BIODIVERSITY MONITORING FOR AGRICULTURAL LANDSCAPES

A protocol using biodiversity metrics to monitor agricultural sustainability under Aichi Target 7

Trees on Farms for Biodiversity

CONTENTS

Correct citation:
Harrison RD, Harrison S, Laumonier Y, Somarriba E, Suber M. 2019. Biodiversity Monitoring for Agricultural Landscapes. A protocol using biodiversity metrics to monitor agricultural sustainability under Aichi Target 7. Report. Nairobi, Kenya: World Agroforestry (ICRAF).

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Published by: World Agroforestry
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Design and layout: Corbett Nash, IUCN

Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
INTERNATIONAL CLIMATE INITIATIVE (IKI)
based on a decision of the German Bundestag

1. BACKGROUND

Aichi Target 7 requires that by 2020 agricultural areas, forests and aquatic resources are managed sustainably ensuring conservation of biodiversity. To date, for agricultural land only subjective indicators, such as the area under "sustainable management", have been proposed and there is an urgent need to develop a framework of objective metrics. This framework should provide a robust system for monitoring agricultural sustainability and its contribution to biodiversity conservation at national scales for reporting to the CBD. In addition, it should support local to national scale decision-making through provision of spatially explicit, fine-grained information on the state of biodiversity and ecosystem services across agricultural landscapes. Here, we present protocols for measuring and monitoring biodiversity in agricultural landscapes that meet these criteria and which at the national scale are designed to be implemented across a series of "sentinel" landscapes.

The protocols focus on Trees on farms (TonF) and their relationship to other components of biodiversity and ecosystem services. TonF are a critical component of farmland biodiversity, because of their contribution to habitat diversity and the mobility of forest dependent species through the farm landscape. Furthermore, because trees and tree features can be seen from space, TonF present a means to scale out field assessments and cost-efficiently monitor the state of agricultural biodiversity through time. The core protocols also cover birds, which are a well understood component of biodiversity that can be reliably and cost-efficiently surveyed. Using data on birds, we can assess the value of agricultural habitats, and their tree components, for species of conservation concern and to understand habitat connectivity for forest dependent species. In addition, we provide optional protocols for monitoring pollinators and natural enemies, soil quality, soil biota, rangeland health and terrestrial vertebrates. Using the optional protocols implementing agencies can adapt the surveys to meet national or local priorities, while ensuring data collection is standardised. Each protocol uses the same plots, thereby enabling us to link data and model these other components of biodiversity and ecosystem services using data on TonF.

2. INDICATORS OF AGRICULTURAL BIODIVERSITY AND SUSTAINABILITY

A good indicator should convey information about the attribute being measured in a clear and transparent manner. It must be based on a solid scientific rational and should perform consistently across a wide spectrum of situations. Ideally, it should be globally applicable.

There is a large body of literature on biodiversity indicators. Many have been developed for specific tasks, such as grading rivers with respect to water quality or assessing the conservation value of forest. Unfortunately, few satisfy all the qualities required of a good indicator at a global scale. Many have narrow application, for example they are only applicable to a specific river or forest environment, and there is often a tension between the need for clarity and simultaneously conveying complexity and nuance. Thus, rather than enter into a debate about the "best" indicator, we prefer to identify a set of useful metrics for agricultural biodiversity and sustainability that can derived from our protocols. Moreover, we prefer to maintain these as separate indices, as each conveys different information which is useful to policy makers and land managers. Each indicator should be mapped across each sentinel landscapes and ideally across the entire country.

ABOVE-GROUND BIOMASS (AGB)

Above-ground biomass is highly dependent on the number and size of trees. It is also critical to national reporting on green-house gas (GHG) emission reductions and climate change mitigation. In many regions AGB has not been well characterised in agricultural land, as estimates are often based on forest cover with scant regard for TonF. And even where TonF have been assessed, the remote sensing products used are usually not well suited to measuring TonF. Hence, tools specifically designed to assess AGB on agricultural land will improve current estimates and help countries better monitor progress on national GHG targets. AGB is expressed in $t\ ha^{-1}$.[1]

Split into separate contributions from native species (AGBnative) and exotic species (AGBexotic) provides an index of the value of this biomass for biodiversity conservation and certain ecosystem services. Native species provide substantially more resources and suitable habitat for native biodiversity, including species such as pollinators.

TREE BASAL AREA BY DIAMETER CLASS

Large trees harbour more biodiversity than an equivalent measure of small trees. Large trees also tend to provide enhanced ecosystem services, such as shade. A plot of basal area proportion by diameter class can be used to determine the relative contribution of large trees. In a landscape with more large trees, the curve is located further to the right. As a focus is on the contribution of trees to biodiversity, curves for native and exotic species should be presented separately. The curve may be generated over a defined area or mapped as a continuous measure of Proportional basal area of trees >30 cm DBH within 500 m.

TREE RAREFIED SPECIES RICHNESS

In forests, tree species diversity is strongly correlated to the number of arthropod species at both plot and landscape scales, and is related to habitat provision for birds and mammals. In addition, studies have demonstrated a correlation between trees species diversity and the diversity of beneficial soil organisms. These relationships are also likely to hold for TonF, although until now this has rarely been tested.

Rarefied species richness controls for the number of trees in a sample and hence enables comparison among sites and through time. Rarefied species richness should be presented for native species and exotic species separately. Rarefied species richness is calculated on a per ha basis.

TREE INTACTNESS INDEX

The Intactness Index measures the degree to which community composition represents some desired reference. Hence, the Intactness Index of TonF will be measured against forest tree composition from the same site. This will provide information on the degree to which TonF, including forest fragments, provide habitat for forest dependent species. Tree Intactness Index is calculated on a per ha basis.

FOREST FRAGMENT AREA / FOREST EDGE DENSITY

Forest fragments support a large proportion of the biodiversity in agricultural landscapes, and provide a matrix for the movement of forest dependent species, connecting populations between large forest blocks of forest. Biodiversity supported by forest fragments is dependent on the total area of forest fragment and the amount of forest edge, which is assessed by measuring edge density. These metrics can be calculated as a continuous measures based on 5 km and 500 m radius circles.

DIVERSITY OF TREE USES / SPECIES PER USE

The diversity of tree uses and tree species per use are measures of the socio-economic importance of trees for livelihoods. The diversity of tree uses assesses the contribution of trees to different livelihood activities, such as supplying energy, food and nutrition and construction materials. In the absence of trees these needs would have to be met through purchases. Tree species per use, calculated using Simpson's Index, assesses the resilience of the use to fluctuations in supply. These metrics are calculated based on a 500 m radius.

AREA OCCUPIED BY BIRD SPECIES OF CONSERVATION CONCERN

Species of conservation concern are defined by the IUCN Red List and include all species in the categories near-threatened, vulnerable, endangered and critically endangered. Species of conservation concern may be divided into forest species and farmland (or open habitat) species. Based on multi-species occupancy modeling, habitat suitability for each species can be mapped (expressed a likelihood of occurrence). A continuous version of the metric may be calculated as proportion of suitable habitat (>50% probability of occurrence) or highly suitable habitat (>80% probability of occurrence) within a 5 km or 500 m radius.

HABITAT CONNECTIVITY FOR FOREST BIRD SPECIES

Focusing on 10-20 common forest species, habitat suitability for forest dependent species is estimated using Multi-species Occupancy models. Each landscape pixel is then assigned as score based on the number of species with >80% probability of occurrence. Scores are then used to parameterise landscape circuit models.

OPTIONAL PROTOCOLS

Indicators for optional protocols are presented under the description of each protocol.

3. SELECTION OF LANDSCAPES

Monitoring biodiversity through ground-based surveys is expensive and time-consuming. Hence, it is critical to provide a sample frame at the national scale that is cost-efficient. A set of "sentinel" landscapes should be selected covering the breadth of the agro-ecological environments[1] occurring in a country or region. Thus, the number of sentinel landscapes needed will vary according to the size of a country and the ecological variability. There should be at least one sentinel landscape per agro-ecological zone and ideally 2-3. The selection of landscapes should be based on local expert advice and should consider aspects, such as existing long-term data, accessibility for survey teams and the importance for conservation. Ideally each landscape should cover the full range of landcover types found within the agro-ecological zone they represent but the exact boundaries of the landscape do not need to be defined. At the national level, the roll out of landscapes may be staggered to avoid over-loading the capacity of survey teams and budgets.

Summary

1. At least 1 landscape should be selected per agro-ecological zone within the country, with an additional 1-2 selected to provide replication where possible.
2. Landscapes should ideally encompass all land cover types within the agro-ecological zone they represent.
3. Selection of landscapes should be based on expert advice and consider aspects such as the availability of long-term data and the importance of the landscape for conservation.

4. SELECTION OF SAMPLE PLOT LOCATIONS

A 25 x 25 km sampling area is positioned within the selected landscape (Figure 1). Ideally, the sampling area should encompass all the important land cover types within the landscape, including forests or range-lands that abut the agricultural areas. It should also incorporate any critical environmental gradients, such as elevation or soil gradients. However, as the focus is on the agricultural land, it is not necessary to encompass habitat types that are restricted to protected areas or forest lands.

Next a broad land cover classification is developed that includes the main land cover classes (e.g. forest, forest fragments, plantations, arable land, pasture, water bodies and other (roads, buildings etc)). The minimum area for a land cover unit is 1 ha. If an existing landcover classification is available, this may be used but will usually need to be simplified.

Forest is defined as natural[2] woody vegetation >100 ha in extent.[3] Smaller areas (1-100 ha) of natural woody vegetation are defined as forest fragments. Highly managed tree assemblages, such as timber plantations or orchards, should be given a category of their own. Similarly, understorey plantations, such as shade grown coffee, cacao or cardamon, should be classified as plantations even if the canopy is composed of remnant forest trees. The definition of land cover types should make sense from land management and biodiversity perspectives. Hence, these are value decisions that should be made by ecologists familiar with the landscape. Fewer land cover categories makes for less sampling (and easier remote sensing) but increases the variance of biodiversity characteristics within in a category.

Hence, the number of categories is a balance between effort and precision. Normally, there should be 3-5 land cover classes[4], not including water-bodies and built up areas. As the minimum size of a land cover unit is 1 ha, if features are commonly smaller than this, they should be reclassified to a larger unit (e.g. mixed arable fields and woodlots). Also, if there are some minor land cover types (i.e. <5% of total land cover) that occur in only small part of the landscape, these can be excised from the sampling (or reclassified to a larger unit), as they will have a very small influence on the biodiversity of the landscape as a whole.

The next step is to divide the 25 x 25 km sampling area into a grid of 5 x 5 km cells. Two cells are then selected from each row and column of the grid (Figure 1). Thus 10 grid cells are selected in total. This ensures that sampling is dispersed across the landscape and that each point within the landscape

[1] Countries employ different systems to characterise their agro-ecological zones, such as Holdridge's Lifezones or rainfall delineated zones. The specific system employed is not important, but selected landscapes should provide a representative sample of the agro-ecological zones occurring in a country or region.

[2] Natural here means naturally occurring. Most trees are naturally regenerating, although they may be managed by people to some degree through harvesting. This definition includes naturally regenerating fallows in a shifting cultivation system. Tree communities may include some non-native species, but these are usually a small component. Definitions blur between an enriched fallow and a plantation (e.g. jungle rubber). If the non-native / managed species dominate, it should be considered a plantation. Otherwise, if may be considered as forest or forest fragment.

[3] This definition identifies native vegetation with shrubs and trees and is biodiversity orientated. It is not intended to correspond with national or international definitions concerning forests or forest lands. The definition is used only to assist in the selection of plot locations.

[4] The land cover classification (LCC) system will normally involve simplifying existing LCC systems, if these exist. This is because the aim is to understand biodiversity processes at a landscape scale, which is enabled through having a smaller number of broad LC classes for selection of plot locations. Our analyses using remote sensing will produce continuous measures of biodiversity characteristics, such as species diversity or biomass, which may be re-projected on to any LCC, such as national land use maps, if that is desirable.

has an equal probability of being selected. Next, a regular 125 x 125 m grid of 1600 points[5] is placed over each of the selected cells and each point is categorised by land cover category. Built up areas and water bodies are not included. Each point is then categorised by a second stratification variable. For agricultural land cover types and plantations, the total percentage native tree cover within a 500 m radius is calculated (as this focuses on native tree cover, exotic plantations should not be included in this calculation).[6] For points within forest fragments, the size of the forest fragment is calculated, while for points in forest the shortest distance to the forest edge is calculated. These variables are used, because neighbourhood native forest cover, fragment size and distance from edge are important for determining biodiversity in agricultural land (or plantations), forest fragments and forests, respectively. The stratification variables are then binned into low, medium and high groups based on the range of values.[7]

In the last step, for agricultural land cover types, plantations, and forest fragments three points per land cover category per 5 km x 5 km grid cell, one from each stratification group, are randomly selected. Thus a total of 30 points per land cover category may be selected. However, often a land cover type or one of its stratification groups does not occur in some grid cells. This is not a problem if the total number of selected points ≥15. However, if the number of selected points is fewer than 15, six points should be selected in each of the grid cells where it occurs. For forests, 12 points are randomly selected across all the grid cells, four per stratification group.[8] The selected points become the positions of the survey plots.

This sampling protocol provides an unbiased sample that is representative of the major land cover types within the landscape. The sampling of the grid cells ensures the entire landscape is covered, while using stratification greatly increases the efficiency in sampling biodiversity. In the absence of stratification, it might be necessary to survey three to five times as many plots to obtain a meaningful sample of rarer land cover types. The sampling of grid cells also means that plots are clustered, which reduces time in the field.

Summary

1. A 25 x 25 km sample area is positioned in the agricultural landscape to include all the major land cover types and environmental gradients.
2. A land cover classification is developed that includes only the main land cover types, based on a minimum area of 1 ha per land cover unit.

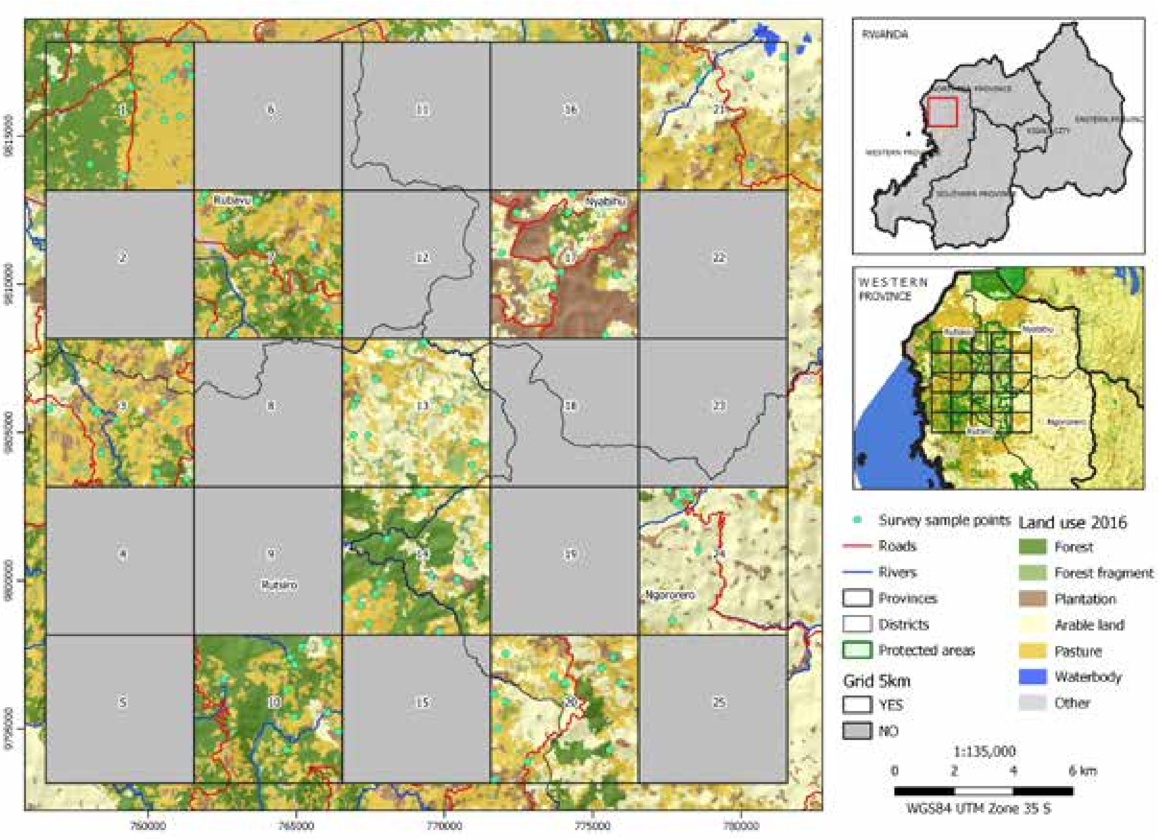

Figure 1. Sampling area (25 km x 25 km) with 10 randomly selected 5 x 5 km grid cells. Sample points (light green dots) were sampled using random stratified protocol, which makes for much more efficient sampling of biodiversity.

[5] This spacing ensures no overlap between plots.
[6] We focus here on native species / vegetation because they support much high levels of biodiversity. Exotic species and plantations are included in the field sampling.
[7] For example, if fragment size in the sample ranges from 3 ha to 75 ha then one would generate three groups of 3-27 ha, 28-51 ha, and 52-75 ha.
[8] This is done because forests are often aggregated in one or two parts of the landscape.

3. Forests are defined as native tree assemblages >100 ha. Forest fragments are defined as native tree assemblages 1-100 ha. Non-native tree assemblages, including understorey plantations, are defined separately. Water-bodies and built up areas are not included. The classification should be meaningful from biodiversity and land management perspectives. The resulting classification should have 3-5 land cover categories.
4. The sample area is divided into 5 x 5 km grid and a total of 10 cells, 2 per row and column are randomly selected.
5. A 125 x 125 m grid of points is laid out across the selected cells and is point is assigned a land cover class. Points in agricultural land cover and plantations are assigned a value for the native tree cover with 500 m. Points in forest are assigned a value for distance to the nearest forest edge. Points in forest fragments are assigned the fragment size. Low, medium and high bins are generated for each stratification variable.
6. For agricultural land cover types, plantations and forest fragments three points per land cover class are selected in each grid cell; one point per bin of the stratification variable. If this results in fewer than 15 selected points, then the number of points selected per grid cell should be increased to 6 (2 per bin of the stratification variable). The points become the centres of the sample plots. For forests, 12 points (4 per stratification bin) are selected across all the selected grid cells.

5. CORE PROTOCOLS: TREES ON FARMS AND BIRDS

5.1 SURVEYING TREES ON FARMS

Trees on farms (TonF) have highly variable abundances and distribution patterns, including linear features, irregularly shaped patches and scattered trees. This creates difficulties for survey design and previous approaches have often advocated applying multiple protocols, each specifically suited to different types of tree feature. However, most of these difficulties can be overcome by using relatively large (e.g. 1 ha) plots. This enables one to treat small scale tree features, such as live fences, boundary trees, scattered trees and small forest fragments, as an integral part of the agricultural system. When a tree is measured the type of feature and use is recorded, so that the contribution of different tree features and management can be assessed. Using relatively large plots also makes it easier to relate tree metrics to remote sensed data, as several pixels of typical remote sensing imagery can be unequivocally attributed to a plot. Nonetheless, we provide an optional protocol for surveying linear features, such as gallery forests or windbreaks, if such features are an important component of the landscape.

Before going to the field: Field surveys are expensive and hence good preparation is important to avoid delays and wasted effort. First, the field survey should be scheduled at an appropriate time of the year. For example, it may be advisable to avoid heavy rains or conversely a dry period when there are no leaves on the trees. One to two weeks before the fieldwork is scheduled, the team leader should visit all the plot locations and seek permission to enter the land and conduct the survey from landowners and relevant authorities (e.g. forest department, protected area management). It is good to have a simple hand-out explaining who is doing the survey and why, what the work entails and providing contact numbers for further information. It is advisable to collect a list of phone numbers, so that when the team is in the field the team leader can make a courtesy call the day before planning to enter the plot. Second, the team leader should assemble all the equipment (see Equipment Required beneath each protocol) and make sure individual team members are familiar with the protocols and their role. They should practice using the ODK forms and the botanists should assemble a list of common species (see Species Identification below), so these may be entered into the ODK forms. Plans should be made for handling and identifying specimens, such as botanical collections and insect collections, to avoid wasting time after returning from the field. Some types of specimen require special handling. For example, soil biota samples need to be stored in a -20°C freezer, so access to a freezer in the field needs to be organised.

Identifying the plot location: When conducting the survey, the team navigates to the selected point using a GPS. The alarm indicating you have reached the point should be set to ~3 m accuracy, and when the alarm sounds a peg is immediately placed in the ground to mark the centre point. This avoids any biases in the selection of the centre point and is much more efficient than wandering back-and-forth trying to obtain the “true” centre.

Plot Design: In agricultural land, a 1 ha plot circular (radius=56.4 m) is used. However, because of the demands of surveying large numbers of trees, we will use a 0.50 ha (39.9 m radius) plots in forests and forest fragments (where the number of trees ≥10 cm dbh ≥100). A 0.50 ha plot is sufficient to provide a reasonable estimate of α diversity in tropical forests, but small enough to be efficiently surveyed using a circular plot in dense forest. The plot dimensions must be measured using horizontal distance, so if the plot is on sloping land the team must be careful to compensate for the slope. For this reason, we recommend using a forestry survey instrument (e.g. Nikon Forestry Pro), as these can rapidly measure horizontal distance to the centre of a plot (to confirm whether a tree is "in") and can also be used to measure tree height.

Land classification data: The following data are collected from the plot centre: GPS position, elevation, slope, land cover class, topographic position, vegetation type, land management and land use history. In addition, data are collected from four 5.64 m radius subplots (100 m2) positioned at the plot centre, and describing a Y up and down slope of the centre (Figure 2). The distance from the plot centre to the centre of the other subplots should be 34 m (Figure 2). Subplot data include: landcover category; percentage cover (rocks/stone, woody shrub cover, tree cover, herbaceous cover); visible erosion (type and percentage of subplot area affected); canopy cover photograph (using the tablet); number of tree stems ≥5 cm dbh (diameter-at-breast-height, 1.3 m) and <10 cm; number of tree stems ≥1 cm dbh and <10 cm. If the plot overlaps with the edge of the land cover type being surveyed, the shortest distance to the edge should be measured so that the area within each land cover category can be calculated.

Trees: Working in a clockwise direction from north, all trees within the plot are surveyed (in forest it is sometimes helpful to mark the first trees surveyed to avoid double counting). Trees are included in the sample if the midpoint of the base of the trunk is equal or less than the horizontal radial distance from the centre of the plot.

A tree is defined as any plant with a free standing stem, not including plants like bananas, bamboos, climbers or hemi-epiphytic figs. For forests and forest fragments all trees ≥10 cm dbh are included. For agricultural land, all stems ≥5 cm dbh are included. For all trees, the dbh and species identity are recorded. If a tree is "standing dead" - the species is recorded as "dead". The dbh is measured at 1.3 m from the base along the length of the trunk. If the tree is on a slope it should be measured from the base at a point perpendicular to the slope (i.e. not up or down slope). If there is a deformity in the trunk (e.g. a fork or swelling), the point-of-measurement (POM) should be moved up and the new POM recorded. For multi-stemmed trees, the dbh is recorded for each stem above the minimum dbh. Each tree is given a unique identifier and each stem belonging to this tree is assigned a separate sub-identifier, so that data can be attributed correctly at the tree and stem level. If a tree has a broken stem, the dbh is measured and the height to the break point measured/estimated. For all trees, the following additional data should be recorded: planted or natural regeneration, management (e.g. canopy pruning, harvesting of stems), number of stems, re-sprout or not, the type of tree feature (e.g. live fence, boundary tree, shade tree) and land cover type. The presence / absence of climbers and hemi-epiphtic figs is recorded, and if present the proportion of the tree canopy covered by climbers is recorded.

Tree height: Tree height is recorded for the five largest (biggest dbh) in the plot and data are linked to the dbh and species data through the unique identifier.

Coarse woody debris: Dead trees are known as coarse woody debris (CWD) and are important to measure for biomass estimation. CWD is surveyed using the line intersect method. A line transect going 25 m N from the plot centre is walked and all fallen dead stems ≥20 cm dbh are measured. The dbh and length are recorded. A similar 25 m transect is then walked S from the plot centre.

Bananas and Bamboos: For each clump of bananas and bamboos, stems taller than 1.3 m are counted and the species identified. The DBH of the largest stem per clump is measured. If the stems are scattered, the number of stems in the plot is counted.

Climbers: Climbers with a stem dbh ≥5 cm are identified and the stem diameter is measured at 1.3 m from the ground. The host tree number is recorded.

Hemi-epiphytes: Stranglers or hemi-epiphytic figs with a stem/aerial root ≥5 cm dbh are identified and the aerial root diameter is measured at 1.3 m from the ground. The host tree number is recorded. In the case of figs with roots encasing the host tree, the aerial root diameter can be estimated by measuring the total diameter of the tree and fig, but this must be recorded in the datasheet.

Species identification: Accurate tree species identification is essential for calculating biodiversity metrics, but is not easy in tropical areas where species richness is high and several species

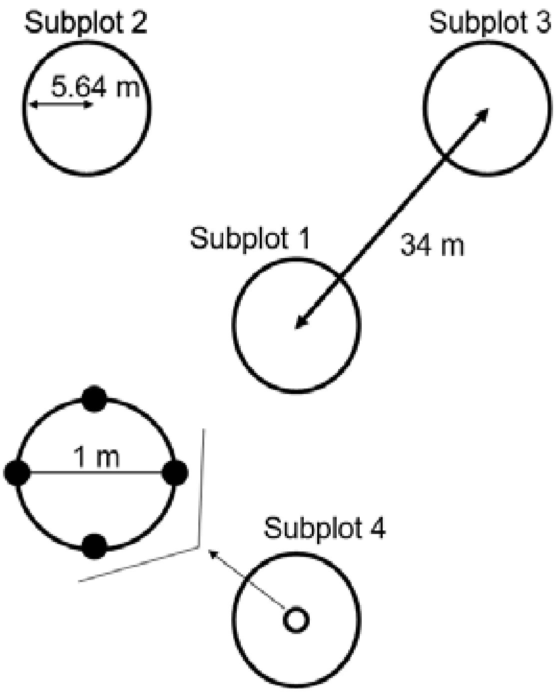

Figure 2. Arrangement of the subplots and the soil biota sampling scheme. Each subplot is 5.64 m radius (100 m2). The first subplot is located in the plot centre. The second and third subplots are located upslope, approximately 120o apart, and 34 m from the plot centre. The fourth subplot is located 34 m downslope. Data on land cover and vegetation are collected in each subplot. For the soil biota sampling (expanded circle to left), a 1 m diameter circle near the centre of each subplot is described and a core sample is taken from four points around the edge of this circle (black dots).

within the same genus may be found together. Unfortunately, local botanists are often overly confident or may use local names - particularly for rarer forest species - that correspond to two or more biological species. However, collecting is time-consuming and herbarium work adds to the costs. Hence, we advocate the following approach. A list of common species that are easily identified by the field team is drawn up and species on the list are simply recorded when observed (species names can be entered into the ODK forms which also speeds up fieldwork). It is essential that the team can reliably identify all the listed species. All other morpho-species are collected once per day. Each voucher is numbered with the tree number from which it was collected (e.g. Plot15 #34) and all subsequent observations of the same morpho-species on that day are recorded as being the same as the voucher (e.g = Plot15 #34). It is important the team take care over matching observations to vouchers. If there is any doubt, they should make a new voucher collection. The vouchers are pressed and identified later in a herbarium. It is an important role of the field team leader to maintain the quality of species identification.

Summary

1. In agricultural land, 1 ha circular plots (56.4 m radius) are used, while in forests or forest fragments 0.5 ha (39.9 m radius) plots are used.
2. Plot level data: GPS position, elevation, slope, land cover class, topographic position, vegetation type, land management.
3. Four subplots (5.64 m radius) are established in a Y shape, 34 m apart, and the following data recorded: land cover category; percentage cover (rocks/stone, woody shrub cover, tree cover, herbaceous cover); canopy cover; visible erosion; and number of saplings (≥1 cm dbh and <5 cm dbh) and poles (≥5 cm dbh and <10 cm dbh).
4. The dbh and length (height) of coarse woody debris (≥20 cm dbh) is recorded along two 25 m line transects.
5. For all trees ≥5 cm dbh in agricultural land and ≥10 cm dbh in forest and forest fragments, the dbh and species are recorded. Common tree species are identified in the field, but for all others at least one voucher per day is collected. Data on tree feature and tree use are also recorded for each tree.
6. For bananas and bamboos the number of stems per clump, the dbh of the largest stem and the species are recorded.
7. For climbers / hemi-epiphytes ≥5 cm dbh the species, dbh and host number are recorded.
8. Height of the five biggest (dbh) trees is measured.

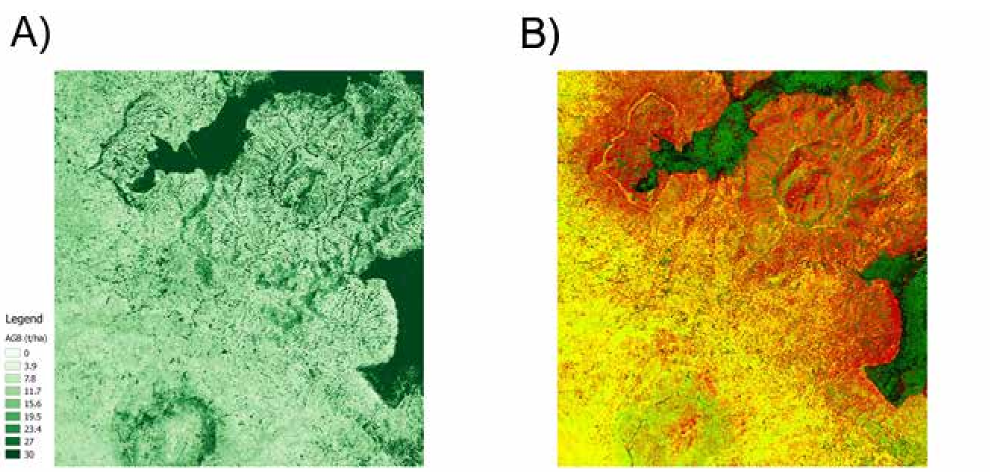

Figure 3. Example of output from modeling tree plot data and using remote sensing. A) Above-ground biomass (scaled to 30 t ha-1). B) Tree composition based on NMDS. Data from Mt Elgon, Uganda.

Team composition:
The most efficient team composition is to work with five members, including two botanists with locally recruited assistants and a team leader.

Equipment required:
Nikon ForesterPro x2
Tablets, with ODK forms loaded x3
GPS x3
Plastic box with good lid for storing electronics
Silica gel 2 kg
Ziplock bags
5 m DBH tape x2
2 m DBH tape x10
Collapsible ladder x2
Long-handled plant cutter
Bags for specimens
Specimen labels x1000
Plant press
Botanical paper / newspaper / cardboard
50 m tape measure x4
30 m tape measure x2
1.5 m poles x10
Flagging tape x2
1.8 m poles for measure POM x4
Calipers for CWD

5.2 SURVEYING BIRDS ON FARMS

The aim of this protocol is to enable bird composition data to be related to TonF features, so that the status of birds many be assessed using remote sensing. The data may also be used to contribute to a nationwide Wild Bird Index.[9]

The same sample plots as in the TonF surveys are used. Each plot centre becomes the centre of a 30 m fixed width point count. Applying standard methods, the observer walks to the point, waits 5 mins and then conducts a 20 min point count. All visual and aural observations are recorded, including species, group size and distance when first observed. If a mixed species flock is observed, observations recorded as part of the flock should be noted. Overflying birds that do not stop within the point's 30 m radius are not counted. Surveys are conducted for ~3 hrs during peak activity in the early morning (usually 7-10 am) and each point is sampled at least five times. The order points are surveyed is shuffled to avoid biases in the time of surveys and if multiple observers are used they must also be shuffled among points.

Summary

1. Birds are surveyed by 20 min, 30 m fixed width point counts, using the same plots as for the TonF survey.
2. Point counts are repeated a minimum of 5 times and the order points are surveyed and the observer are randomised.

Team composition:
We recommend two independent teams, including one birder and a locally recruited assistant. If the assistant has a motor-bike this may help enable more rapid assess to plots.

Equipment needed:
8 x 32 or 8 x 40 binoculars (1 pair per observer)
Field note books
Field guide / app to birds and bird calls
30 m tape measure
GPS (1 per team)

6. OPTIONAL PROTOCOLS

6.1 SAMPLING POLLINATORS AND NATURAL ENEMIES

The biodiversity and abundance of pollinators and natural enemies provides valuable information on the status of the ecosystem services they support. In addition, by linking the sampling protocol with that for TonF valuable information on the contribution of TonF attributes to these services is gleaned. Through modeling, future predictions about the biodiversity of these groups may be based on an analysis of TonF and remote sensing. The protocols presented here are rapid and do not require expert knowledge in the field, hence are cost-efficient. However, sorting of specimens into functional groups should be conducted under the supervision of a trained entomologist.

Pollinators: Crops requiring insect pollination include most fruit and nuts, including crops like coffee and cacao, and many vegetables. Often the quality of pollination affects both the yield and quality of a crop (e.g. coffee). Moreover, among those crops that do not require pollination for production of the edible component of the plant, many still need pollinators to produce viable seeds. The quality of pollination is determined by diversity of pollinators as well as the abundance of important pollinators, such as bees.

Natural enemies: Many organisms that live in farmers' fields and their environs feed on crop pests and hence reduce the pest damage and pest losses to farmers. These organisms are known as natural enemies and include many arthropods, particularly spiders and insects, birds and bats. Again, diversity

[9]Sheehan et al. 2010. The Wild Bird Index: Guidance for National and Regional Use UNEP-WCMC

is an essential component because different natural enemies feed on different pests and on pests at different stages in their life cycle. Our methods focus on arthropods, but data on insectivorous birds may also be derived from the bird survey.

Indicators: The abundance and functional diversity of pollinators and natural enemies.

Survey method: Arthropod surveys can become very expensive and time consuming. However, the method proposed here is cheap, and simultaneously surveys both pollinators and natural enemies. The traps are made of inexpensive materials and require very little training to use. Sorting captures is made easy by focusing on functional groups.

Using the same sample plots as the TonF survey, arthropods are surveyed with combination pan-pitfall traps of three colours; white, yellow and blue. Traps should be approximately 20 cm diameter and 6 cm deep. The sides of the trap should slope at >45º. Causing as little disturbance as possible, a hole is dug in the ground with a trowel and a trap placed in the hole so that the edges are flush with the ground. It is essential that there is no lip, as this will prevent arthropods crawling into the trap. Spare soil should be used to fill any holes or gaps around the trap. It is often helpful to insert two traps, one inside the other, while adjusting the fit and then removing the inner trap so that soil that has fallen in can be discarded. Water (2 cm deep) with a little unscented detergent is poured into the pan to serve as the trapping fluid. To empty the trap the contents are poured through a fine mesh (e.g. tea strainer) and then rinsed with 70% alcohol into a wide mouthed sample bottle (using a funnel). The sample bottles should be stored in a cool location, cellar or air-conditioned room, out of direct sunlight.

Nine traps are set out as follows: A set of three, one of each colour, is placed within 2 m of the subplot centre of the 2nd, 3rd and 4th subplots. Traps should be placed in an open location, without obstructing vegetation and ideally in direct sunlight for at least part of the day. The traps are checked and emptied after 48 hrs. One person can cover one plot in 30 mins (not including the time taken to access the location). All the captures from one plot are lumped into a single composite sample. A label should record the landscape name, plot number, collection date and collectors name and should be placed in the bottle. Ideally sampling should be done in the "best" season, which is usually early to mid wet season. However, periods of heavy rainfall should be avoided. If heavy rains have washed out the trap contents, it will be necessary to repeat the sampling.

Baiting for social bees: Social bees are disproportionally important pollinators. They can be surveyed using baiting stations. In each subplot, a white plastic plate is placed on the ground with yellow sponge (5 x 5 cm) in the middle. Sugar solution (20%) with food flavouring (e.g. lemon or rose) is sprayed on to the sponge and on to surrounding vegetation in a 1 m radius. The stations are checked after 30 mins and the number of bees of each species observed with a 1 min period are recorded.

Pitfall pan traps designed to sample pollinators and natural enemies.

Sorting samples: People invariably underestimate the time and costs of sorting arthropod samples. It is essential the the team has a plan and resources in place to conduct the sorting before collecting the samples in the field. Sorting should be supervised by an entomologist, but may be conducted by casual labour with minimal training. Equipment required includes a large magnifying glass with illumination, petri dishes, white trays, forceps, assorted specimen bottles, and a supply of 70% alcohol. The sample is sorted into functional groups with particular relevance to pollinators and natural enemies. These groups include social bees (honey bees, stingless bees, bumble bees and carpenter bees), solitary bees, large solitary wasps, social wasps, small wasps (i.e. parasitoids), spiders, ground beetles (e.g. Carabidae, Staphylinidae), small flying beetles (e.g. Chrysomelidae), earwigs, flies and others. The morpho-species diversity and abundance of these groups is then used as an index of pollinator and natural enemy availability, which can then be modeled with respect to TonF attributes. An alternative to manual sorting is to use high-throughput next-generation sequencing approaches. The cost may not differ much from traditional sorting approaches in some countries. An advantage is that DNA approach provides far higher taxonomic coverage. However, current methods cannot be used to assess abundance so information is presence/absence only, which may be a disadvantage for assessing the ecosystem services provided.

Summary

1. Arthropods are sampled using combination pan-pitfall traps.
2. Three traps (~20 cm diameter; white, yellow and blue) are set in three replicate sites in each plot (Figure 2, 2nd, 3rd and 4th subplots).
3. Traps are set flush with the ground and water with scent-free detergent is used as the trapping fluid. Trap locations should be selected to avoid obstructing vegetation and so that traps have direct sunlight for at least part of the day.
4. Traps are left out for a 48 hr period. The trap is emptied through a fine aquarium net and then rinsed into a sample bottle with 70% alcohol. All the captures from one plot are lumped together.
5. Samples are sorted into functional groups and morpho-species.

Team composition:
In the field, one non-expert technician. In the laboratory, one expert entomologist and 3-4 non-expert technicians for sorting material.

Equipment needed:
30 white pan-pitfall traps (~20 cm diameter)
30 blue pan-pitfall traps
30 yellow pan-pitfall traps
Tablet
GPS
30 m tape measure
Hoe / small spade
5 l plastic Jerry can x2
Scent-free detergent
Fine mesh (tea strainer)
Supply of 70% alcohol
Squeezy bottle for alcohol
White tray
Large, blunt nosed forceps
Plastic funnel
Specimen jars ~0.25 l
Paper for labels / 2B pencils
Plates and sponges
Scented 20% sugar solution in spray can

6.2 ASSESSMENT OF SOIL NUTRITION

Soil nutrition can provide important metrics of agricultural sustainability, such as soil organic carbon, soil infiltration rate and soil fertility. However, sampling and soil processing are time consuming. If soil analysis is done using mid-infared spectroscopy this substantially reduces the costs.

Indicators: SOC, erosion prevalence, soil fertility, infiltration rate

The methods applied here follow those defined in the Land Degradation Surveillance Framework (LDSF[10]). Soil infiltration is measured within 2 m of the plot centre and a cumulative mass soil sample[11] is collected nearby, including 0-20 cm, 20-50 cm, 50-80 cm and 80-110 cm depths. In addition, surface (0-20 cm depth) and sub-soil (20-50 cm depth) samples are collected using an auger from four points (in the same shape as for the subplots but 12.2 m from the centre). These samples are lumped into one surface and sub-soil sample per plot. At the field laboratory, the soil samples need to be dried and sieved (2 mm) before being sub-sampled for analysis. The cumulative mass samples are dried and sieved and the dry mass of roots and stones in each sample measured. The samples are then sub-sampled for analysis.

Summary

1. Surface (0-20 cm depth) and sub-surface soil samples are collected using an auger from each subplot and pooled at the plot level.
2. A soil cumulative mass sample is collected from the plot centre for 0-20 cm, 20-50 cm, 50-80 cm and 80-110 cm depths.
3. Soil infiltration measurements are collected for each plot.

Team composition:
In the field, two non-expert technicians; one to do the augering and one to do soil infiltration measurements

Equipment needed:
GPS
30 m tape measure
Soil auger
2 plastic bucket of different colours
Cumulative mass plate
Ziplock bags
Paper for labels / 2B pencils
Metal plates for drying samples
2 mm sieve x2
Data sheet for soil infiltration

6.3 SOIL BIOTA

Soil organisms can be easily sampled at the same time as the TonF surveys. However, identification is best done using high-throughput next-generation sequencing approaches, because of the greater taxonomic breadth provided and because so many soil organisms belong to poorly known taxa.

Indicators: The abundance and functional diversity of soil organisms.

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[10] Vagen et al. 2016. Geoderma 263, 216-225
[11] Winoweicki et al. 2015. Geoderma 263, 274-283

Replicate samples should be collected from each subplot used for the TonF survey. For each replicate, pool 4 soil cores from 4 points on a 1 m diameter circle (Figure 2). To collect soils, at each point, scrape away leaf litter and use a soil corer (3-5 cm diameter) to sample soil down to 15 cm depth. Collect bulk soil, not rhizosphere, and avoid large roots. To avoid cross-contamination between replicates, take a 'dummy core' and discard. Clean the corer between plots with alcohol and a paper towel. For each replicate, place the 4 cores in a labeled, sturdy ziplock or whirlpack bag. In the laboratory, thoroughly homogenize each sample, remove roots and then take a sub-sample (~10 ml) in a pre-labeled centrifuge tube or small ziplock bag. This subsample is then to be stored in a -20o C freezer for later DNA extraction. Remaining soil can be stored at 4o C for soil analyses.

Summary

1. Four cores (3-5 cm diameter) to 15 cm depth are collected from 4 sample points within each subplot and lumped into one composition sample per subplot (Figure 2).
2. In the laboratory, the samples are homogenised and roots are removed. Then a 10 ml sub-sample is taken and stored at -20o C until DNA extraction.

Team composition:
In the field, one non-expert technicians.

Equipment needed:
GPS
Soil corer
Ziplock / Whirlpak bags
Paper for labels / 2B pencils
70% alcohol
Paper towels

6.4 SURVEYING TERRESTRIAL VERTEBRATES

Terrestrial vertebrates include many species that are of conservation concern. As with the birds, data on terrestrial vertebrates can be used to calibrate circuit models to understand the connectivity among forests or other natural habitats.

Indicators: Area occupied by species of conservation concern and habitat connectivity for forest dependent wildlife

Terrestrial vertebrates are surveyed using camera traps. A post is driven into the ground near the plot centre, and a camera trap is mounted at approximately 0.5 m height on the post. The camera should have an unobstructed view of the area in front and should be tested before being left. The camera traps are left for 2 weeks in each plot. The order plots are surveyed should be randomised and the whole survey should be conducted within the same season.

Summary

1. A camera trap is mounted on a post near the centre of the plot (0.5 m high).
2. Traps are left for 2 weeks in each location and the whole survey should be completed in one season.

Team composition:
Two field technicians familiar with setting up camera traps.

Equipment needed:
GPS
Camera traps x20
Spare batteries
Hard drive to store images

6.5 RANGELAND HEALTH

In grasslands, including savannas and pastures, rangeland health may be more important than TonF for biodiversity.

Indicators: Density and diversity of perennial and annual grass species, proportion of points not under canopy

A 50 m transect is conducted from the centre of the plot going north. The following data are recorded at 2 m intervals along the transect: under tree canopy (Y/N), under shrub canopy (Y/N), grass tuft (Y/N), nearest grass or herb (annual/perennial), nearest perennial grass species, distance to nearest perennial grass species.

Summary

1. A 50 m point transect is conducted sampling at 2 m intervals
2. The following data are collected at each point: under tree canopy (Y/N), under shrub canopy (Y/N), grass tuft (Y/N), nearest grass or herb (annual/perennial), nearest perennial grass species, distance to nearest perennial grass species

Team composition:
Botanist skilled in grass and herb identification and field assistant.

Equipment needed:
GPS
50 m tape measure
Tablet
10 m tape measured

Plant press
Botanical paper / newspaper / cardboard
Bags for plant specimens
Specimen labels

6.6 PROTOCOL FOR SURVEYING LINEAR TonF FEATURES

Large linear features, such as windbreaks and gallery forests, may not be properly sampled using circular plots, so this optional protocol can be used if these are an important component in the landscape. This protocol should be completed in addition to the circular plot sampling for TonF.

Indicators: Same as for trees under main protocols

We define linear features as being ≤50 m wide and having a long axis at least 5x longer than the short axis. The density of linear features is assessed by the Line Intercept Method, using remote sensing tools such as Collect Earth. A set of 10 x 1 km transects, using random start points and random directions, are generated within each of the selected grid cells. Each transect is then "walked" using the remote sensing tools. When a linear feature is crossed, the feature category (e.g. gallery forest or wind break) is identified, the distances a and b along the transect where it crosses the boundaries of the linear feature, and the smallest angle of the linear feature to the transect are measured. These data can then be used to calculate the density of the linear features.

From the list of features identified, a sample of 30 of each type is randomly selected for survey, three from each grid square.

Surveying linear tree features: Linear features are surveyed using the transect method. Trees are surveyed in a 50 m long linear transect covering the full width of the feature (note: linear features are ≤50 m wide). The start point is taken as the point a above and the survey is conducted towards the North and/or West. For linear features shorter than 50 m in this direction the full length of the feature is surveyed and the surveyed length recorded. The width and direction of the linear feature should be measured at 10 m intervals so that the area can be accurately estimated. This is especially important for features with irregular boundaries, such as forest following a stream. All trees that are part of the linear feature should be surveyed, but those that may be considered part of the land cover categories on either side should be omitted.

Summary

1. Ten 1 km transects are "walked" using Collect Earth or similar tools, and the points a and b and smallest angle to the transect are recorded.
2. Three of each category of linear feature are selected per grid cells for survey
3. Using the point a as the start point, each feature is surveyed in a N and/or W direction using a 50 m transect. The width and direction of the feature are recorded at 10 m intervals.
4. Methods for measuring trees are the same as for the circular plots above.

Team composition:
Botanist and field assistant

Equipment needed:
GPS
50 m tape measure x2
Tablet
Other equipment as for TonF above

7. DATA ANALYSIS

TonF: We will calculate basic summary statistics for each plot, including AGB, basal area by size class, rarefied species richness, species composition, and tree use diversity and species per tree use. These metrics will then be modeled using remote sensed data (primarily Sentinel-1 and Sentinel-2 data from the European Space Agency) using machine learning (Random Forest Algorithm) to derive the best model. Modeling inputs may be increased to include topographic and landscape metrics. Model performance will be assessed by model verification, whereby data from 20% of plots will be withheld and predicted using the model derived from the remaining 80% of plots. The r^2 of model predictions vs observations is used as the metric of model performance.

Unless local allometric equations are available, AGB will be calculated using Chave et al.[12] equations with tree height. Wood Specific Gravity will be derived from the global database and tree height estimated based on the plot specific tree height – dbh relationship derived from measurements of the five biggest trees.

Species metrics will be calculated by first generating a species by site matrix. Rarefied species richness will be based on 30 individuals per plot. Composition will be assessed using Non-metric Multi-dimensional

[12] Chave et al. (2014) Global Change Biology 20, 3177-3190

Scaling (NMDS) and intactness estimated based on Jaccard's distance from the centroid of forest plots. Tree uses will be presented as the total number of tree uses, according to a standardised list, and tree use diversity as the Simpson's Index of species per tree use. Fragment area and edge density will be calculated based on 5 km and 500 m radii for each plot.

Birds: Multi-species occupancy modeling will be used to estimate the probability of occurrence of a species at any point in the landscape. Model inputs will include the distribution of forest fragments, TonF, topography, landuse and human settlement. Maps may be stacked across multiple species to calculate number of species with >50% probability of occurrence or >80% probability of occurrence. These staked maps will be used to assess hotspots for species of conservation concern and, focusing on common forest species, as an index of habitat suitability for forest dependent species.

We will also investigate whether we can use models based on remote sensed data to predict bird species composition.

Insects: Pollinator and natural enemy abundance and functional diversity will be measured for each plot and then modeled across the landscape using TonF data.

Soil fertility: Soil fertility metrics will be measured for each plot and then modeled using TonF data and remote sensing, as well as topography and soil / geological maps.

Soil biota: Soil biota abundance and functional diversity will be measured for each plot and then modeled using remote sensed data and TonF data.

Terrestrial vertebrates: As for birds.

Rangeland health: Metrics will be measured on a plot basis and then upscaled through modeling with remote sensed imagery.

Agroforestry on Mt Elgon, Uganda with coffee, bananas and beans.

Trees on Farms for Biodiversity