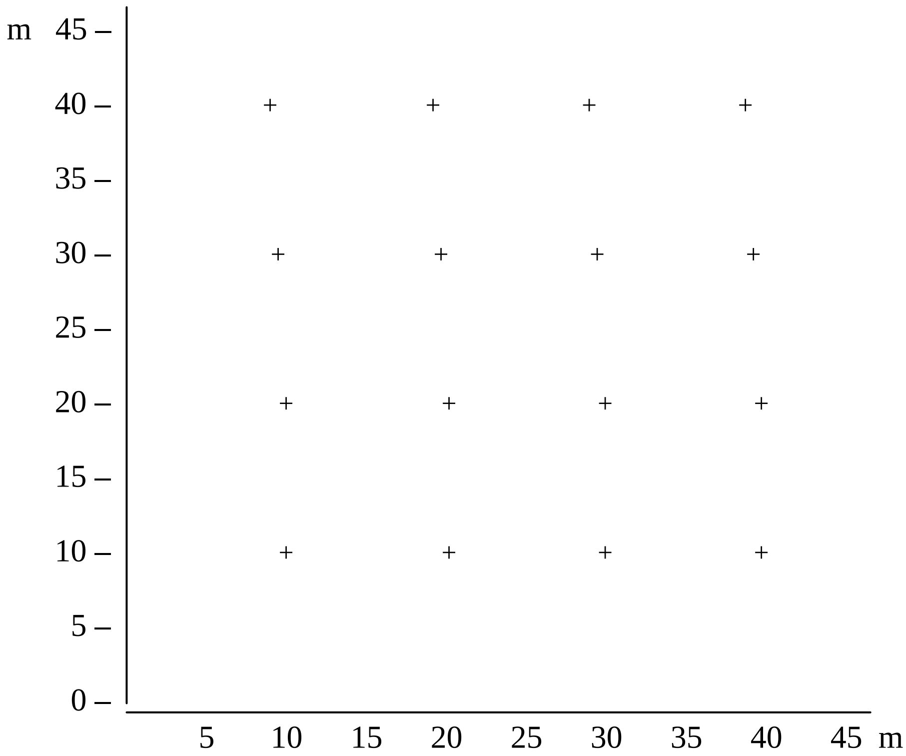
Bryophyte (Cov/abund Domin) : ……………………

Woody plants (Cov/abund Domin) ………………...

Furcation index (FI) of nearest 20 canopy stems

Vegetation profile

(40 x 5m belt transect along contour or ridge/ gully)



Page ….of…..

PLANT FUNCTIONAL TYPES AND SPECIES

Sheet B

Plot No………… Date: …………………… Observers: ……………………………………………

Functional elements													
No.	Leaf								Life form	A/Gr Root type	Species	W	X
	Size	Incl	Chlorotype			Morphotype							
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													

W = Weed X = Exotic

PLANT FUNCTIONAL TYPES AND SPECIES

Sheet C

Plot No………… Date: …………………… Observers: ……………………………………………

Functional elements													
No.	Leaf								Life form	A/Gr Root type	Species	W	X
	Size	Incl	Chlorotype			Morphotype							
26													
27													
28													
29													
30													
31													
32													
33													
34													
35													
36													
37													
38													
39													
40													
41													
42													
43													
44													
45													
46													
47													
48													
49													
50													

Sheet D PLANT FUNCTIONAL TYPES AND SPECIES Page ….of…..

Plot No………… Date: …………………… Observers: ……………………………………………

Functional elements													
No.	Leaf								Life form	A/Gr Root type	Species	W	X
	Size	Incl	Chlorotype			Morphotype							
51													
52													
53													
54													
55													
56													
57													
58													
59													
60													
61													
62													
63													
64													
65													
66													
67													
68													
69													
70													
71													
72													
73													
74													
75													

43. Global comparisons

Table 6. Comparative richness in plant species and plant functional types in humid lowland tropical, subtropical and temperate forests in 27 countries *

No.	Country	Location	Georeference	Plot ID	Forest type	Species richness	PFT richness	PFC value
1	Indonesia (Sumatra)	Tesso Nilo, Riau Province,	0º 14' 51" S 101º 58' 16" E	TN02	Complex primary forest, logged 1997	202	68	338
2	Indonesia (Sumatra)	Pancuran Gading, Jambi Province	1º 10' 12" S 102º 06' 50" E	BS10	Lowland forest interplanted with 'jungle' Rubber (*Hevea brasiliensis*)	112	47	236
3	India	Arunachal Pradesh Tipi – Pakke Sanctuary.	27º 2' 3" N 92º 36' 58" E	NBL06	Complex lowland forest selectively logged	107	74	314
4	Indonesia (Borneo)	Gunung Banalang, Long Puak, Pujungan, East Kalimantan	2º 43' 32" N 115º 39' 46"E	BUL02	Disturbed complex ridge forest	104	44	232
6	Papua New Guinea	Kuludagi / West New Britain Province	5º 38' 46" S 150º 06' 14" E	KIMBE2	Complex, primary lowland forest.	99	52	234
7	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
5	Cameroon	Awae Village	3º 36' 05" N 11º 36' 15" E	CAM 01	Late secondary forest. Previously logged.	94	43	232
8	Brazil	Pedro Peixoto, Acré (West Amazon basin)	10º 01' 13" S 67º 09' 39" W	BRA19	Secondary forest (Capoeira) 3-4 years after abandonment	78	43	230
9	Brazil	Alcalinas Canamá N.W. Mato Grosso (West Amazon basin)	10º 04' 06" S 58º 46' 00" W	PN24	Primary lowland forest on shallow granitic soils.	75	54	298
10	Perú	Jenaro Herrera, Ucayali river (West Amazon basin)	4º 58' 00" S 73º 45' 00"W	PE02	'High terrace' lowland forest - selective logging	72	39	208
11	Vietnam	Cuc Phuong National Park Ninh Binh Province	20º 48' 33" N 105 42' 44" E	FSIV02	Lowland forest partly disturbed; on limestone	69	46	256
12	Perú	Von Humboldt forest reserve, Pucallpa, (W. Amazon basin)	8º 48' 01" S 75º 03' 54" W	PUC01	Primary forest selectively logged, 1960	63	31	258
13	Fiji	Bua, Vanua Levu	16º 47' 36" S	FJ55	Disturbed lowland forest on ridge	60	37	158

No.	Country	Location	Georeference	Plot ID	Forest type	Species richness	PFT richness	PFC value
			178º 36' 45" E					
14	Thailand	Ban Huay Bong, Mae Chaem watershed	18º 30' 42" N 98º 24' 13" E	MC18	Humid-seasonal, deciduous dipterocarp forest fallow system	58	44	200
16	Kenya	Shimba Hills near Mombasa	4º 11' 33" S 39º 25 34" E	K01	Semi-deciduous forest in game park area. Disturbed (logged).	56	33	214
15	Malaysia (Borneo)	Danum Valley, Sabah	4º 53' 03" N 117º 57' 48" E	DANUM3	Primary forest subject to reduced impact logging, Nov 1993.	54	39	208
17	Guyana	Iwokrama forest reserve	4º 35' 02" N 58º 44' 51" W	IWOK01	Primary lowland swamp forest in blackwater system.	52	34	192
19	Georgia	Gergeti, Mt Kazbegi Central Caucasus Mts	42º 40' 01" N 44º 36' 27" E	CAUC05	Birch (*Betula litwinowii*) High montane Krummholz	47	35	198
20	Bolivia	Las Trancas, (Santa Cruz)	16º 31' 40" N 61º 50' 48" W	BOL02	Semi-evergreen, lowland vine forest,. Logged 1996	46	33	302
21	Australia	Atherton tableland North Queensland	17º 18' 28" S 145º 25' 20" E	DPI012	Upland humid forest managed for sustainable timber extraction	46	25	187
22	Panama	Barro Colorado island	9º 09' 43" N 79º 50' 46" W	BARRO1	Semi-evergreen vine forest, ground layer grazed by native animals	43	30	238
23	Brazil	Reserva Biologica da Campiña Km 50 near Manaus (East Amazon basin)	2º 35' 21" S 60º 01' 55" W	BRA24	Moderately disturbed, microphyll, evergreen vine forest on siliceous sands	42	27	276
18	Philippines	Mt Makiling, Luzon	14º 08' 46" N 131º 13' 50" E	PCLASS1	Regen. forest planted in 1968 with *Swietenia macrophylla*, *Parashorea*, *Pterocarpus indicus* .	42	26	194
24	Outer Mongolia	Bear Cub Pass, Khentii Mountains	48º 58' 35" N 107º 09' 18" E	MNG04	Mixed Larch (*Larix sibirica*) and Birch (*Betula platyphylla*) forest	40	25	188
25	Vanuatu	Yamet, near Umetch, Aneityum Island	20º 12' 32" S 169º 52' 33" E	VAN11	Coastal primary forest, logged with Kauri (*Agathis macrophylla*) overstorey	38	22	217
26	Mexico	Zona Maya, Yucatan peninsula	19º 02' 26" N 88º 03' 20" E	YUC02	Logged secondary lowland forest.	37	26	288
27	Indonesia (Borneo)	Batu Ampar, Central Kalimantan	0º 47' 48" N 117º 06' 23" E	BA07	Primary forest, heavily logged 1991/92	35	23	286
28	West Indies (France)	Near Mont Pelée, Martinique	0º 47' 48" N 117º 06' 23" E	MQUE1	Humid, lowland forest on volcanic slopes, heavily disturbed.	32	24	279
29	Argentina	Iguazú Parque Nacional de las Cataratas	25º 39' 00" S 54º 35' 00" W	IGUAZU01	Lowland vine forest, disturbed	28	24	302

No.	Country	Location	Georeference	Plot ID	Forest type	Species richness	PFT richness	PFC value
30	French Guyana	B.E.C. 16 km from Kourou	14º 49’ 23” N 61º 7’ 37” W	FRG05	*Tierra firme* simple evergreen forest on white sand	28	18	146
31	Indonesia (Borneo)	Mandor Nature Reserve, North of Pontianak	0º 17’ 12” N 109º 33’ 00” E	PA02	Low microphyll evergreen forest in blackwater system on siliceous sand	25	21	228
32	Austria	Heilligenkreutz	48º 03’ 19” N 16º 7’ 48” E	AUSTRIA 01	Disturbed riparian forest	23	16	116
33	England	Newbridge, River Dart NP Devon	50º 31’ 23” N 03º 50’ 7.5” W	ENG13	Deciduous oak forest	20	19	160
34	Spain	Pedro Alvarez Reserve,Tenerife	28º 32’ 4” N 16º 19’ 0” W	TENERIFE 04	‘Laurisilva’ upland forest	12	9	46

* Unpublished data summary from plots with richest vascular plant species and Plant Functional Type (PFT) and Plant Functional Complexity (PFC) values extracted from a series of global, ecoregional surveys and restricted to closed forests. All data collected using a standard ‘VegClass’ sampling protocol (Gillison, 1988, 2001, 2002). Forest conditions range from relatively intact to highly disturbed. *Source:* International Centre for Agroforestry Research, Alternatives to Slash and Burn Programme (ICRAF/ASB); Center for International Forestry Research (CIFOR); WWF AREAS project and CBM (Center for Biodiversity Management).

THESE DATA SHOULD NOT BE QUOTED OR USED FOR PUBLICATION WITHOUT FIRST CONTACTING THE CENTER FOR BIODIVERSITY MANAGEMENT (andy.gillison@austarnet.com.au)

44. Plant species: PFT ratio as a predictor of termite species diversity

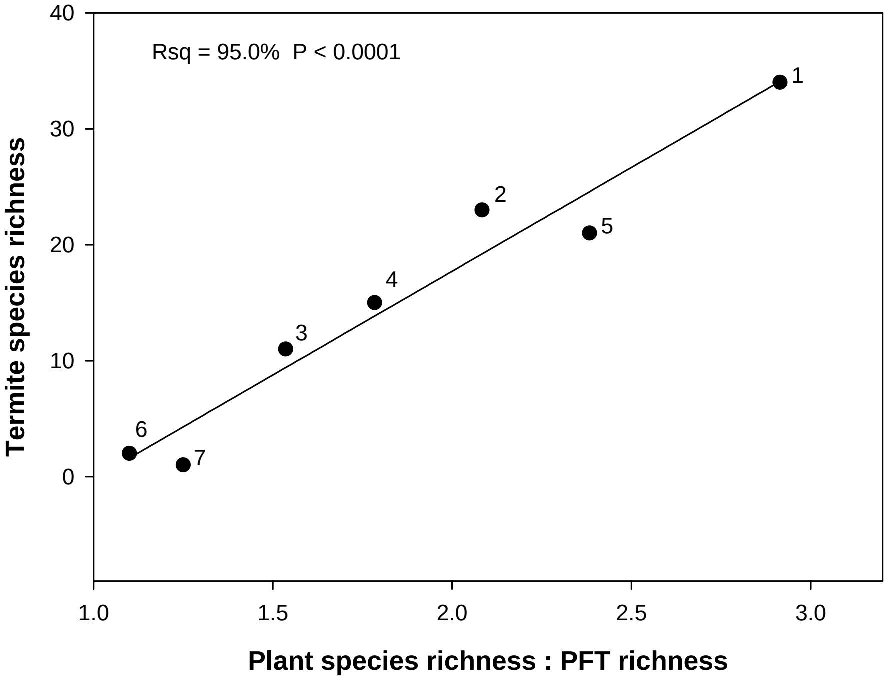
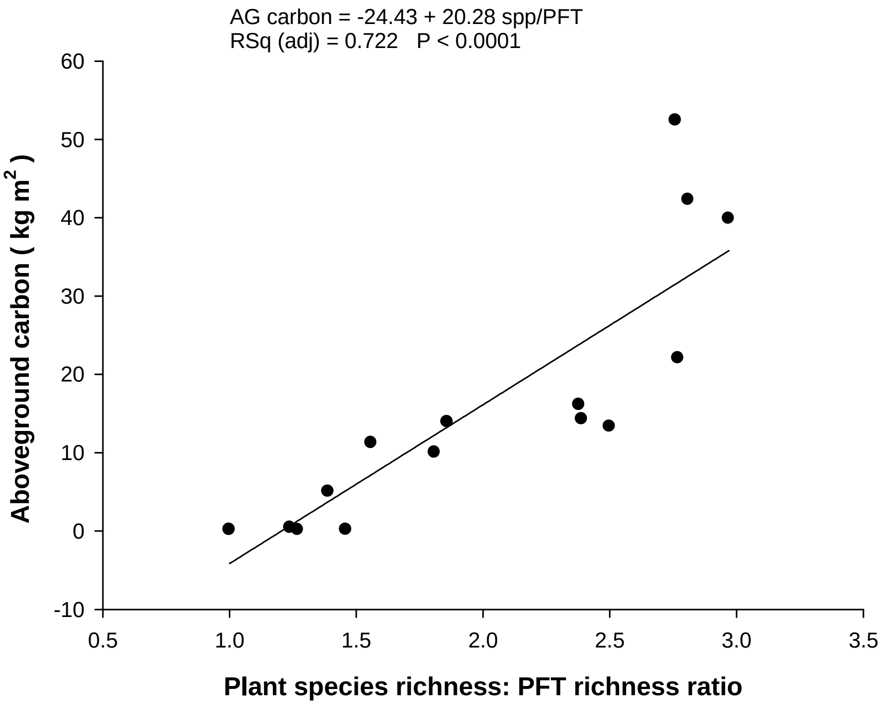


Figure 23. Relationship between termite species richness and the ratio of plant species richness to PFT richness

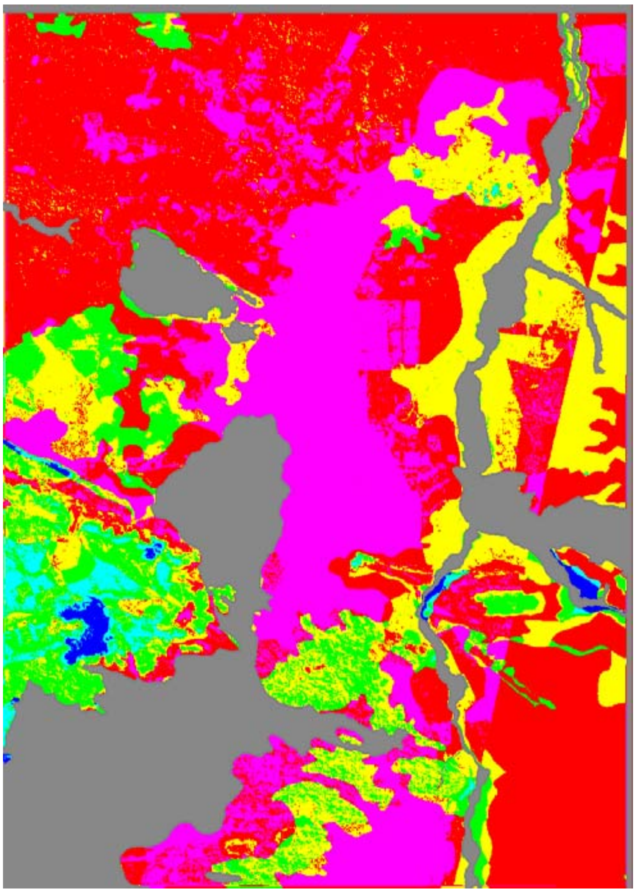
From: Gillison, A.N., D.T. Jones, F.-X. Susilo and D.E. Bignell. (2003). Vegetation indicates diversity of soil macroinvertebrates: a case study with termites along a land-use intensification gradient in lowland Sumatra. *Organisms, Diversity and Evolution* **3**:111-126.

45. Plant species: PFT ratio and above-ground carbon



Spp:PFT predictor of aboveground carbon, Jambi, Sumatra (Gillison,unpubl.)

46. An example of using VegClass and DOMAIN in potential mapping of species richness



DOMAIN map of Cotriguaçu, Juruena, Castanheira showing similarity of sites with < 25 plant species per 200m^2 . Based on Satellite imagery (20 classes); soil type (5 classes); geology (7 classes) and elevation (9 classes).

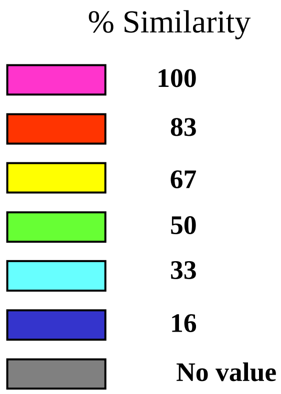


Illustration of how georeferenced VegClass data can be used for spatial analysis involving potential mapping of species richness.

From: Gillison, A.N. (2001). *Promoting biodiversity conservation and sustainable use in the frontier forests of Northwestern Mato Grosso: Bioregional assessment, land use and zoning for biodiversity conservation.* Report prepared for UNDP/GEF and PróNatura.

Details about the DOMAIN potential mapping software can be found in:

Carpenter, G., Gillison, A.N. and Winter, J. (1993). DOMAIN:a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity Conservation* **2**: 667-680.