ANNEX 1: PROPOSAL FOR INTEGRATING PAPUA NEW GUINEA'S NATIONAL FOREST INVENTORY WITH APPROPRIATE BIODIVERSITY INDICATORS

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A PROPOSAL FOR INTEGRATING PAPUA NEW GUINEA'S NATIONAL FOREST INVENTORY WITH APPROPRIATE BIODIVERSITY INDICATORS

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1. REDD+ AND FAO IN PAPUA NEW GUINEA

In 2005, during the negotiations on a post-Kyoto regime held in Montreal at the UNFCCC COP 11, a proposal was put on the agenda: to develop a mechanism that would create positive incentives for countries that succeed in avoiding deforestation and thus contribute to the mitigation of global greenhouse gas (GHG) emissions (Pistorius et al. 2011). That proposal led to the concept of Reducing Emissions from Deforestation and Forest Degradation (REDD+), which was introduced as a formal topic of discussion by a group of countries (notably Papua New Guinea and Costa Rica) that opened a dialogue aimed at developing scientific, technical, policy and capacity responses to address the problem of emissions resulting from tropical deforestation (Thompson et al. 2011).

At the beginning of the REDD+ debate it was widely assumed that the proposed mechanism, which was intended to avoid deforestation, would be generally beneficial for biodiversity (Pistorius et al. 2011). Yet, what was originally conceived as a "simple mechanism", over the years expanded considerably its focus and ambitions, proving to be much more complex than expected. On the one hand, little attention had been paid to the impact of uncertainties associated with the estimation of forest area and carbon stock changes on accountable carbon credits, so that even small assessment errors may outweigh successful efforts to reduce deforestation and degradation (Köhl et al. 2009). On the other hand, criticism was being raised that a mechanism focusing on biomass merely from the quantitative perspective of carbon storage would pose a series of risks to biodiversity (Pistorius et al. 2011). It could provide incentives for a conversion of primary forests and degraded forests into commercial tree plantations, or it could lead to "inter-ecosystem leakage" e.g. induced shift of land use activities such as agriculture to non-forest and low carbon forest ecosystems with high relevance for biodiversity, which would increase pressure on such ecosystems (Pistorius et al. 2011; Tyrrell & Alcorn 2011).

Since 2009, the UNFCCC negotiations have increasingly taken up the concerns regarding potential negative effects of a potential REDD+ mechanism, reaching consensus regarding the need to include biodiversity safeguards and to enable additional benefits (FCCC/CP/2010/7 2010; Pistorius et al. 2011). The most recent developments of REDD+ in light of the so called "Cancun safeguards" reflect the need to go beyond deforestation and forest degradation by mainstreaming conservation, sustainable management of forests and enhancement of forest carbon stocks into the original REDD program (UN-REDD 2011).

Whilst at the policy level a strong call exists for integrating biodiversity concerns into the REDD+ design (Epple et al. 2011), only a few published specific papers examine biodiversity integration in tropical forests and REDD+ design at national scale (Dickson & Kapos 2012) and reaching divergent conclusions.

A Multipurpose National Forest Inventory (MNFI) for Papua New Guinea (PNG) is currently being designed with the support of the UN Agency for Food and Agriculture (FAO) and other international Agencies (JICA, AusAID, etc.), and will collect the forest data to support the National Forest Monitoring System (NFMS) that PNG is required to establish in order to participate in a future REDD+ mechanism (UN-REDD PNG 2011).

Whereas traditional forest inventories are largely centred on the appraisal of timber resources, current inventories are evolving toward multipurpose resource surveys by broadening their scope, aiming to incorporate the multiple values (products and services) that forests provide, including those related to biodiversity (Marchetti et al. 2012). PNG's NFI project aims to combine inventory activities

for carbon and GHG measurement with other significant features such as biodiversity and cultural features in addition to timber volume (UN-REDD PNG 2011).

2. PROPOSED BIODIVERSITY INVENTORY METHODOLOGY

The aim of this proposal is to develop a methodology for biodiversity assessment and monitoring that can be integrated into the design of the MNFI of PNG. This would allow for an objective analysis of the trade-offs between protecting biodiversity and reducing emissions, so that a careful targeting of REDD+ funds could aspire to maximizing both objectives simultaneously. One of the main challenges is to reconcile the methodology of a forest inventory with biodiversity monitoring, while dealing with all the constraints related to the establishment of a forest inventory in terms of time, number and type of monitored species and logistic issues.

Tropical forests are well known to harbour the highest biological diversity among terrestrial ecosystems. It would not be feasible to evaluate the entire biodiversity in a tropical forest, in terms of time and people needed, as well as costs (Lawton et al. 1998). Given this complexity and the inadequate descriptions of local biodiversity currently available (e.g., Torsvik et al. 1990), it is difficult to judge whether these forests are being managed in an ecologically sustainable way (Botkin & Talbot 1992). Moreover, it is impossible to measure and monitor the effects of various management practices on all species. An array of international and national initiatives have sought to overcome this problem by identifying indicators that could serve as proxies for total biodiversity and/or could be associated with ecosystem functioning.

FAO is developing a MNFI for PNG to collect data needed to feed a NFMS. As a requirement for all countries willing to participate in a future REDD+ mechanism (UN-REDD PNG 2011), such a monitoring system will allow to assess over the years, through structural and compositional tree diversity, the variation of the carbon stocks of PNG's forests (Gibbs et al. 2007; Kauffman et al. 2009).

The methodology for the establishment of the new MNFI has been presented by FAO to PNG's Forest Authority in April 2014 in the framework of the programme financed by the European Union, titled "Technical support to the Papua New Guinea Forest Authority to implement a multi-purpose National Forest Inventory". A series of preliminary discussions with FAO underlined how the large amount of data collected for the new MNFI could be used also to measure and calculate several indicators related to biodiversity. In particular, data about structural complexity and tree composition at the stand level will be collected for the MNFI in 5000 plots (1000 cluster-plots, each consisting of 5 plots, 4 of which occupy the vertices of a square with sides of around 300m and one is located in the centre).

Tree diversity, including species richness and abundance, is a promising indicator for biodiversity monitoring in REDD+ (Imai et al. 2014) because the sampling of trees is relatively easy (Gardener et al. 2008), their taxonomy is generally more well described and tree assemblage has shown a high cross-taxon congruency (Barlow et al. 2007; Howard et al. 1998; Kati et al. 2004).

However, biodiversity surrogacy remains a highly contentious issue (Lawton et al. 1998; Hess et al. 2006). Numerous studies have shown that the richness of one group is often highly correlated with that of unrelated groups (e.g. birds and butterflies; Blair 1999; Swengel & Swengel 1999), even though the richness of any particular group is a notoriously unreliable surrogate of the richness of all groups combined (Hess et al. 2006). Moreover, there is increasing recognition that a range of taxa is required for a reliable surrogacy of total species richness (Inara et al. 2010), and that surrogate taxa are likely to be biome-specific (Larsen et al. 2009).

MNFI data can also be used for assessing PNG's forest biomass and productivity, whose relationship with species richness has been widely investigated (Waide et al. 1999; Mittelbach et al. 2001), even

though reaching contrasting conclusions (Tilman et al. 1996; Wardle et al. 1997; Vila et al. 2003; Houle, 2007; Vance-Chalcraft et al. 2010; Con et al. 2013).
Due to these limitations we decided to assess the potential integration of the planned MNFI data with additional biodiversity indicators, to be measured within the time constraints of the MNFI.
Out of the four types of biodiversity (genetic, species, ecosystem and landscape diversity), our proposal focuses on three broad forest biodiversity indicator typologies (Lindenmayer 1999): (1) structure based indicators (stand and landscape-level features such as stand structural complexity, connectivity, heterogeneity), (2) taxon-based indicators and (3) indicators of functional diversity (based on plant functional traits or type *sensu* Dìaz & Cabido, 2001). Genetic biodiversity is not included, due to the above mentioned time and cost constraints.
The data collected and the indicators measured in the first MNFI campaign will be further assessed in terms of their performance with respect to the REDD+ goals, in order to select the most appropriate to be measured in a subsequent MNFI measurement campaign.

2.1 Structure based indicators

2.1.1. Landscape level

Structure based indicators at landscape level are generally measured through remote sensing and/or GIS software and their main goal is to monitor the fragmentation of natural habitat. There is a wealth of information that has been produced regarding forest fragmentation and its impacts on biodiversity, total carbon storage and other ecosystem processes (e.g., Fahrig 2003, Fisher & Lindenmayer 2007). A review (Fazey et al. 2005) of publications of conservation biologists found that habitat fragmentation was the largest single area of study in conservation biology.
Empirical evidence shows that fragmentation has significant and largely negative implications for biodiversity affecting species composition and stand structure of the areas with altered spatial patterns (e.g. area reduction, reduced interior space, increased edge exposure, isolation) (Fahrig 2003). Alteration of forest spatial patterns affects biodiversity in both tropical and non-tropical forests (Wade et al. 2003). There is also evidence that forest fragmentation may reduce total carbon storage at the landscape scale (Groenveld et al. 2009) and that hydrological cycles are appreciably altered by forest fragmentation causing changes both in evapotranspiration and local climates (REF) and changes in run-off (Ziegler et al. 2007). Fragmentation appears, therefore, to be an excellent indicator for biodiversity degradation for all types of forests.
Fragmentation is usually defined as a process involving both the loss and the breaking apart of formerly continuous vegetation. Fahrig (2003) noted that empirical studies of fragmentation are often difficult to interpret because of (a) many measures fragmentation at the patch scale, not the landscape scale, and (b) most measures of fragmentation do not distinguish between loss of vegetation cover (deforestation) and fragmentation *per se*, i.e., the breaking apart of vegetation after controlling for vegetation loss (degradation).
Further complexity is added by the perspective adopted when studying or reporting results from fragmentation studies. A small arboreal mammal will perceive a road or a treeless area as a barrier, so its habitat has been fragmented, but a large ground-dwelling herbivore may consider treeless as useful paths or food patches, and so its habitat has not been fragmented. Connectivity is organism specific and so is habitat fragmentation. It is therefore important to make a distinction between habitat loss and loss of native vegetation cover because some species can survive or thrive in modified landscapes. Some naturally fragmented landscapes are extremely species rich and letting the habitat

return to a 100% forest cover would result in a decrease in biodiversity measured as number of species (but in a net gain in carbon stocks).
Keeping all these elements of complexity in mind, we can however suggest that if our baseline is a primary forest ecosystem (that can be fragmented naturally) or a sustainably managed forest, then an increase in fragmentation over expected natural levels is generally indicative of degradation, and needs to be objectively assessed against management objectives from a forest degradation perspective.
Fragmentation indicators are only mentioned in this proposal, but they could be further explored in collaboration with the team responsible for the sampling strategies of forest plot, which are working with all the available GIS layers and satellite images.
Several metrics can be used to quantify the structure of landscape. We have selected (Tab. 1) the most useful indicators for assessing the major ecological effects of fragmentation processes (area, edge and isolation effects). To calculate these metrics we need a land-use or vegetation map that describes and represents the forest typologies that we are interested in analyzing. This map has been presented in March 2014 by JICA.

Table 1. List of proposed indicators for assessing the major ecological effects of fragmentation processes

Metric	Calculation	Unit	Relation to degradation	Caveats and constraints
Mean Patch Size	Total forest area divided by the total number of patches	Hectares	Decreasing mean patch size over time is likely to indicate increasing degradation due to area effects	Mean patch size can increase as a result of elimination of small forest patches
Mean Perimeter-Area Ratio	The mean ratio of the patch perimeter to area across all patches in the landscape	Dimension-less	Increasing mean perimeter-area ratio can indicate increasing degradation, especially via edge effects	Ratio can decline through the elimination of smaller and more complex patch shapes
Patch density	The number of patchdivided by total landscape area	N/100ha	Increasing patch density can indicate increasing degradation especially via edge effect	Limited interpretative value by itself: it conveys no information about the size and spatial distribution
Incidence function model (Hanski 1994)	The mean distance between all landscape patches, based on shortest edge-to-edge distance	Meters	Increasing mean nearest neighbor distances is likely to indicate increasing degradation through the effects of isolation	Loss of individual isolated patches can cause a decrease in the mean nearest neighbor distance
Forest Integrity Index (e.g., Kapos et al 2000)	Combined metrics of patch size, connectivity, and edge effects	Dimension-less	Declining integrity index is likely to indicate a reduced ability to produce goods and services, and therefore increasing degradation	Relationship to specific goods and services not established – complexity may obscure more understandable trends

2.1.2. Stand level

Structural diversity is an important property of forest stands. In forest science, stand structure refers to the within-stand distribution of trees and other plants attributes such as size, age, vertical and horizontal arrangement, or species composition (Powelson & Martin 2001). Its assessment has become an important goal for forest ecologists, given the hypothesized relationships between forest structure and other features of forest diversity (McCleary & Mowat 2002), among which is biodiversity (Uuttera et al. 2000; Lahde et al. 1999; Koop et al. 1994; Buongiorno et al. 1994). To be an efficient and effective biodiversity proxy, any measure of structural complexity will need to be based on an appropriate suite of structural attributes. This suite should be sufficiently comprehensive to capture the variety of structural components that occur in forests, reflect observed relationships with animal and floristic diversity, and remain concise enough to function as a practical tool for land

managers. The most effective attributes reported in the literature (see the review of Mc Elhinny et al. 2005) include those regarding trees (canopy, diameter, height, gap, biomass, species, dead wood, saplings), understory vegetation (cover, height, richness) and foliage (height, density in different strata, number of strata).

Data about trees will be collected according to FAO's methodology for the new MNFI. Depending on the forest type and ecological conditions, the relative contribution of understory herbs, shrubs, lianas and epiphytes varies considerably (Linares-Palomino & Kessler 2009). The understory of a tropical forest is often constituted by trees seedling while herbaceous species are less abundant (Richards 1996). Yet, understory herbs can represent, at local and regional level, about 45% of the vascular plant diversity in tropical forests (Gentry & Dodson 1987, Poulsen & Balslev 1991, Cicuzza et al. 2013). Our proposal recommends adding to the tree data the collection of understory vegetation (lianas, shrubs and herbs) data, that has already proven (Gillison et al. 2013) to be useful to characterize different forest types and evaluate different forest levels of disturbance, from small disturbance as extraction of non-tree timber products, to logging activities. Foliage arrangement was not considered because of sampling constraints and the little consensus on the choice of the measure. In order to quantify structural complexity, the different attributes need to be considered simultaneously, as it is the combined effect of the number of different structural attributes and the relative abundance of each one of them that endows a stand with its level of structural complexity.

Our approach is similar to the one reported by Mc Elhinny et al. (2005), which implies the establishment of a large initial set of attributes with a demonstrated association with the biodiversity elements of interest, or a likely association based on expert judgment. This initial set could then be reduced to a core set by establishing correlations or other relationships between attributes. Once the core attributes are identified, the effectiveness of using one or more of the most popular indexes in literature can be analyzed (see Tab. 2) and/or new tailor-made indexes can be developed.

Table 2. Indices used to quantify stand structural complexity (from Mc Elhinny et al. 2005)

Index	Number of attributes	Comment
Structural Complexity Index (Barnett et al. 1978)	4	Additive index. Attributes describe small mammal habitat
Habitat Complexity Score (Newsome and Catling, 1979A; Watson et al. 2001B)	5[A], 6[B]	Additive Index. Attributes describe small mammal habitat[A], or bird habitat[B]
Old-growth index (Acker et al. 1998)	4	Measures degree of similarity to old-growth Douglas-fir conditions
LLNS Diversity Index (Lahde et al. 1999)	8	Distinguishes successional stages of Finnish boreal forests
Biodiversity Index (Van Den Meersschaut and Vandekerkhove, 1998)	18	Used to characterise biodiversity in Belgium forests. Attributes benchmarked against levels in forest reserves
Vegetation Condition Score (Parkes et al. 2003[C]; Oliver and Parkes, 2003[D]; Gibbons et al. 2004[E])	8[C,D] ,10[E]	Assesses vegetation condition in temperate Australian ecosystems. Attributes benchmarked at the scale of vegetation community
Rapid Ecological Assessment Index (Koop et al. 1994)	9	Attribute levels benchmarked against levels in unlogged natural forest
Extended Shannon–Weiner Index (StaudhammerandLeMay, 2001)	3	Uses an averaging system to extend the Shannon–Weiner Index to height, dbh and species
Index of Structural Complexity (Holdridge, 1967, cited in Neumann and Starlinger, 2001)	4	Based on traditional stand parameters, which are multiplied together. Sensitive to number of species

Stand Diversity Index (Jaehne and Dohrenbusch, 1997, cited in Neumann and Starlinger, 2001)	4	Combines measures for the variations in species, tree spacing, dbh and crown size
Structural Complexity Index (Zenner, 2000)	2	Measures height variation based on tree height and spatial arrangement of trees
Structure Index based on variance (STVI) (Staudhammer and LeMay, 2001)	2	Based on covariance of height and dbh. Independent of height or dbh classes

2.1.2.1 Field collection for stand structural diversity

For a complete evaluation of the structure of forest communities in PNG, we propose to integrate the MNFI with an assessment of Non-Tree Plant Diversity (NTPD). NTPD occurring in the plot is divided into three main categories: shrubs, herbs and giant herbs.
This first classification will give us preliminary information on the vegetation structure and abundance for each of the three categories.
We propose to evaluate, through visual estimation, the cover of the vegetation layers, as described below, in a sub-plot of 10m radius located in the centre of each plot (Fig. 1A). A second estimation of the vegetation cover of each species in the 10 m subplot should be performed only in the central plot (Fig. 1B) of each cluster-plot. The last measurement will be conducted during the Taxonomic diversity evaluation, in the same sub-plot of 10m radius.

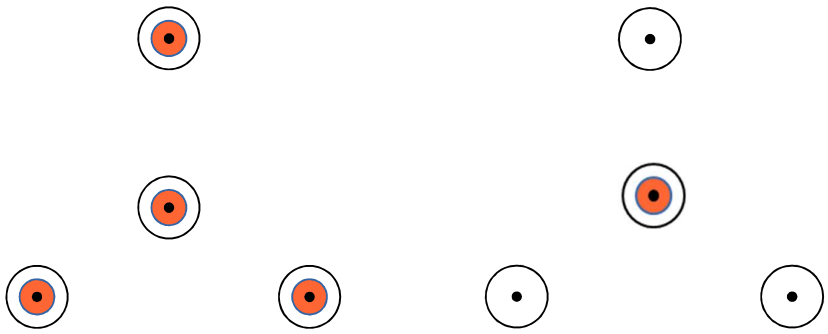

Figure 1. A: A 10 m radius subplots for the assessment of the cover of vegetation layers is located in all the plots of each cluster; **B**: A single 10 m radius subplots for the assessment of the cover of each species present is located only in the central plot of each cluster.

The cover is assessed by the vertical projection of the vegetation on the ground as viewed from above and it is generally referred to as the percentage of ground surface covered by vegetation. However, numerous definitions exist:
- **aerial cover** is the total area covered by the vegetation above the ground surface (Figure 2A). You can visualize the aerial cover considering a bird's-eye view of the vegetation. Small openings in the canopy and intraspecific overlap are included (Fig. 2C);
- **basal cover** is the area where the plant intersects the ground (Fig. 2A);
- **foliar cover** is the area of ground covered by the vertical projection of the aerial portions of the plants. Small openings in the canopy and intraspecific overlap are excluded (Fig. 2B).

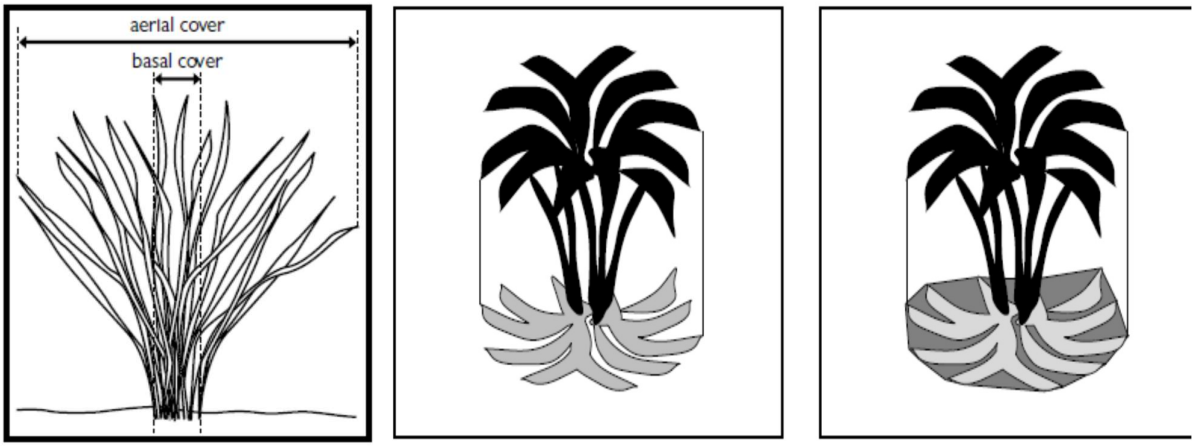

Fig. 2. A: basal cover compared to aerial cover; B: foliar cover; C: canopy cover is the same of aerial cover, but specific for tree plants.

In our proposal we referred to aerial cover expressed as a percentage of the plot area.

Shrubs

Shrubs' category includes plant species shorter than three meters. Within this category we consider two life forms. The first includes actual shrubs (*chamaephytes*, woody plants with perennating buds on branches on or near the ground, <3m). The second considers only the juvenal or the seedling of tree species (*phanerophytes,* woody plants with perennating buds above ground, >3m) that constitute the forest structure.

Three layers of shrubs (High: 2-3m, Middle: 1-2m, Low: 0-1m) have to be recorded, and for each one of them the percentage cover has to be estimated through visual estimation. The cover values have to be ranked according the following groups: (1) <5%; (2) 5-25%; (3) 25-50%; (4) 50-75%; (5) 75-100%.

Herbs

Herbs are described as non-woody species with annual or perennial life cycle. Most of them are *Hemicryptophytes* and *Therophytes*. *Hemicryptophytes* are plants with perennating buds at ground level, with or without stolons or rhizomes. Some examples are *Alpinia caerulea*, *Asplenium nidus*, *Imperata cylindrica*. *Therophytes* are annuals where the individual exists as a seed during the most unfavourable season. Some examples are *Ageratum conyzoides*, *Crassocephalum crepidioides*. In many cases it is necessary to must rely on local knowledge to determine whether a species is a true annual and not bi-annual or tri-annual as is the case of some grass species.

Cover of terrestrial herbaceous species has to be assessed through visual estimation according four classes: (1) <5%; (2) 5-25%; (3) 25-50%; (4) 50-75%; (5) 75-100%.

Giant herbs

Even if most of the herbaceous species in tropical forests are represented by small plants not taller than one meter, there are numerous species/genera that are particularly tall. Examples of tall

herbaceous plants are Musa (banana plants, Fig. 3A), *Araceae* (Fig. 3B), *Bamboos,* tree ferns, *Marattiaceae* (ferns, Fig. 3C), *Pandanus* and *Zingiberaceae*. These tall herbs can cover vast areas of tropical understory floor and in many cases they occur along streams or humid environments. At the same time when these herbs occur the forest canopy usually presents small gaps (Cicuzza, personal observation), either natural or as a consequences of small degree of disturbance. Keeping the "giant herbs" data separated during the analysis of the entire database is necessary to better understand the NTPD in relation to the forest tree structure and composition.

Cover of giant herbs species related to disturbance (*Araceae*, *Bamboos, Cycas, Musa, Marattiaceae* (tree ferns), *Pandanus, Zingiberaceae* (Ginger) has to be assessed through visual estimation according four classes: (1) <5%; (2) 5-25%; (3) 25-50%; (4) 50-75%; (5) 75-100%.

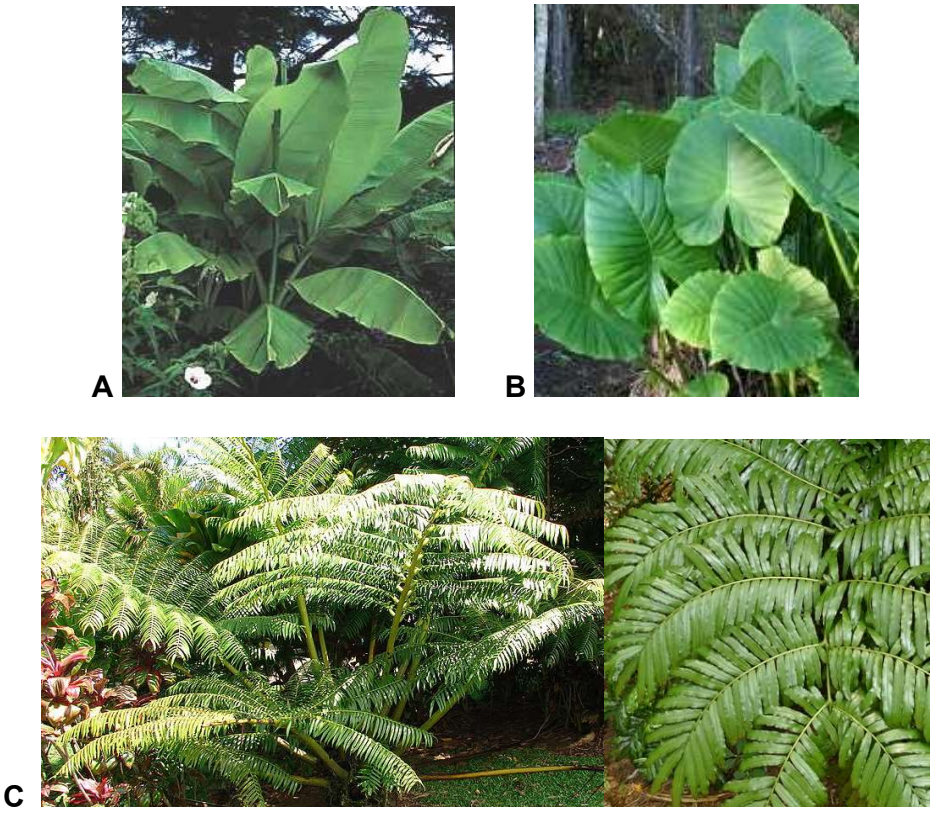

Figure 3. A *Musa*; B *Araceae*; C *Marattiaceae*

2.2 Taxon–based biodiversity indicators

The evaluation of biodiversity through taxon-based indicators is expensive and time-consuming. For this reason we propose to carry out this biodiversity assessment in only one plot for each cluster-plot. The data collection has to be carried out within a subplot with a radius of 10m (Fig. 3). Consider all the NTP (Non-Tree Plant species: herbs, ferns, shrubs, lianas, "giant herbs"), as well as all the trees below 10cm DBH.

If the botanists are not completely sure about the identification of the species, samples have to be collected for each presumed species located within the subplot (Fig. 4 A,B). It is preferable to collect samples from different individuals with flowers and, in case, fruits or seeds, in order to have all the taxonomic traits needed for a complete identification. Specimens may be stored in a plastic bag, tagged with plot's reference number and, after pressing overnight, packed tightly between newspapers in plastic bag and saturated alcohol (Fig. 4 C,D). When preserved in this way, specimens will keep for up to three months in a tropical climate. Finally, the samples collected in the plots will be sent to the nearest herbarium for drying, storage and identification.

Based on these data (species identities and abundances) it is possible to calculate several diversity indexes, including for instance Fisher's α, Simpson and Shannon. The performance of the first two is well understood and they are intuitively meaningful. α is relatively unaffected by sample size once N>1000 and there is no need to confirm that species abundances follow a log series distribution. Simpson's index provides a good estimate of diversity and will rank assemblages consistently. Confidence limits can be attached to both measures. Additionally, we also recommend calculating the estimated richness of tree species and other taxa, if enough data is available, using nonparametric estimators such as the ones devised by Chao et al. (2005). They are elegant and efficient and offer probably the most significant advance in diversity measurement in more than a decade (Magurran 2004). Furthermore, they have been widely used in tropical contexts (e.g. Shulze et al. 2004; Imai et al. 2014), where high diversity of fauna and flora are combined with poorly documented biota and invariably limited funds. Their accessibility is further increased by Colwell's EstimateS program (2001).

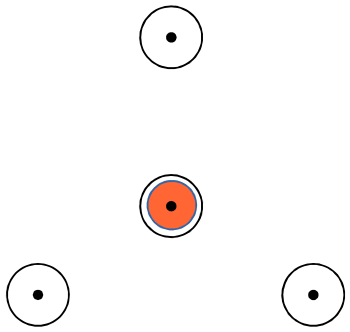

Figure 3. Location of plots for taxonomic traits: in subplots (10m) centered in the Center plot of each cluster-plot

Figure 4. Specimens collection through slingshot (A) and telescopic pruner (B) and packaging of specimens methodologies (C, D). Figures 5 C and D taken from "Tree species ID Training Manual" of the Forest Authority Research Institute.

2.2.1 Phylogeny and taxonomical investigation of Syzygium spp.

Background

We propose to take the opportunity of NFI for deepening the knowledge about *Syzygium* genus in PNG. Main reasons in order to focus on *Syzygium* spp. are:

- probably it is the most species rich genus in PNG (more than 200 species);
- its taxonomy and phylogeny is yet unresolved;
- several *Syzygium* species are important timber trees;
- they are primary species;
- it is geographically widespread and distributed across wide range of altitudes (0-3000m), providing enough material for studies and representing an important component of forest vegetation;
- FA-Research Institute researches (Kipiro Damas PhD) and knowledge about this genus represent a precious starting point;

Collecting and measuring

The collection of leaf material is not related to any specific design (plots and cluster-plots), but it is opportunistic. Wherever the botanists find a *Syzygium* sp., they have to stop and collect leaf material, according the following procedure, and a specimen to confirm the field identification in the herbarium. Data about leaf material and specimen (ID, data and GPS coordinates) have to be inserted in the dedicated Collect Mobile software.

We recommend collecting 4–6 grams of fresh leaf material torn into pieces not exceeding $2cm^2$. For storing and drying this material for DNA extraction we suggest to use empty teabags such as those that are widely available in supermarkets and specialist tea shops. The material is placed inside the teabag with a collector label placed against the wall of the bag so that it is easily legible (Fig. 5A) and sealed (usually by folding the top over). The teabag is then placed in an airtight container and completely submerged in silica gel until completely dry (Fig. 5B). The container is shaken frequently over the first day to make sure dry silica gel is always in close contact with the plant material. Once the material is completely dry, the teabag can then be removed from the silica gel and placed in an airtight container which has a fresh layer of silica gel at its base (Fig. 5C) for longer term storage. This silica gel layer can be easily replaced if it becomes hydrated.

Fig. 5. A. Ripped leaf material placed in teabag with internal paper label. B. Teabag submerged in silica gel (regularly shaken). C. Longer term storage of teabags in sealable container with layer of silica gel at base. (Photos: P. Wilkie)

Equipment

- 2000 teabags
- 10kg Silica gel
- 15 sealable containers (40cmx25cmx15cm)

2.3 Functional diversity indicators

Plant Functional Traits (PFTs) are morphological and physiological features that represent plant ecological strategies and determine how plants respond to environmental factors, affect other trophic levels and influence ecosystem properties. Numerous evidences have convinced many ecologists that functional traits offer the best available approach for achieving a general predictive understanding of communities and ecosystems. Trait-based approaches are now being used to predict the outcome of community assembly, global vegetation dynamics and the rate of ecosystem processes.

They have been proved to be a useful surrogate of a complete floristic inventory when this information is incomplete or difficult to be achieved (Gillison et al. 2013). Moreover an understanding of how changes in species richness and composition, and biodiversity in general, influence ecosystem properties requires an understanding of the functional traits of the species involved. By definition, functional traits are those that influence ecosystem properties or species' responses to environmental conditions.

The definition of PFTs for terrestrial vascular plants requires (1) to have some relationship with plant function, (2) to be relatively easy to observe and quick to quantify (3) to use measurement that can be standardized across a wide range of species and growing conditions (Cornelissen et al. 2003) (4) to have a consistent ranking across species when environmental conditions vary (Garnier et al. 2001) (5) to represent the key responses and effects of vegetation at various scale from ecosystems to landscape, biomes, and continents; (6) to be suitable for relatively easy, inexpensive and standardized measurement over the world. (Lavorel et al.2007).

The functional meaning of plant traits in response to environmental variation has been identified through observations of the variations in trait values across environments differing for one or several factors. These results show the adaptive significance of traits or combination of traits, which can be used to predict the response of organisms to climate, nutrient and disturbance. More recent studies have demonstrated the importance of PFTs to evaluate biodiversity and in some cases as a biodiversity indicator (Gillison et al. 2013).

Although there is no limit to the number of relevant traits in different research contexts, a small number of traits have been considered relevant almost universally, because they are at the core of the plant life cycle (Grime et al. 1997; Westoby 1998). These are plant size (usually expressed as height), seed size (usually expressed as seed mass) and the structure of leaf tissue (often expressed as specific leaf area or leaf dry-matter content). Beyond this, there are some 'core lists' of plant traits that are considered important for plant resource use, regeneration, dispersal and response to widespread disturbances (e.g. Hodgson et al. 1999; McIntyre et al. 1999; Weiher et al. 1999; Lavorel and Garnier 2002; Knevel et al. 2003). Logistic and financial considerations are equally relevant (Pérez-Harguindeguy et al. 2013) and considering all the constraints related to the forest inventory in PNG we have selected some PFTs related to plant size and leaf-traits, considering only tree species (except, obviously, for the life form, that has to be evaluated for all the species).

2.3.1 Field collection of functional diversity indicators

The evaluation of all PFTs in the field, for every morpho-species, is extremely time consuming and expensive. To overcome this problem we propose that they will be collected only in the center plot (10m radius for dbh>10cm in; 15m for dbh>20cm) of each cluster-plot.

The procedure is the same described above for taxon-based indicators, but in this case we do not need an accurate research of individuals with all taxonomical characters (e.g. flowers, fruits) useful for their identification. This way, only a subset of PFTs will be recorded in the field, while others will be analysed later in the herbarium, so as to reduce the sampling time.

The functional traits to be considered in the analysis of functional richness are listed below (1: data obtained from the NTPD protocol; 2: data obtained subsequently from the herbarium material):

- Growth form: mainly determined by canopy structure and canopy height, may be associated with plant strategy, climatic factors and land use. Within growth form we will consider life form[1] and plant height[1].
- Leaf traits: Leaf Area[2] (LA), Specific Leaf Area[2] (SLA), Leaf Dry Weight[2](LDW).

Growth form

Life form

Life form is a classification system designed by Raunkier (1934) and further expanded by various authors (e.g. Ellenberg & Műller-Dombois 1967) based on the relation of the perennating tissue to the ground surface. The perennating tissue refers to the embryonic (meristematic) tissue that remains inactive during unfavorable periods (cold winter, dry season…) and after resumes growth. So the location of these tissues is an essential feature of the plant's adaptation to climate (Whittaker 1975).

Life form is a categorical trait assessed from field observations, descriptions, photos or in the literature. We already mentioned the most common life form, here is the complete list with short description:

1) *Phanerophytes*: plants that grow taller than 2m and whose shoots do not die back periodically to that height limit (e.g. many shrubs, trees and lianas);
2) *Chamaephytes*: plants below 2m, or plants that grow taller but whose shoots die back periodically to that height limit (e.g. dwarf shrubs);
3) *Hemicryptophytes*: periodic shoot reduction to a remnant shoot system, so that buds in the "harsh season" are close to the ground surface (e.g. many grasses and rosette forbs). With or without stolons or rhizomes, examples are: *Alpinia caerulea*, *Asplenium nidus*, *Imperata cylindrica.* 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;
4) *Geophytes:* annual reduction of the complete shoot system to storage organs below soil surface. Examples are: *Alocasia longiloba*, *Dioscorea alata, Curcuma longa.*
5) *Therophytes:* plants whose shoot and root system dies after seed production and which complete their whole life cycle within 1 year. Examples are: *Ageratum conyzoides*, *Crassocephalum crepidioides*. 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 for some grass species.
6) *Helophytes:* vegetative buds for surviving the harsh season are below the water surface, but the shoot system is mostly above the water surface;
7) *Hydrophytes:* the plant shoot remains either entirely under water or partly below and partly floating on the water surface

Lianas and epiphytes may be classified here as phanerophytes or chamaephytes.

A key modification of the Raunkiaer system proposed by Gillison (2006) is the addition of above-ground root modifiers of any of the perennial life forms:

1) *Adventitious*: typically, roots growing from an above-ground stem such as *Ficus virens* or in many *Garcinia* or *Myristica* or *Pandanus* or *Rhizophora* species. Often indicators of moist and sometime anaerobic environments;
2) *Aerating*: 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.
3) *Epiphytic*: 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*).

4) *Hydrophytic*: 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, following Gillison (2006). 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;*
5) *Parasitic:* 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 qualify as an epitphyte for the purposes of this classification. Other species such as *Balanophora, Exocarpos, Rafflesia* and *Santalum* extract carbon and nutrients from below-ground root system.

Plant height

Background

Plant height is the shortest distance between the upper boundary of the main photosynthetic tissues (excluding inflorescens) on a plant and the ground level, expressed in metres. Plant height, or maximum height (*H* max), is the maximum stature a typical mature individual of a species attains in a given habitat. It is associated with competitive vigour, whole plant fecundity and with the time intervals between disturbances (fire, storm, ploughing, grazing) (Cornellissen *et al.* 2003).

Collecting and measuring

The height to be measured is the height of the foliage of the species, not the height of the inflorescence (or seeds, fruits), or the main stem if this projects above the foliage. The height recorded should correspond to the top of the general canopy of the plant, discounting any exceptional branches, leaves or photosynthetic portions of the inflorescence.
For estimating the height of tall trees we adopt the trigonometric methods. The forestry team will be responsible of collecting these data according the PNGFA-FAO field manual procedure.

Equipment

- Equipment for tree height measurement (length tape 50m, clinometer…) as chosen by forestry team.

Leaf traits

Leaf Area (LA)

Background

The area of a leaf is the most common metric for leaf size and is defined as the one-sided or projected area of an individual leaf, expressed in mm^2. Interspecific variation in LA has been variously related to climatic variation, geology, altitude and latitude, where heat stress, cold stress, drought stress, nutrient stress and high-radiation stress all tend to select for relatively small leaves. Within climatic zones, variation in the LA may also be linked to allometric factors (plant size, twig size, anatomy and architecture, leaf number, number of lateral buds produced) and ecological strategy with respect to environmental nutrient stress and disturbances, and phylogenetic factors can also play an important role.

Collecting and measuring

Select the relatively young (presumably more photosynthetically active) but fully expanded and hardened leaves from adult trees (dbh>10cm in 10m radius sub-plots and all trees dbh>20cm in 15m radius sub-plot). Do not consider NTP (Non-Tree Plant species: herbs, ferns, shrubs, lianas, "giant herbs"). Collect minimum 5, preferred 10 leaves, per, if possible, 2-3 individuals of each species. Wherever possible, avoid leaves with obvious symptoms of pathogen or herbivore attack, or with a substantial cover of epiphylls. LA is strongly affected by light intensity. Therefore, for many research questions it is best (giving the fairest comparison across individuals or species) to sample outer canopy leaves (also called 'sun leaves') from plants growing under relatively optimal conditions using slingshot when needed . For species that typically grow in the overstorey, take leaves from plant parts most exposed to direct sunlight. For true shade species (those that never grow in full sunlight), collect leaves from the least shaded parts found (but not from those that look light-stressed or bleached).

Determine LA with a scanner in the Herbarium. Scan in colour mode to maximize information for the threshold level between the leaf and the background. Coloured scans will also allow for *post hoc* measurement of other features of interest. In all cases, make sure that the leaves are not curled-up or overlapping. Try to position the leaves as flat as possible in the position that gives the largest area, but without squashing them to the extent that the tissue might get damaged. Cutting leaves into smaller pieces may facilitate flattening. In both cases, LA can be measured with image analysis freely downloadable software.

Special cases

1. *Compound leaves.* We recommend taking both measurements of individual leaflet and the whole leaf.
2. *Needle-like leaves.* Needle-like leaves are a specific case where projected and total LAs are different. Projected LA could be measured following the standard routines; however, because the leaves are generally narrow, make sure that your equipment is sensitive enough to adequately measure such leaves. For a rough measurement, you can measure leaf length with a ruler and leaf width with a calliper and subsequently multiply 2 x length x width.
3. *Leaves of tall trees*. Upper-canopy leaves of sun-exposed trees should be preferred. If these cannot be easily reached, we can rely slingshots. In not extremely tall trees, an alternative could be to consider exposed leaves halfway the crown length, at the outer half of the crown (inner leaves are sometimes older), which could be accessed with a pruner on an extension pole.
4. *Very large leaves*. Once they have been placed in plastic bags, large leaves may be put in a hard-cover folder to avoid wrinkling and folding. If leaves are larger than the window of the area meter, cut the leaf up into smaller parts and measure the cumulative area of all parts. Leaves with very thick veins or rachis can cast a lateral shade on the LA meter, thus overestimating the LA. In the case of a thick central vein, remove with a scissor the protruding upper or lower part of the vein and scan the leaves without that removed part, but include it in the dry-mass measurement. In the case of a thick rachis, remove the rachis and measure its diameter and length halfway, and calculate the rachis area as the product of the two. Then scan the leaves without rachis but include the rachis in the dry mass.
5. *Heterophyllous plants.* In the case of species with two or more types of leaves with contrasting shape and anatomy, such as e.g. plants with both rosette and stem leaves, collect leaves of both types in proportion to their estimated contribution to total LA of the plant, so as to obtain a representative Specific Leaf Area value of the individual.

Equipment

- Material for collecting and storing plants in the field described above
- 2 Scanners for the Papua New Guinea National Herbarium (Lae)
- Free software

Specific Leaf Area (SLA)

Background

SLA is the one-sided area of a leaf, divided by its oven-dry mass. SLA is frequently used in growth analysis because it is often positively related to potential Relative Growth Rate (RGR) across species. RGR is a prominent indicator of plant strategy with respect to productivity as related to environmental stress and disturbance regimes. SLA and its components are often, but not always, related to each other and to productivity gradients in a simple way.

Collecting and measuring

After the LA measurement (see "Collecting and Measuring" of LA), put each leaf sample in the oven ideally at 60°C for 24 h; then determine the Leaf Dry Weight with a precision balance. Be aware that, once taken from the oven, the samples will take up some moisture from the air. Put them therefore in a desiccator with silica gel until weighing, or else back in the oven to re-dry. Weighing several tiny leaves as if they were one and then dividing the weight by the number of leaves will generally improve the accuracy of the weighing.

SLA is LA of a leaf divided by its oven-dry mass. SLA=LA/LDW.

Special cases

See "Special cases" of LA section.

Equipment

- Same equipment for LA measuring
- Precision balance
- Oven dryer

The following table reports a synthesis of the biodiversity indicators, related sampling methodology and information retrieved from indicators.

All	Level	Sub-level		Required measurements / sampling	N. and dimension of plots	Information retrieved from indicators
Structure-based	Landscape			Measured through remote sensing and/or GIS software. Based on new forest map developeb by PNGFA/JICA.		Fragmentation of natural habitat, as an indicator of degradation (see table 1)
	Stand	Non-Tree Plant species	Lianas	Number of trees with lianas attached at their trunk;	All cluster-plots (10 m)	
			Shrubs	Cover of three shrub layers (High:2-3m; Middle: 1-2m; Low: 0-1m);	All cluster-plots (10 m)	
			Herbs	Cover of herbs layer; Cover of giant herbs (e.g. Musa, Araceae, tree ferns, Marattiaceae, Zingiberaceae)	All cluster-plots (10 m)	
Taxon-based	Stand	Trees		**Taxonomic identification** (NFI)	All cluster-plots (25m)	Measures and estimates of biodiversity: α, Simpson, Shannon, Estimated richness (nonparametric estimators)
		All species		Collection of three individuals (with taxonomic traits: e.g. flowers, fruits, seeds) to be collected for each presumed species within a plot; Storage of samples; Shipment to Herbarium (PNG, Rome)	1 plot each cluster-plot (10m)	
Functional diversity	Stand	Trees		**Life form**: assessed in the field; **Plant height**: all trees inside a plot will be measured with trigonometric method (clinometer), NTP measured by length tapes; **Leaf Area (LA)**: in the herbarium the specimens (3 individuals, 5 leafs by each) will be rehydrated through storing for 12 hours, in sealed, moist plastic bags and LA measured with a scanner and a freely downloadable software; **Specific Leaf Area (SLA)**: SLA is LA of a leaf divided by its oven-dry mass (at 70°C for 72h). SLA=LA/LDW (in Herbarium)	1 plot each cluster-plot (for trees dbh>10cm in 10m radius and for all trees dbh>20cm in 15m radius sub-plot)	Measures of functional diversity. PFTs as surrogates of a complete floristic inventory; PFTs as indicators of disturbance

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