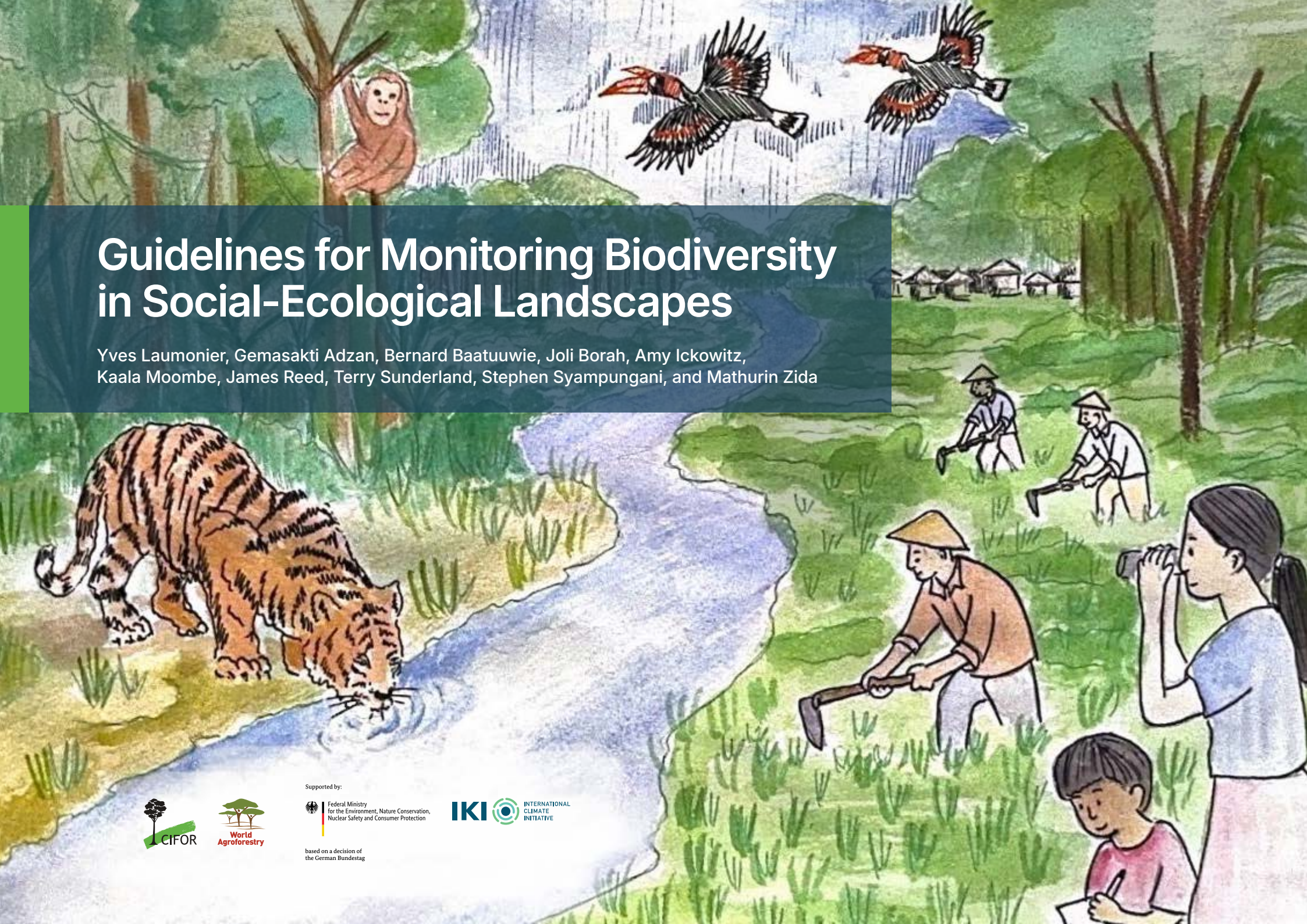




# Guidelines for Monitoring Biodiversity in Social-Ecological Landscapes

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Photo by Yves Laumonier/CIFOR-ICRAF

# Introduction

Despite playing an essential role in safeguarding food security, livelihoods, and human well-being, biodiversity is in precipitous decline globally with devastating social, environmental, and economic impacts (Pörtner et al. 2023). Thus, incorporating biodiversity into integrated landscape management strategies is crucial for reconciling conservation and livelihoods in multifunctional landscapes. However, doing so can be challenging in context of limited resources, competing land demand, land tenure issues, lack of institutional capacity, socioeconomic factors, and livelihood dependency on natural resources. Moreover, climate change impacts, lack of awareness about the value of biodiversity, insufficient stakeholder engagement, and inadequate community involvement in decision-making processes can impede the incorporation of biodiversity considerations into landscape management strategies. Significant concerns exist that the international conservation targets set for 2030 will not be met (Palomo et al. 2024).

To address these, Integrated Landscape Approaches (ILAs) have gained increasing support in the conservation and development discourse (Defries and Rosenzweig 2010; Sayer et al. 2013; Reed et al. 2016), emphasizing ecological approaches to quantify spatial variation in biodiversity and ecosystem services (Reed et al. 2021). This involves collecting or compiling data on landscape structure, species presence and abundance, the ecological services they deliver, and their uses and relational values perceived by local people (Pascual et al. 2021). Acquiring such data requires a combination of remote sensing techniques to assess ecological conditions across a region and to capture the full range of dominant vegetation types and land uses, with adequate taxa sampling on the ground and qualitative methods to capture the wellbeing needs and aspirations of local people.



Photo by Yves Laumonier/CIFOR-ICRAF

Analysing the composition and configuration of the matrix land cover is indeed critical for designing biodiversity-friendly landscapes, as it is a key determinant of forest species' ability to survive (Galán-Acedo et al. 2019; Hendershot et al. 2020). Riparian vegetation strips and mosaics of successional stage patches of fallow forests function as ecological corridors, improving environmental connectivity. Addressing biodiversity at the broader landscape scale can also help to overcome debates related to optimal scale and configuration of land units: for example, a single large forest patch versus several small forest patches (Simberloff and Abele 1982; Fahrig 2020); and management options for land sharing (combining land uses in a multifunctional system) versus land sparing (segregation of land uses) (Green et al. 2005; Perfecto and Vandermeer 2010; Phalan et al. 2011).

Several handbooks extensively discuss biodiversity survey and monitoring methods (Hill et al. 2005; Sutherland 2006; Gardner 2010; Larsen, ed. 2016; Walters and Scholes, eds. 2017). The guidelines presented here serve as a framework and baseline for monitoring biodiversity in ILA projects, designed to facilitate interactions among social and biophysical scientists, Indigenous People and Local Communities (IPLCs), policymakers, decision makers, and practitioners.

The guidelines were designed with a multifaceted approach to serve a diverse audience. While part of the handbook provides detailed academic insights tailored for scientists and researchers, the other is made accessible and practical for local practitioners, NGOs, and community members involved in on-the-ground conservation efforts. This strategy ensures that the guidelines are both scientifically rigorous and valuable for those actively engaged in biodiversity conservation and management at the local level, helping overcome recurrent scale and integration issues in contemporary landscape management (Fritsch et al. 2020; Gonzalez et al. 2020).

The guidelines combine conventional scientific studies at multiple scales with the participation of local communities and emphasize local perceptions, knowledge, and experiences in natural resource management. They are divided into two main sections: the conventional biophysical subregional scale approach (district, large watershed) and a more participatory-minded section devoted to a participatory and citizen science approach at the local scale.



Photo by Nanang Sujana/CIFOR-ICRAF

# 1 Biodiversity Monitoring at the Sub-Regional Scale

## 1.1 Historical remote sensing study on LULCC in the landscape

The purpose is to first monitor rather large areas, analyse large landscapes, and zoom in on specific areas using higher-resolution satellite data if available. Drone remote sensing can complement this for various purposes; for example, by calibrating satellite remote sensing data and encouraging local engagement and participation (see section 2).

The Landsat program provides free online satellite data ideal for historical forest cover mapping at scales from (1:50,000) 1:100,000 to 1:250,000. Its extensive archive of images (1970s–present) is easily accessible via Earth Explorer or Google Earth Engine (GEE) platforms. At the same time, one can evaluate the use of SPOT, Sentinel 1 & 2 (free); if available for the selected sites, it could be helpful to work with greater resolution (10 × 10 m for Sentinel, and C radar band or fusion optical-radar (Figure 1), or approximate 5 × 5 m using PLANET Satellite). See Box 1 for information on how to access satellite data.

For larger scale (district / big watershed) visual delineation of land units, we recommend Landsat band RGB composites (recommended bands 5,4,3 for Landsat 8). Although it is often disregarded, this is a very viable approach for forest-vegetation mapping assessment, particularly if image analysis tools and experience are limited.

### Box 1. Main websites for satellite data access



#### Landsat

**Landsat data** can be accessed through the US Geological Survey (USGS) website

USGS EarthExplorer <https://earthexplorer.usgs.gov/>

USGS GloVis <https://glovis.usgs.gov/app>



#### Sentinel satellite

**Sentinel satellite data** is available through the Copernicus Open Access Hub

<https://dataspace.copernicus.eu/explore-data/data-collections>



#### Planet

**Planet Labs** provides satellite imagery, but access is typically restricted to paid subscribers or through specific programs for researchers. However, a NICFI program allows users from tropical areas to get specific base map data for free.

<https://www.planet.com/get-started/>

One can access all the above directly via Google Earth Engine (see main text).

<https://developers.google.com/earth-engine/datasets/catalog/landsat>

<https://developers.google.com/earth-engine/datasets/catalog/sentinel>

[https://developers.google.com/earth-engine/datasets/catalog/projects\\_planet-nicfi\\_assets\\_basemaps\\_asia](https://developers.google.com/earth-engine/datasets/catalog/projects_planet-nicfi_assets_basemaps_asia)

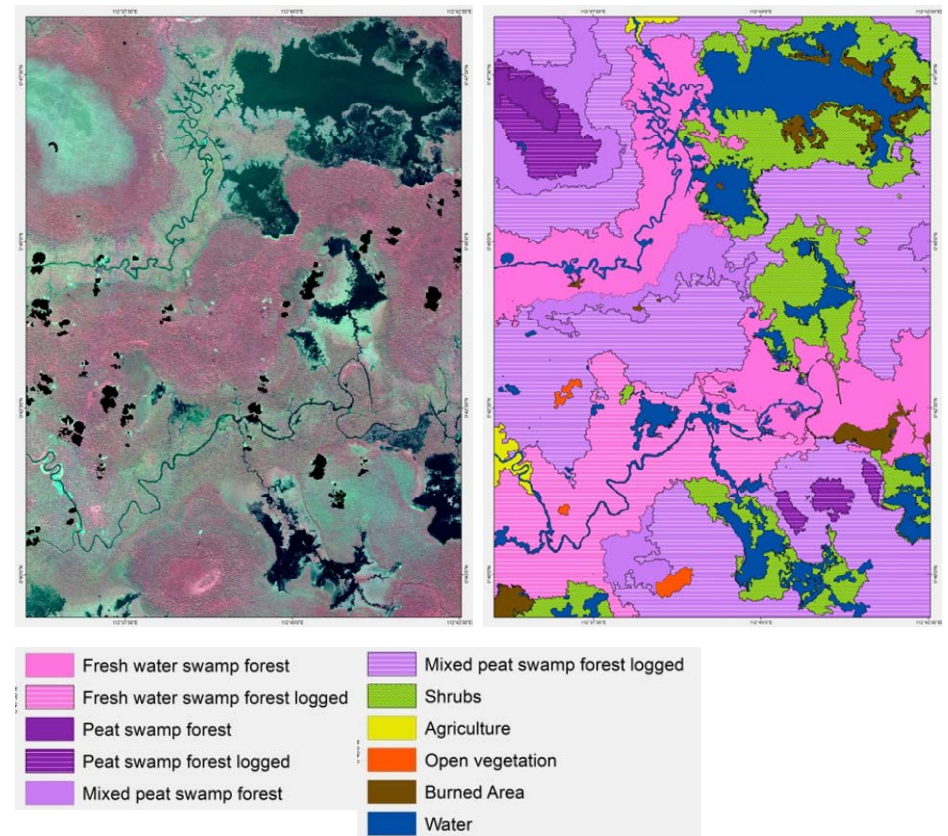
Source: Authors 2025

The visual delineation of land units on printouts is not recommended: on-screen delineation with direct labelling on the screen should be preferred to produce direct digital results. When performed by interpreters who know the area, this technique invariably surpasses or enhances any digital classification (see Box 2 for practicalities).

If visual interpretation is not an option, a machine learning approach is recommended to analyse larger landscapes, time series and change detection analysis, such as using the [Google Earth Engine \(GEE\)](#). This is a web-based platform hosting an extensive catalogue of analysis-ready satellite imagery stored in a public data archive. It includes historical images dating back more than 40 years, with imageries from [MODIS](#), [Landsat Science](#), [Sentinel](#), [Planet](#), etc. The data catalogue is paired with scalable computer power backed by Google data centres, enabling use of the data, even without downloading them; and performing some spatial analysis (including image corrections) on this platform. It is possible to produce a free-cloud mosaic generated in GEE (composite using two to three years of aggregation). GEE also provides many algorithms, either unsupervised (K-Means, X-Means, Cascade K-Means) or supervised (Random Forests, Support Vector Machine, Gradient Tree Boost, and Decision Tree). Tools from the OpenForis platform, such as the System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) (FAO 2021) and Collect Earth (Saah et al. 2019), are also worth considering – particularly for practitioners unfamiliar with remote sensing, since data are pre-analysed.

For forests and woodlands degradation monitoring, mapping of cumulative disturbed forest areas is suggested, based on time-series of surface reflectance with temporal characteristics from shortwave infrared bands and four vegetation indices (Wang et al. 2019). This should be done using [Breaks For Additive Season and Trend \(BFAST\)](#) (Verbesselt et al. 2012; Muñoz et al. 2020; Hamunyela et al. 2020) or Landsat-based [Detection of Trends in Disturbance and Recovery \(LandTrendR\)](#) (Kennedy et al. 2018).

A vegetation/land cover classification is developed that includes the main vegetation classes (e.g. forest, forest fragments, secondary regrowth, woodlands, savannahs, grasslands, agriculture fields, etc.) The minimum



**Figure 1. Example of wetland vegetation classification in Borneo**

The satellite-derived map corresponds closely with field observations, an outcome that is not always easy to achieve. The map is based on high-resolution (10 × 10 m) optical-radar fusion data. Shrub vegetation (green) is clearly identified around the lake, while freshwater swamp forest is detected along the river. Further from the banks, mixed peat swamp forest is distinguished, although peat swamp and low-pole peat forest are grouped. The landscape is dominated by mixed peat swamp forest, and for each forest type, a distinction is made between logged and intact stands.

## Box 2. On-screen visual interpretation of satellite data.



### On-screen interpretation of color composite images:

- 4,5,3 band combination (red, near-infrared and green); variations in moisture content are better identified with this set of bands), and
- 7,4,2 band combination (short wave infrared, red and blue) to accurately interpret areas with humid vegetation (swamp).



### A mixed computerised and manual classification approach can be made to differentiate between (see King 2002):

- “Localized, spectrally mixed, usually small, with few occurrences (LSM: localized spectrally mixed), not interpretable using supervised classification (example mosaic of swidden agriculture landscape or swamp vegetation mosaic), and
- Widespread, spectrally consistent, usually large and with many occurrences” (RSC: repetitive spectrally consistent) suitable for supervised classification (for example, irrigated rice fields).

Such a wall-to-wall on-screen visual interpretation of the vegetation is then overlayed with ancillary data (bioclimates, geomorphology, soils, elevation) to produce large-scale ecological vegetation maps showing details of forest types and conditions and the composition of the landscape matrix.

area for these vegetation units is 1 ha (since one uses mainly Landsat at first approximation, 9 pixels will correspond to the smallest mappable unit, which aligns with the ground vegetation plot survey). This also aligns with the most-used standard tool for quantifying forest characteristics on the ground, the 1-ha forest inventory plot (Alder and Synnot 1992; Mitchard 2016).

The resulting classification should be as detailed as possible. It is crucial to point out detailed forest types, landscape fragmentation levels, ecosystems, and agricultural uses linked to landscape management options beyond the classic forest/non-forest matrix. While government classifications of land use and land cover (LULC) are often promoted to facilitate mutual understanding among stakeholders, we argue that relying solely on such standardized systems can obscure ecologically important distinctions. Researchers should instead advocate for finer scale data collection and knowledge development to support more rigorous and context-sensitive landscape management. Land use planning will be enhanced by applying management on a per-forest-type basis, rather than simply by forest or non-forest, and detailed vegetation assessment will ensure more robust biodiversity sampling strategies.

Since the Convention on Biological Diversity (CBD) Sourcebook on Remote Sensing and Biodiversity Indicators Explorations (Strand et al. 2007), research on the connections between remote sensing and biodiversity has drastically increased (Geller et al. 2017), as recently reviewed (Cavender-Bares et al. 2022; Reddy 2021).

Remote sensing primarily captures structural attributes such as canopy height, density, and spectral variability; thus, it excels in estimating vegetation biomass (see Labrière et al. 2022 for a forest biomass reference measurement system). Although many experts and scholars argue that high carbon stocks in plant biomass correlate with high biodiversity, particularly in intact, old-growth tropical rainforests, not everyone agrees (Sabatini et al. 2018). Certain ecosystems, including savannas, shrublands, and early successional habitats, may exhibit relatively low carbon stocks while still supporting high levels of biodiversity. Furthermore, the relationship between carbon storage and biodiversity can vary depending on spatial scale (Sullivan et al. 2017). While a positive correlation may be evident at the regional or landscape scale, this relationship could be weak or nonexistent at the local or stand-scale level.

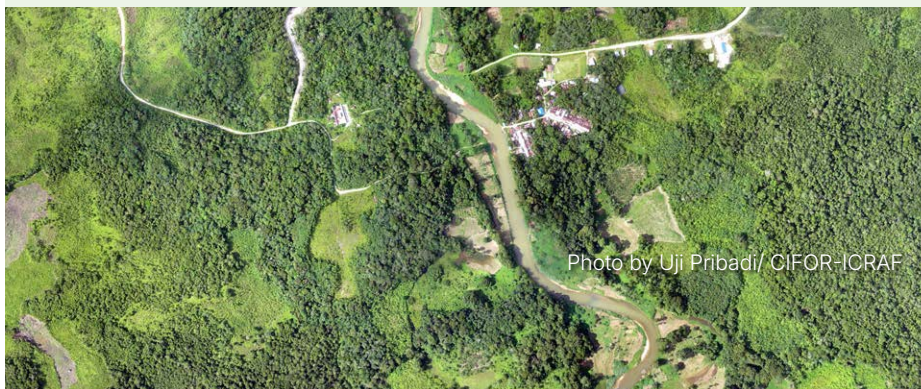


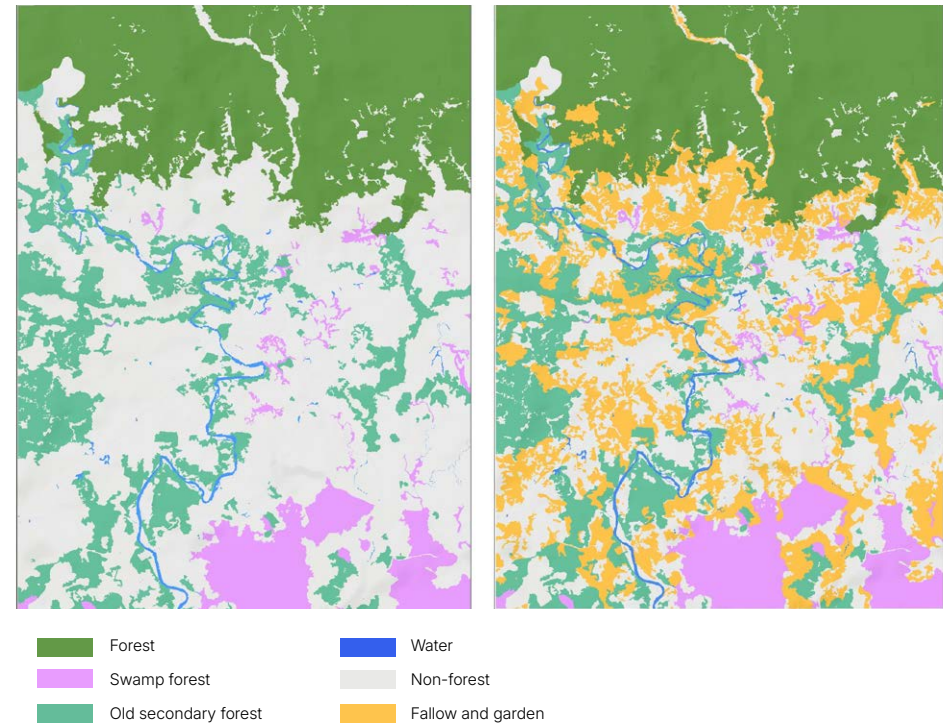
Photo by Uji Pribadi/ CIFOR-ICRAF

Therefore, relying solely on remote sensing to identify biodiversity values is limited and should be supplemented with on-the-ground assessments and ecological surveys for a more comprehensive understanding. However, promising new methods using spectral diversity has emerged as a new proxy for terrestrial plant diversity (Wang and Gamon 2019).

## 1.2 Landscape fragmentation and connectivity

Fragmentation analysis of the landscape structure over time is crucial for informing management, with the composition and configuration of the landscape linked to functional biodiversity and ecosystem services. How the spatial arrangement and composition of agricultural fields and other landscape habitats impact wildlife (vegetation, birds, arthropods) and their functions (pest control, pollination and yields, pollinator and natural enemies) is still poorly known. Addressing various scale levels remains crucial in any connectivity and fragmentation assessment.

Several specialised software programs are available to calculate landscape metrics. The most widely used is Fragstats (McGarigal and Marks 1995; McGarigal et al. 2023). Fragstats is a spatial pattern analysis program for quantifying landscape structure. It offers a comprehensive choice of landscape metrics and computes several statistics at three levels of analysis: patch, class, and landscape. Many of the metrics are highly correlated (Wang et al. 2014). The most used metrics in land cover fragmentation change analysis are given in Box 3 at landscape and patch levels. An R package called 'landscapemetrics' is also available and allows the calculation of landscape metrics for categorical landscape patterns (Hesselbarth et al. 2019).



**Figure 2. Importance of detailed vegetation mapping for understanding fragmentation impacts on wildlife.**

A simple forest/non-forest classification (left) obscures key ecological features, whereas the inclusion of secondary forest (old fallows) (orange colour right) reveals potential corridors that many animal species can use to move between more intact forest patches. Such fine-scale mapping is essential to assess connectivity, species movements and guide conservation planning.

**Table 1. Suggested metrics for Landscape and Patch level analysis.**

| Landscape level                                        |                                                                                                                                                                                                                                                                   |
|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Number of Patches (NP)</b>                          | Total number of patches in the landscape.                                                                                                                                                                                                                         |
| <b>Patch Density (PD) [number per 100 hectares]</b>    | Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size.                                                     |
| <b>Landscape Shape Index (LSI)</b>                     | The ratio between the actual landscape edge length and the hypothetical minimum edge length; standardised measure of total edge or edge density that adjusts for the size of the landscape.                                                                       |
| <b>Largest Patch Index (LPI)</b>                       | The percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.                                                                                                                                              |
| <b>Total Core Area (TCA)[ha]</b>                       | Total core area (TCA) represents the total cover of all patches of the corresponding patch type.                                                                                                                                                                  |
| <b>Euclidean Nearest-Neighbor Distance (ENN_MN)[m]</b> | Euclidean nearest-neighbour, the simple measure of patch context, used to quantify patch isolation, distance between the focal patch and its nearest neighbour of the same class.                                                                                 |
| Patch level                                            |                                                                                                                                                                                                                                                                   |
| <b>Number of Patch (NP)</b>                            | Simple measure of the amount of class.                                                                                                                                                                                                                            |
| <b>Edge Density (ED)</b>                               | Represents the edge length per unit area.                                                                                                                                                                                                                         |
| <b>Perimeter-Area Fractal Dimension (PAFRAC)</b>       | The perimeter area fractal dimension (PAFRAC) represents the shape complexity.                                                                                                                                                                                    |
| <b>Total Core Area (TCA)</b>                           | Total Core Area (TCA) represents the total of all patches of the corresponding patch type.                                                                                                                                                                        |
| <b>Edge Contrast Index (ECON_AM)</b>                   | Contrast metrics represent the difference between neighboring patch types.                                                                                                                                                                                        |
| <b>Clumpiness Index (CLUMPY)</b>                       | The clumpiness index (CLUMPY) shows the frequency with which similar patch types appear side-by-side.                                                                                                                                                             |
| <b>Euclidean Nearest-Neighbor Distance (ENN_MN)</b>    | Euclidean nearest-neighbour distance is a simple measure of patch context: isolation, distance between the focal patch and its nearest neighbour of the same class.                                                                                               |
| <b>Patch Cohesion Index (COHESION)</b>                 | Patch cohesion index measures the physical connectedness of the corresponding patch type. Below the percolation threshold, patch cohesion is sensitive to the aggregation of the focal class. Patch cohesion increases as the patch type becomes more aggregated. |

Source: McGarigal and Marks 1995

### 1.3 Ground survey, sampling protocol for vegetation (trees and other plant group), birds, arthropods, small mammals, amphibians and fish

Vegetation (trees and other plants), birds, and selected groups of arthropods and fish are widely recognized as effective indicators for landscape-level biodiversity monitoring, while amphibians and small mammals are also used to a lesser extent. Among these, plants, birds, butterflies, and ground beetles are the most commonly applied indicator groups due to their data availability, relative ease of collection and identification, and their well-known sensitivity to environmental change and ecological functions such as pollination, seed dispersal, or pest regulation (Bibby 1999; Brown and Freitas 2000; Koivula 2011; Lawton et al. 1998; Peh et al. 2006; Rainio and Niemelä 2003). Birds are often used as surrogates for overall biodiversity (Kati et al. 2004; Schulze et al. 2004; Larsen et al. 2012).

Strong, interdependent relationships exist between trees, birds, and insects (nesting sites, food chain, pollination, seed dispersal, biological control) that maintain and promote resilience to environmental changes. Understanding, conserving, and monitoring these relationships is crucial for ecosystem health, biodiversity conservation, and sustainable management of natural resources. Depending on objectives, working on a combination of trees, birds, and arthropod groups is a recommended priority. When aquatic ecosystems need to be monitored, fish are the usual targets, but some aquatic arthropods could be excellent indicators of the health of the environment and could be considered.



### Vegetation sampling and tree plots

The large-scale ecological vegetation maps and corresponding classifications performed previously are used to pre-stratify and design an equally stratified sampling protocol covering the main vegetation types (see Box 3). This sampling strategy is known for being robust and has many advantages over pure random or proportionally stratified sampling (Hirzel and Guisan, 2002; Rolecek et al. 2007).

Since the 1980s, large plot (25 to 50 ha) networks have been established worldwide to monitor forest function and dynamics (Hubbell and Foster 1983; Manokaran et al. 1990). These networks necessitate large investments but bring tremendous new knowledge (see ForestGEO network). A minimum of 4 ha was recommended for forest types in the humid tropics (Laumonier et al. 2010).

Nowadays, worldwide recommendation is for One-hectare samples (100 m x 100 m) for humid and seasonal tropical and subtropical forests/ woodlands. Since the ultimate goal is to contribute to future monitoring, permanent plots are also strongly recommended (Baraloto et al. 2012; Condit et al. 2014; Phillips 2023). The plot establishment procedure and tree measurements follow classic guidelines (Alder and Synnott 1992; Dallmeier 1992). They have been recently standardised for the humid (RAINFOR Phillips et al. 2018) and the seasonal tropics (DRYFOR Moonlight et al. 2020; SEOSAW partnership 2021).

Positions of all trees of diameter 10 cm and above (rainforest), or 5 cm and above (woodland, fallow forest) are mapped (10 × 10 m grid recommended) and measured for their total height, the height of the first branch (free bole), and diameter at 1.3 m above the ground (see Appendix 1). Measuring diameter at 0.3 (stem base) and 1.3 m (each branching stem) is recommended in woodlands where many species are multitemmed.

### Box 3. Sampling design

An equal-stratified sampling pattern is recommended: It implies allocating an equal number of sampling units to each previously identified ecologically meaningful strata. As demonstrated by Hirzel and Guisan (2002), equal-stratified sampling consistently outperforms random and proportional-stratified methods in habitat suitability modelling, yielding higher prediction accuracy and lower variability in model outcomes. By evenly representing environmental gradients, this strategy minimizes sampling bias and improves the detection of species–environment relationships, especially when sample sizes are limited.

#### Legend

- (A) Regular grid sampling
- (B) Random sampling
- (C) Equal-stratified sampling
- (D) Proportional- stratified strategy

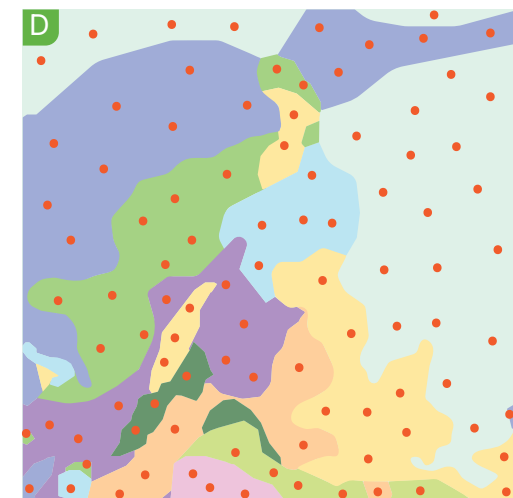
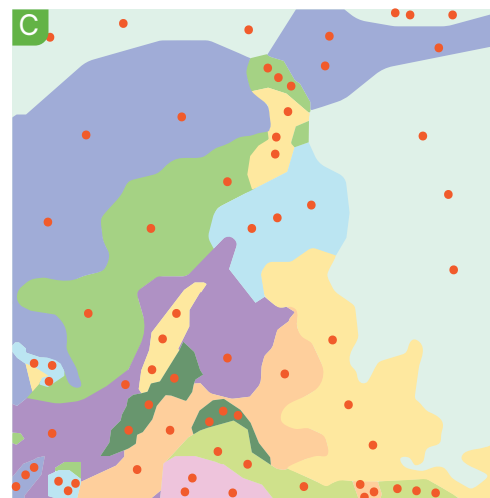
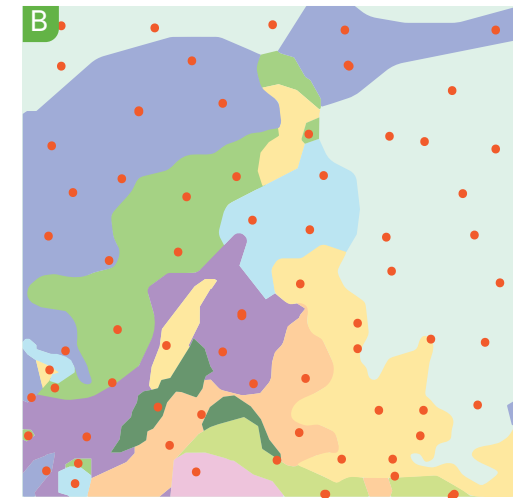
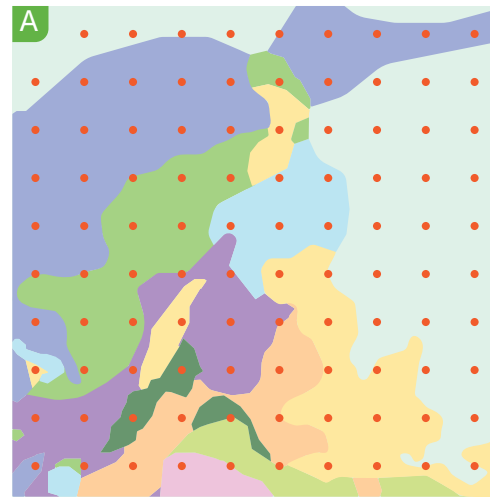


Photo by Axel Fassio/CIFOR-ICRAF

While time-consuming, the tree crown projection is also an excellent ecological parameter to record as another way of looking at dominance beyond classical diameter at breast height (DBH) measurements and can complement measurements of light availability under the canopy (Gourlet-Fleury et al. 2001) (see Appendix 2).

The conservation value of riparian (riverine) forests has also long been recognised (de Lima and Gascon 1999). Riparian forest buffers play a vital role in conserving some forest-dependent species and serve as ecological corridors that enhance connectivity within forest patches while offering additional resources like food, water, and shelter. For sampling of riparian forests, belt transects 20 m wide and 250 m long are set up on each riverside to cover 1 ha (see Appendix 1).

Besides natural forests, successional stages of forest regeneration following abandoned agricultural plots are well recognized for their importance in the landscape in terms of biomass (some old fallow forests are structurally very similar to natural forests), species diversity (Poorter et al. 2016; Arroyo-Rodríguez et al. 2015; Rozendaal et al. 2019), and improving the quality of the landscape matrix to maintain forest species (Chazdon et al. 2016).

For semi-natural vegetation like parklands/agroforestry or young successional stages (shrubs, young fallows), 10 to 20 smaller plots (20×20 or 40×40 m) are sufficient.

When working on large areas and depending on objectives, it could be more efficient to establish, for each vegetation type, a network of small rectangular 20 × 100 m (instead of 1 ha blocks) parallel to contour lines and along gradients on slopes to assess variations such as land facets (e.g. riverine, lower slope, mid-slope, upper slope, ridge).

Full practical details are given in Appendix 1 and 2.

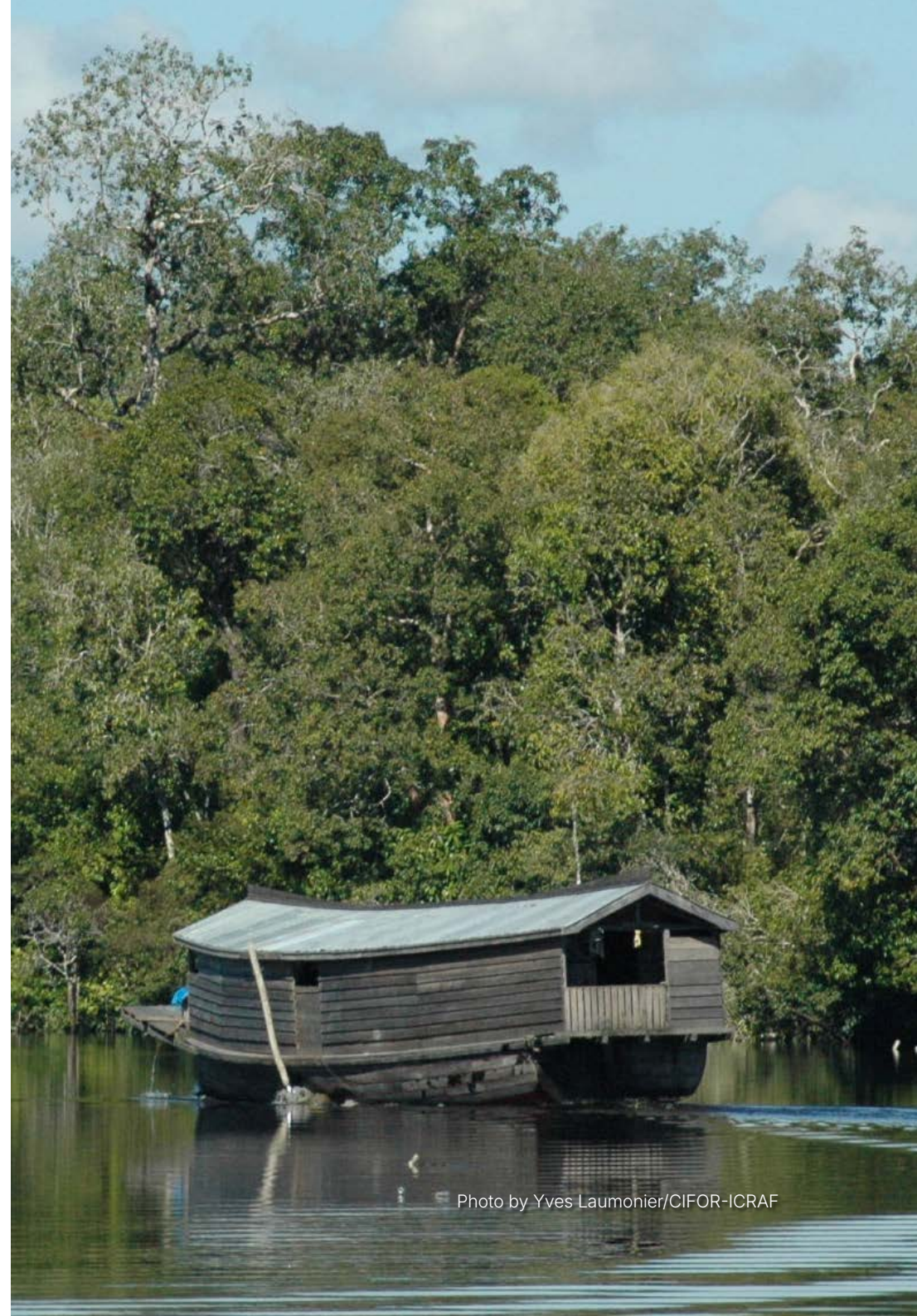


Photo by Yves Laumonier/CIFOR-ICRAF



## Other plant groups and life forms

Besides trees, other less often considered plant groups can be excellent indicators of the quality of the environment. Climbers (lianas), shrubs, and herbs are often important for communities that may use them for food or medicine. Sampling of lianas should differentiate between woody and non-woody (e.g., rattans and other climbing palms) climbers, measuring

diameters (greater than or equal to 2 cm) at a fixed distance along the stem from the rooting point. Gerwing et al. (2006) proposed a sampling protocol for lianas.

Grasslands are a crucial landscape element in dry woodland and savanna ecosystems, maintaining biodiversity, storing below-ground carbon, and providing ecosystem services. Andrade et al. (2019) discussed grassland sampling and data analysis. Species composition assessment using 1 m<sup>2</sup> quadrats under stratified random sampling is the most used protocol in such ecosystems, but various transect methods have also been recommended when designing monitoring protocols (see Box 5).

### Box 4. Examples of transect layout designs in grasslands

|                                                  |                                                                                                                                                                                                                                                                |                                                                                       |
|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>a) Spoke Design</b>                           | 25 m spoke design covers ~0.3-hectare (~0.7 acres). 50 m (~75 ft) spoke design covers a 1 hectare (~2.35 acres) area. Transects begin 5 m (15 ft) from the plot's center to focus trampling around center stake and minimize disturbance effects on transects. |    |
| <b>b) Intersecting Design</b>                    | The intersecting transect design covers ~0.2 hectares (~0.4 acres). Two 50 m (150 ft) transects intersect at the 25 m (75 ft) mark at plot center. The transect arms are oriented 45 degrees in both directions from magnetic north.                           |   |
| <b>c) Parallel Transect Design</b>               | Standard transect length is 25 m (75 ft). Parallel transects are evenly spaced. Transects may run perpendicular to the slope or perpendicular to a randomly selected azimuth.                                                                                  |  |
| <b>d) Single Transect Design</b>                 | Standard transect length is 25 m (75 ft); a multiple single transect design is often used to maximize replication at landscape scale.                                                                                                                          |  |
| <b>e) Linear Feature Design (e.g., riparian)</b> | Standard transect length is 25 m (75 ft); a multiple single transect design is often used to maximize replication at landscape scale. Length may vary depending on linear feature size, extent, or potential impact.                                           |  |

Source: Herrick et al. 2016



## Birds

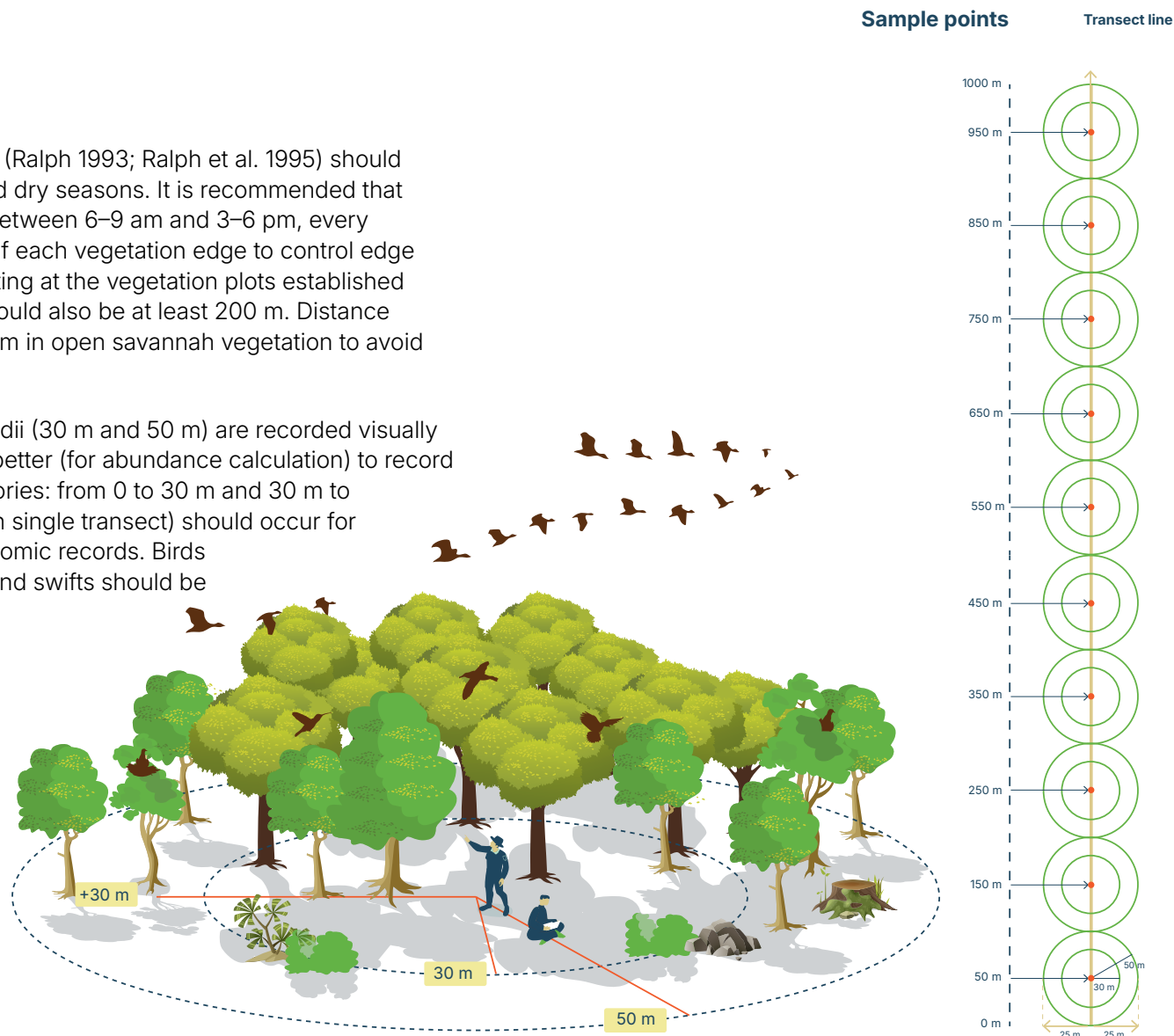
Classic bird surveys using the point count method (Ralph 1993; Ralph et al. 1995) should be conducted, preferably during both the rainy and dry seasons. It is recommended that 10-minute point count recordings are conducted between 6–9 am and 3–6 pm, every 100 m along 1,000 m transects and within 200 m of each vegetation edge to control edge effects (Restrepo and Gómez 1998; Figure 3), starting at the vegetation plots established previously (if any). Distance between transects should also be at least 200 m. Distance between recording points can be extended to 150 m in open savannah vegetation to avoid pseudo-replication risk.

All seen and heard bird species within two fixed radii (30 m and 50 m) are recorded visually and by standardised tape recordings. It is always better (for abundance calculation) to record the distance from the observer listed in two categories: from 0 to 30 m and 30 m to 50 m. Sample replication (remeasurement for each single transect) should occur for at least four days. Mist net use can enhance taxonomic records. Birds flying over the site, migratory birds, birds of prey and swifts should be disregarded.

**Figure 3. One kilometer bird survey transect example and one sampling point enlarged**

Each bird point count is conducted by two people (sometimes three, with an additional spotter): one observer dedicated to detecting and identifying birds, and one assistant responsible for recording observations and keeping track of time. This division of tasks allows the observer to remain fully focused on bird detection, while the assistant ensures accurate timing and data entry. Using two people reduces errors and increases the reliability of the survey compared to having a single observer do both tasks (Bibby et al., 2000).

Source: Authors 2025





## Small mammals and bats

Small mammals are usually divided into small terrestrial and volant mammals (bats) and correspond to species weighing less than 500 g, the upper size limit that can easily be caught in commercially produced live traps (Hoffmann et al. 2010).

Terrestrial small mammals, shrews, moles, most rats, mice and many squirrels' assemblages can be easily sampled with traps or pitfalls, and population estimated using capture-mark-recapture protocols (Krebs 1989). Most small mammals are easily handled and require relatively little specialized equipment. The foldable and portable Sherman live trap has become the standard, but less expensive and often locally-made wire or cage traps can be sufficient.

Bats are elusive creatures, active at night, making them hard to study. As a result, monitoring their diversity can be quite challenging. Common methods for capturing bats include ground-based and canopy mist nets (vertical stratification of bat assemblage is an important aspect when assessing local bat species diversity), or harp traps (Kunz et al. 2009). Harp traps consist of two to four parallel rectangular metal frames (usually 2×3 m) at 4 cm to 6 cm distances. Each carries a layer of vertically oriented monofilament fishing lines at 2 cm to 3 cm distances (Figure 4). Acoustic sampling of bats is also possible.

As a general rule, all people handling wild animals must consider the possibility of exposure to zoonotic diseases, and therefore wear protection like gloves and masks and regularly disinfect equipment (Kunz et al. 1996; Chomel et al. 2007). People capturing bats should be informed about potential health risks and vaccinated against rabies at least (Aguilar-Setién et al. 2022).



**Figure 4. Sketch of harp trap setup for bats**

Bats are extracted promptly after capture—ideally within 20 minutes—or whenever the trap is accessible, to minimize stress and reduce potential harm. This quick turnover has been shown to preserve bat welfare (BaTML, 2005; U.S. National Park Service SOP, 2023).



## Amphibians

Amphibians have proven to help monitor forest restoration programs. Survey techniques are relatively easy to implement (see Crump et al. 1994). Litter frogs, for instance, can be surveyed in evenly spaced 5×5 m plots along transects (Gascon, 1996). Plastic mesh fences of 50 cm in height are initially placed around the selected plot, and two people carefully search the area within the fence for litter frogs. All frogs are identified and released (Lips et al. 2001).



## Arthropods

Arthropods play a crucial role in forested landscapes due to their diverse ecological functions and significant contributions to ecosystem health (pollination, seed dispersion, natural enemies, litter decomposition, and food source). Certain arthropods, like ants, dung beetles and butterflies, are sensitive to environmental changes and often used as forest health indicators (Audino et al. 2014; Barragán et al. 2011; An and Choi 2021). Monitoring arthropod populations can provide valuable insights into ecosystem dynamics, habitat quality, and the impacts of disturbances like deforestation or climate change.

Ground and flying arthropods, pollinators and natural enemies can be surveyed relatively easily using the 'three-colour pan-pitfall trap' protocol, supplemented by Malaise traps at various heights in the canopy. Specimen identification is Malaise and three-colour pitfall traps installation in the forest.

An interesting approach is using aquatic arthropods for water quality monitoring in small streams (Ephemeroptera, Plecoptera and Tricoptera, or EPT index), and has been applied in some tropical landscapes (Suhaila et al. 2012; Bonzemo 2018). It is also a valuable citizen data collection exercise and can be organised with school children.

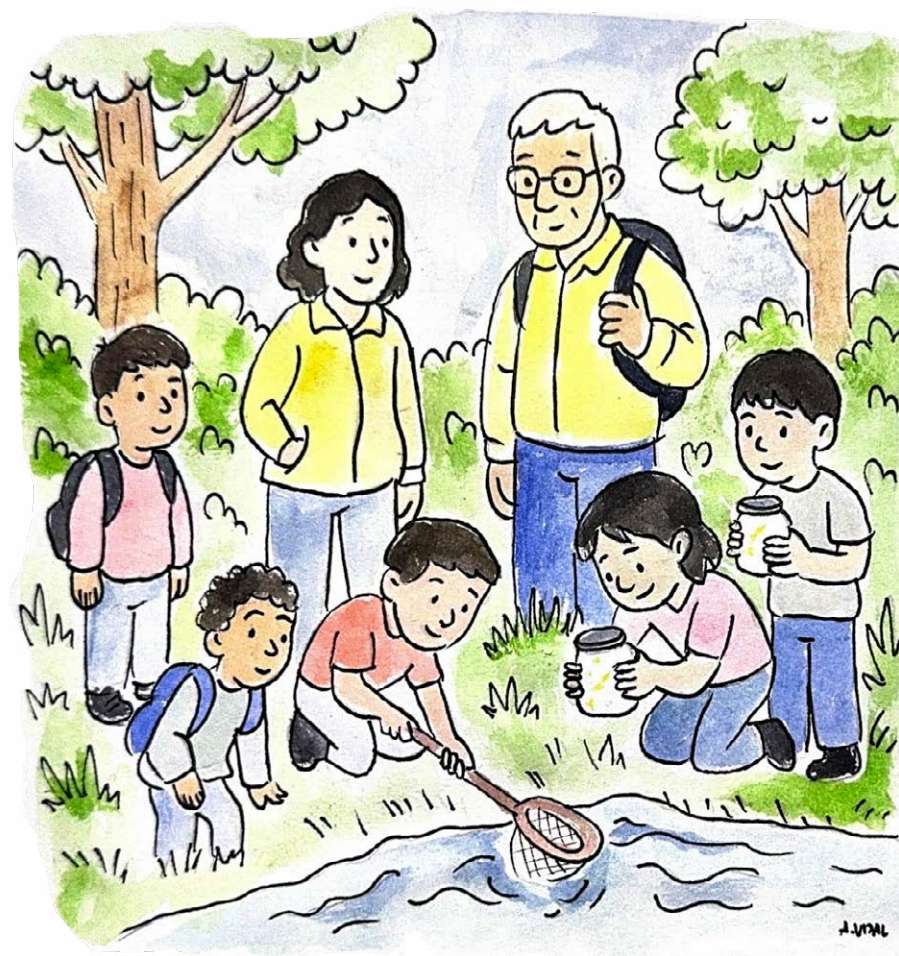


Illustration by Aurélie Vidal



## Fish (freshwater)

In a recent review, Radinger et al. (2019) highlight the importance of identifying the key aims in monitoring programmes and outline the different methods of sampling freshwater fish used to achieve these aims. Guidelines on sampling methods for fish population assessment, species identification, size measurements, and monitoring, including netting (seine, gill, fyke nets), trapping or electrofishing, have long been perfected (Bonar et al., 2009; Zale et al. 2012). They vary according to habitats, whether working in headwaters, rivers or lakes. Non-capture methods also exist that use acoustic tags and receivers to track fish movements, migration patterns, and habitat use over time (Lees et al. 2021), while new environmental DNA (eDNA) techniques involve collecting water samples to detect traces of fish DNA, providing a non-invasive method to assess biodiversity and monitor rare or elusive species (Evans and Lamberti 2017). Standard protocol (Bonar et al. 2017) is highly encouraged, while fish monitoring involving capture-recapture procedures is also recommended. Fish are typically tagged before being released, significantly enhancing the quality of information gathered (Pollock 1991). The well-recognized programme MARK allows for analysis of such data.



## 1.4 Digital technologies in wildlife monitoring

Beyond digital tools like geographic information systems (GIS) and satellite remote sensing, digital technology has revolutionised wildlife and conservation research in the past decade. The development of GPS trackers, camera trapping, acoustic recorders and unmanned aerial vehicles (drones) has allowed researchers to remotely monitor wildlife movements, behaviours, and populations. Digital technology enables real-time monitoring of environmental parameters, such as temperature, humidity, and sound levels, that can impact wildlife habitats. It has been accompanied by the tremendous development of digital platforms and software that enable the processing and analysis of large datasets and mobile applications that facilitate citizen science and crowd-sourcing initiatives.

Marvin et al. (2016) and Piel et al. (2021) reviewed the role of several methods – camera traps, acoustic monitoring, drones, and portable field labs – and improvements in machine learning that offer rapid, reliable means of combing through large datasets that these methods generate.



### Camera trapping

The use of camera trapping (CT) to survey and monitor wildlife has increased dramatically since the beginning of this century (Burton et al. 2015). It encompasses many models and ecological applications, mostly assessing wildlife distribution, abundance, behaviour, and community structure (Wearn and Glover-Kapfer 2017).

The standard spatial configuration recommends deploying cameras in a 1×1 km or 2 × 2 km regular grid at a height approximately 30–50 centimeters off the ground (Jansen et al. 2014; Rovero and Ahumada 2017). Kays et al. 2020 found that 25–35 camera sites were needed for precise estimates of species richness. The precision of species-level estimates of occupancy was highly sensitive to occupancy level, with fewer than 20 camera sites needed for precise estimates of common species, but more than 150 camera sites likely needed for rare species. Running a camera at a site for 3–4 weeks was needed for precise estimates of the local detection rate. Metrics for all mammal communities were sensitive to seasonality. At the same time, differences in the performance of camera trap models and settings were evaluated by Palencia et al. (2021), who also provided empirical guidelines for best practices in camera trapping.



Photo by Mokhammad Edliadi/CIFOR-ICRAF



## Drone ecology

Frazier and Singh (2021) provided a general introduction to integrating drone data into real-world applications and applying this knowledge to environmental monitoring and land-use studies. Since the pioneer 'conservation drones' of Koh and Wich (2012), this technology is increasingly used for a wide range of applications in ecology and biodiversity conservation (Manfreda et al. 2018; Nowak et al. 2019; López and Mulero-Pázmány 2019; Wich and Koh 2018), more specifically for marine animal research but also terrestrial wildlife population survey and monitoring, e.g. orangutan populations (Szantoi et al. 2017; Burke et al. 2019), macaques (Fornace et al. 2014), langurs (Gazagne et al. 2023), flying-foxes (McCarthy et al. 2021), and elephants (Hartmann et al. 2021; Rahman et al. 2023).

Unmanned aerial vehicles (UAV) technologies and miniaturized remote sensing sensors adapted for them are evolving quickly. The tool suffered earlier shortcomings, mainly because of the short flight duration capability, legal constraints that continue, and complicated permit applications in many countries. In addition, users must remember that besides surveillance and ethical issues, drone deployment also raises important critical questions for wildlife and people in its vicinity (see section 2) (Sandbrook 2015; Millner et al. 2023; Jackman et al. 2023; Sauls et al. 2023). Some bears, for instance, have shown heartbeat disturbance when approached by drones, and low-flying UAVs caused a herd of bighorn sheep to scatter (Ditmer et al. 2015). Elephants appear very sensitive to drone noise (Mesquita et al. 2022), which they perceive as identical to bee swarms (King et al. 2018). Recent developments for mapping and surveying purposes are towards the use of vertical take-off and landing (VTOL) drones that combine the practicality of vertical take-off and landing and the capacity to transform into fixed-wing craft once into the air, with much longer flight time and larger range of operation and a higher payload capacity (e.g., LIDAR, Multispectral and Thermal/IR cameras and very high-resolution sensors, up to 61 megapixels).



Illustration by Komarudin



## Bio and Eco-acoustics

The bio-acoustic approach is well-known in biodiversity inventories (Obrist et al. 2010). It focuses on recording sounds produced by living organisms (e.g. birds, bats, fish, insects, mammals), identifying species and analysing animal vocalisations and calls, studying behaviors and communication patterns. This approach can provide insights into animal interactions, mating calls, territoriality, migration patterns, and responses to environmental changes. Bioacoustics is widely used in wildlife research, conservation biology, and ecological studies to monitor species' presence, abundance, and behaviour through acoustic signatures. Eldridge et al. (2018) highlighted a correlation between bird species richness and eco-acoustic data, although it appeared valid for temperate datasets and not for tropical ones.

Sound analysis can also be applied to study landscape configuration (Fuller et al. 2015). The eco-acoustic approach analyses sound recordings from natural environments to categorize and monitor landscapes, evaluating the global acoustic environment ('soundscape') of an area (Pijanowsky 2011; Sueur et al. 2014). Researchers can gain valuable insights into the dynamics of the landscape. Several indices (e.g., Soundscape Saturation Index) have been proposed that aim to capture community-level dynamics by providing statistical summaries of the frequency or time domain signal (Pieretti et al. 2011; Farina 2014; Sueur et al. 2014) or of the time-frequency dynamics, claimed to be more ecologically robust (Eldridge et al. 2016). Sound diversity declined and became less synchronized with forest fragmentation and loss in Papua New Guinea and Borneo (Burivalova et al. 2018; 2022). A recent application of soundscapes and deep learning enabled the tracking of biodiversity recovery in tropical forests in Ecuador (Müller et al. 2023).

## 1.5 Biodiversity and ecological modelling

By combining these field data, remote sensing GIS technologies and digital tools, modelling results can inform land-use planners, conservation planners, and decision makers, providing evidence-based scenario comparisons to promote sustainable land use practices, biodiversity conservation, and landscape management.

In addition to climate change modelling not discussed here, various biodiversity-related models can assist in conservation planning and land use decision-making processes. Species Distribution Models, or SDMs (Elith and Leathwick 2009) and Habitat Suitability Models, HSMs, often using the popular maximum entropy MaxEnt model (Phillips et al. 2006; Elith et al. 2011), predict species' potential distribution or habitat suitability for specific species based on environmental variables. Connectivity models evaluate landscape connectivity for wildlife movement and dispersal, guiding the design of ecological corridors and habitat networks, for example, [Circuitscape](#) based on circuit theory, (McRae et al. 2008, 2016); or approaches based on the graph theory and network analysis (Urban and Keitt 2001), for example, [Conefor 2.6](#), (Saura and Torné 2009) (see also Box 5). All these models guide conservation strategies to maintain population viability and help prioritise conservation or restoration areas (Saunders et al. 2023). Together with land use and land cover change models, they assess the impact of land use changes on species populations, assisting in scenario planning. Finally, ecosystem services modelling quantifies and maps the benefits provided by ecosystems, informing sustainable development that considers both ecological and human well-being aspects. The next section addresses them in more detail since biodiversity often mediates them.

### Box 5. Graph Theory and Circuit Theory approaches to connectivity

Graph Theory conceptualizes the landscape as a network where habitat patches are nodes and dispersal pathways are edges. This framework, introduced into landscape ecology by Urban and Keitt (2001), allows for the assessment of connectivity by calculating metrics such as patch importance, shortest paths, and network cohesion. It is especially useful for evaluating which patches or corridors are most critical for maintaining overall connectivity, often using binary representations (connected or not) of movement potential.

In contrast, Circuit Theory, implemented in tools like Circuitscape, models the landscape as an electrical circuit (McRae et al., 2008). Here, the matrix is treated as a resistive surface, and animal or gene movement is analogized as electrical current flow. This approach accounts for multiple, probabilistic pathways, not just the single least-cost route. It is particularly powerful for identifying movement bottlenecks and for modeling connectivity under uncertainty or heterogeneity in the landscape.

Together, these two methods offer complementary perspectives: Graph theory excels at network structure analysis and priority setting, while circuit theory captures diffuse flow dynamics and redundant pathways, both of which are vital for conservation in fragmented or changing environments.

Source: Authors

The ecosystem services (ES) concept has garnered significant attention in recent years. ES are the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being, that is, the benefits people derive from functioning ecosystems (Costanza et al. 1997; Millennium Ecosystem Assessment - MEA, 2005). It is essential to distinguish between ecosystem processes and functions, on the one hand, and ecosystem services, on the other (Costanza et al. 2017).

The MEA 2005 proposed the following categorization into four broad types, which were adopted but slightly modified in The Economics of Ecosystems and Biodiversity project (TEEB 2010): provisioning (food, water, timber, genetic and medicines resources, agrobiodiversity), regulating (climate regulation e.g. temperature, precipitation, greenhouse gas; water regulation, run-off flooding; erosion; water purification; pollination), supporting (photosynthesis, primary production, C sequestration, water and nutrient cycling, genetic diversity, provision of habitats), and cultural services, or non-material benefits that people can obtain from ecosystems (spiritual enrichment, recreation and aesthetic values).

Ideally, the types of ecosystem services (ES) to be assessed and monitored should be decided collectively by the stakeholders, acknowledging that work on some of the ES mentioned above is often challenging in poor data regions. In such areas, the most likely ES to be available are the provisioning and supporting services. The most accessible supporting service will be carbon sequestration due to the plethora of carbon REDD+ projects in recent years. Habitat provisioning is also an option.

Habitat provisioning by forests and other natural or human-made vegetation for multiple taxa and trophic levels is considered an essential ecosystem service, positively influencing forest ecosystem functioning. There is an issue of definition, although linked with scale: for some, 'habitat' means considering forest vs. grassland and agriculture fields at the landscape level. For others, it could mean the various land facets within a forest (lower-, mid- or upper slope, ridges) or even within the structure itself of the forest

(undergrowth, canopy, niches, microhabitats). Here, we prefer to use 'vegetation types' at the landscape level and consider 'habitat' within each vegetation class assessed in point 1.1.

Many ES modelling and valuing tools exist (Bagstad et al. 2013); the most commonly used are Integrated Valuation of Ecosystem Services and

Tradeoffs (InVEST), Artificial Intelligence for Ecosystem and Sustainability (ARIES) and Toolkit for Ecosystem Service at Site-based Assessment (TESSA) (see Box 6).

### Box 6. Most used Ecosystem Services modelling and valuing tools

InVEST (now version 3.9.) is a free software developed by the Natural Capital Project (a partnership between the universities of Stanford and Minnesota in the United States). It offers biophysical and/or monetary indicators for EGS using an approach based on ecological production functions. Typical inputs include land-use and land-cover (LULC) maps, climate, topographic and soil data. The InVEST tool has been applied in various locations worldwide, mainly to compare future land use scenarios under different policies. InVEST is modular, relatively easy to run, and does not require programming knowledge but basic to intermediate skills in GIS software. <https://naturalcapitalproject.stanford.edu/software/invest>

More complex, ARIES is an artificially intelligent modelling platform that chooses which models to run in response to a user query, based on the Knowledge Laboratory (k.LAB) technology: an AI-powered and digital software for rapid ecosystem service assessment and valuation. ARIES is well suited for land use planning, spatial mapping and quantification of ecosystem services, spatial economic valuation of ecosystem services, or optimization of payment schemes for Ecosystem Services (PES). It has been recently adopted by the Statistics Division of the UN Department

of Economic and Social Affairs (UN DESA) and the UN Environment Programme (UNEP) as the SEEA Explorer platform. <https://aries.integratedmodelling.org>. Bagstad et al. (2014), Balbi et al. (2015), and Willcock et al. (2018) provide examples.

TESSA (v.3) has been developed to determine the ecosystem services to evaluate, the necessary data for their measurement, the appropriate methods or resources applicable in various scenarios, and the subsequent communication of the outcomes. Decision trees are employed to direct users towards particular methods, along with supplementary advice on data gathering and analysis, to enhance user-friendliness. However, because sites vary widely, methods are designed as templates only, and users need to adapt the methods according to local conditions (Peh et al., 2013). It is presented as being more accessible to non-experts and conservation practitioners than InVEST and ARIES. <https://birdlife-hatch.org/topics/30877/page/assessing-ecosystem-services-tessa>

Source: Authors

## 2 Biodiversity Monitoring at the Local Scale

Building upon the recommendations on using conventional biodiversity science in the preceding section, this second part of the guidelines shifts towards participatory research and practical applications. Assuming that relevant local government officials and community actors have been engaged in identifying their priorities and needs, this section aims to propose field tests of participatory methods in biodiversity assessment across multiple communities. By field-testing these methods at the grassroots level, the objective is to generate insights that will inform subsequent discussions and decisions on collaborative implementation strategies for biodiversity conservation in human-modified landscapes. Moreover, this part of the guidelines seeks to establish connections between conventional scientific approaches and traditional knowledge systems, fostering an all-inclusive understanding of biodiversity conservation practices. IPLCs' perceptions of biodiversity are deeply tied to their cultural, spiritual, and practical relationships with nature. Understanding these perspectives can enrich global biodiversity frameworks and highlight the importance of integrating traditional ecological knowledge into conservation efforts.



## 2.1 Participatory mapping, perceptions and folk classification of the ecosystems and biodiversity

Initiating a study of landscape perceptions with participatory mapping not only provides valuable insights into how communities interact with and interpret their environment, but also promotes community engagement. This inclusive approach respects local knowledge systems, fostering a sense of ownership and pride among community members. This, in turn, can lead to more holistic and culturally sensitive research outcomes, enriching the understanding of the landscape and its significance to the community (Lynam et al. 2007).

Participatory mapping (Lynam 2001; Chambers 2006) should follow the general principles set out by the International Fund for Agricultural Development (IFAD) (2009) and consider recommendations made by Denwood et al. (2022) and Braslow et al. (2016) when linked to communities' perceptions of ecosystem services. In addition, when specifically using drones, one should consider further recommendations from Millner et al. (2023) and the [UAViators code of conduct](#) (n.d).

While drones have been extensively used in ecology (see section 1.3. above), they have been less used on the socio-political front. They are often associated with surveillance, ethical concerns, and potential amplification of conflict dynamics and social exclusion (Sandbrook et al. 2021; Millner et al. 2020; Jackman et al. 2023), e.g., as tools for political interventions against land grabs by palm oil and mining companies and counter-mapping (Radjawali and Pye 2017; Radjawali et al. 2017). However, they have been used with success for community-based monitoring and participatory mapping (Paneque-Gálvez et al. 2014, 2017), including situations when communities are entirely in control of the tool (see the 'community drones' of Vargas-Ramírez and Paneque-Gálvez, 2019).

Below is a basic protocol for drone participatory mapping linked to knowledge co-production, folk classifications, perceptions of landscape, ecosystem services and biodiversity. This protocol aims to bridge the gaps between scientists and local knowledge, which is crucial for efficient landscape and biodiversity monitoring.

### 2.1.1 Participatory mapping initial steps

The first field visit for a participatory mapping exercise is often conducted with customary leaders and elders to understand how they perceive their territory and land use's position in the landscape.

A general base map (approximate 1:10,000 in scale) can be prepared in advance (satellite image, Google Earth print) and brought to this first visit, depicting neighbouring villages, roads, principal rivers and mountain peaks around the village(s). Whenever possible, apply geo-referenced border points to this base map so as to train local communities to eventually use GPS. This first approach aims to gain a basic understanding of the village's boundaries, activities, history, and socio-economic situation. After the introductory tour, a village meeting is organized to explain the objectives and methodology of the mapping project and obtain Free, Prior and Informed Consent (FPIC) (see Box 7). Neighbouring villages must also be informed.

In the second visit, an initial scoping survey in the field should be carried out with knowledgeable community members who can share local traditional ecological knowledge of the landscape and its vegetation. Local 'experts' can be identified with the help of community members, leaders, and informants from local NGOs already working in the area, eventually supplemented by snowball techniques (Bernard 2002) to find other informants. These village experts will become key informants for different landscape topics, such as forest types and land use, tree diversity, and medicinal plants. They can also help create a calendar of agriculture and other main subsistence activities (for instance, in conjunction with activities in section 2.2.i below).

Without a drone, sketch mapping is produced at that stage (see Appendix 3.1.). If a drone is available, flying missions can then be organised with community members' participation.

### Box 7. Free Prior and Informed Consent

Free Prior and Informed Consent (FPIC) is a complex concept that lacks a universally accepted definition and can be interpreted differently. This often leads to a gap between international norms and actual practice in different countries.

Still, many international scholars interpret FPIC as ‘the rights of Indigenous People to exercise their right of self-determination under international human rights law instruments such as the International Covenant on Civil and Political Rights.’

For the International Fund for Agricultural Development (IFAD) (2021), *“Free, prior and informed consent is an operational instrument that empowers local and Indigenous Peoples’ communities, ensuring mutual respect and full and effective participation in decision making on proposed investment and development programmes that may affect their rights, their access to lands, territories and resources, and their livelihoods. FPIC is an iterative process solicited through consultations in good faith with the representative institutions endorsed by communities”*.

The Food and Agriculture Organization of the United Nations (FAO) interpreted FPIC as *“a specific right granted to Indigenous Peoples recognised in the UN Declaration on the Rights of Indigenous Peoples (UNDRIP), which aligns with their universal right to self-determination”*. FAO has developed [a manual for practitioners \(FAO 2016\)](#), including a toolkit and eLearning tools.

E-learning: [Free, Prior and Informed Consent \(FPIC\). An indigenous peoples’ right and a good practice for local communities](#), 2016.

Source: Authors

### 2.1.2 Participatory drone mapping

A classic unmanned aerial system includes either fixed-wing or multirotor aircraft, equipped with a 12 to 24 Mp RGB sensor camera mounted on a stabilised gimbal, a lithium polymer battery for power, a radio communication system, and a dedicated controller. On board, most drones also include GPS and various sensors to help avoid collisions and intelligent flight modes that can automatically focus on a point of interest or track a moving subject. Recent developments are towards the use of vertical take-off and landing (VTOL) drones that combine the practicality of vertical take-off and landing and the capacity to transform into fixed-wing craft once into the air, with at present means much longer flight time, higher payload capacity and larger range of operation.

In addition, users will need drone mission planning software, among others, [Mission Planner](#), [DroneLink](#), or [DJI Flight Planner](#) to pre-set fly line patterns. The flying heights range from 120–350 m above ground, depending on topographic conditions and country regulations for using aerial space with drones. Image acquisition should be set up with a front overlap of 75–85 percent and a side overlap of 70–75 percent, following a plan of back-and-forth flight lines (boustrophedonic lawnmower pattern) and the camera pointing straight down (nadir) on all photos (see Appendix 3.2.). In addition, supplementary flights to capture oblique images should be considered because they produce better identification results across all participants (Kleinschroth et al. 2022).

After collecting the orthophotos, specific software is used to analyse the photos and produce orthophoto mosaics (e.g., [Agisoft Metashape](#) ; [Pix4D](#)). A less expensive solution is to use web-based [Maps Made Easy](#)).

### 2.1.3 Final map co-production/folk classification

This orthophoto mosaic (or the sketch map when drone product is unavailable) should be printed on a large document (preferably A3 minimum) and shared with community members as a base map showing the main rivers, roads,

paths, and land uses. The photomosaic should be laid on a large table or floor and oriented towards the north. Community members locate different landscape units and vegetation cover types using this photomosaic, draft them on tracing paper superposed on the photomosaic, and discuss associated specific uses.

Participants could discuss the nature of the tree cover and the various interpretations of such terms as 'forest', 'woodland', 'swamps', 'fallow', 'gardens', and 'food crop fields' and what variations there may be (age, different species mix, different levels of utilization and management). Villagers can draw the borders of their territory indicating potential zones of conflicts, if any (in such a case, no border is drawn); the main natural resources, the different types of land and the related uses, such as fallows, protected areas, etc. Symbols for the various land uses, if applied on the map, should be created before the meeting, following the land-type classification established by the local community during focus group discussions. It is good practice to have men and women divided into two groups, with each group consulted separately, creating two sketch maps (see Appendix 3.3.).

Once the participants' perceptions of the generic categories of land-use types have been identified, each group is asked to describe each land use in detail to identify local subcategories (Vogl et al. 2004). Then, details of activities inside each land-use type are described. This exercise is crucial to collaboratively identifying the different land uses, practices, and vegetation types surrounding the village.

The final maps (women's and men's, either sketch map or interpreted orthophoto mosaic) are brought to the village's general assembly and discussed/commented on. At that stage, the maps can also be merged and legalized, being at scale and representing concrete, realistic views of the community territory to be used in potential land negotiations with developers.

### 2.1.4 Ground checking

The exercise can stop there or continue with a joint ground check organised with community members, recording structural and floristic data for each land use/vegetation. A village meeting should then be organised: first to explain why such measurements are required, aligning with information on the map they co-produce (REDD+ project, land use and management plan, monitoring of changes in the quality of the environment, habitat, local natural resources, etc....see, for instance, Danielsen et al. 2011, who found no significant differences in the estimates of mean above-ground biomass made by community members and by professional foresters).

Community members are then trained by a specialist (from a university, NGO, or forester) to establish plots, measure tree diameter, estimate height, and record and name tree species encountered. The techniques used do not differ much from the academic approach and can align with the participatory recording of the provisioning services in the next section. The plots are generally circular (0.1 ha, radius of the circle equal to 17.85 m, or 0.2 ha, radius equal to 25.23 m; tree diameter above 5 cm) since they are easier to set up with fewer potential measurement errors from non-surveyors. Participants use local names and must be encouraged to not name a tree if they are not certain of its name. Participants can agree together on a proposed name. In case of doubt, they should collect twigs and leaf samples to bring them back to the village for potential further identification by others and, eventually, a botanist at an herbarium. Tree heights can be estimated using cheap clinometers (e.g., a protractor; see Appendix A2.1.).

The training starts with a classroom-type session describing the background for doing the inventory (monitoring of forest carbon, the importance of accuracy), correctly using all equipment for plot delineation and tree measurement, and the applied inventory techniques. Following this first session, all community participants will join in measuring a 'dummy plot' closely supervised by the specialist. Special notice will be given to possible biases and ways to avoid them. The next day, community teams (e.g., two to three teams of three to four members) will split up and do two to three plots

in the forest. Each team will be accompanied by specialist team members, who will supervise the work and offer corrections and suggestions for improvement. All data collected during this training day will be analysed in the evening, discussed, and later discarded so as not to compromise the integrity of the final dataset.

## 2.2 Assessing cultural and provisioning ecosystem services

To supplement participatory mapping while assessing cultural and provisioning ecosystem services, conducting qualitative semi-structured and structured interviews is recommended, supplemented by quantitative methods such as the Pebble Distribution Method (Sheil et al. 2002) and Free Listing (Weller and Romney 1988; Quilan 2017). The Guidelines for the Rapid Assessment of Cultural Ecosystem Services (GRACE), described in Infield

et al. (2015), provide guidance on other important tools such as timelines, cultural calendars, ranking exercises, photovoice and photochoice, and exploring responses to attitude statements (Likert scales).

### 2.2.1 Semi-structured interviews, Timelines and Cultural calendars

Semi-structured interviews with the same people who participated in the scoping survey, or with randomly chosen new people – for example, 15 to 30 farmers – can be used to identify local landscape management practices. A set of questions covers the attributes of farms and information on management practices, from creating a new farming plot to permanently established or temporary agricultural land uses. Other questions can address harvests, plant diseases, and problems (for instance, changes in seasonal patterns). Following the procedure recommended by Vogl et al. (2004), interviews can also cover identifying the local uses of tree species. Walking through the owners' fields/gardens with him/her during each



interview is a must since it will enhance the reliability of the information. For commercial species, record the sales prices and market locations.

In addition to the history of the settlement (Adriansen 2012) and cultural calendar, it is essential to learn about the plot's history, including when it was opened for the first time, under forest cover or not, whether it was under a fallow cycling system, and how many times it has been cultivated.

### 2.2.2 Scoring exercises on the perception of land categories and overview of which type of land is valued for what kind of use

Focus group discussions (FGDs) using the Pebble Distribution Method (PDM) as a scoring exercise (Colfer et al. 1999; Sheil et al. 2002) are organized for four different participant groups, each with six to ten individuals. These should include young men (under 35 years old), older men (over 35 years old), young women (under 35 years old), older women (over 35 years old). The purpose is to value the importance of land categories and main natural resource uses (see forms labeled data sheets (DS 1, DS 2 and DS 3 in Appendix 4.1 to 4.3), and quantify the relative perceived value of each land use, according to gender and age. The PDM method is a flexible, simple diagnostic scoring procedure that clarifies participants' understandings and priorities. The results of DS 2 and DS 3 are used to build the matrix of DS 4.

Participants distribute 100 pebbles among cards representing the different land use systems, the most important land use having the highest number of pebbles. Then, the participants will be asked to place the pebbles on the land unit cards according to their relative importance regarding income (see Appendix 4, data sheet 4). Different land uses and land cover are rated for the following functions: income, overall use category, and individual use categories (food, medicine, market, traditional ceremony, livestock, agriculture, firewood, fodder, construction, basketry, mining, hunting, fishing, fruit trees, charcoal, among others); and livelihood (hunting, agriculture, livestock, fishing, non-timber forest products (NTFP) sales,

healing, timber selling). Finally, the villagers are also asked to distribute the pebbles on cards expressing their perceptions of the forest's present, past and future (Appendix 4, data sheet 5).

### 2.2.3 Free Listing

Free listing is a structured interview method used in cognitive anthropology, ethnobiology and socio-ecological research to elicit systematic data on 'cultural domains' (Quinlan 2005, 2017). A 'cultural domain' is an organized set of words, concepts or sentences comprising a single mental category or semantic domain (Weller and Romney 1988).

The free listing interview consists of asking the respondents to create an inventory of all the items they know within a given category (domain), uncovering the most culturally salient items of the domain (based on their frequency of mention across lists and their rank of citation within lists), see Smith and Borgatti (1997), Sutrop (2001) and Quinlan (2017). The two most important results from the free listing are the frequency and order with which each item is cited across all respondents. According to cognitive anthropology, items mentioned frequently and near the top of the lists are culturally important. Also of interest are the differences in list length and content, which reveal intra-cultural variations in respondents' knowledge (Quinlan 2005).

For most coherent domains, having 20 to 30 informants is usually sufficient (Weller and Romney 1988). Respondents are asked, for instance, to name wood for house building, landscape or land use features, medicinal plants from the forest, wildlife, diseases, etc. For biodiversity and ethnobiology, this approach provides an idea of what species are culturally significant to a person (Borgatti and Halgin 1998) and what species the villagers know best or generally use most. The informants, 10 to 12 men and 10 to 12 women are randomly chosen, with the goal of including two to three persons per age class (under 30, 30–45, 45–60, over 60 years old) to represent all ages of the society.

All growth forms (not only tree species) and wildlife can be included in the free-listing exercise for different land uses to capture all the biodiversity that communities use. This method makes it possible to collect supplementary data about local uses of species in forests, fallows, mixed gardens, for example, and to identify other critical valuable species. It can start with broad items ("all the plants you can think of"), then narrow the domain in additional interviews ("all the medicinal plants you can think of in the forest", a process often called 'successive free listing' (see Brewer 2002).

The data can be analysed using cultural domain analysis software, such as ANTHROPAC v. 4.98 (Borgatti 1989) in combination with Excel (Smith 1993) or using the online, open-source software for free-list analyses Free-List Analysis under R Environment (FLARES) using Shiny, (Wencelius et al. 2017). Its initial version, called FLAME, was reviewed by Borgatti (2015).

Using the FLARES tool, the differences in species cited between the different gender and age groups are analysed. FLARES can identify duplicate items in the same list and analyse data saturation to determine when enough data has been collected. FLARES can calculate two salience measures, Smith's S (Smith and Borgatti 1997) and the Sutrop index (Sutrop 2001). It highlights the psychologically or culturally important tree, medicinal plant species or wildlife, differentiation in species choice, and the degree of importance according to gender. Species with the greatest salience are those that respondents list the most often and tend to recall before other species (Borgatti and Halgin 1998). FLARES not only places statistical weight on the rank of each species in the list but also on the overall length of each list. Species named by at least two informants are considered, and the ten highest Smith S values from the men and the women are identified.

To quantify the qualitative differences between species listed by men and women, a similarity index (measured in percent) can be calculated for each use. Then, the composite salience value of each species for each use can be determined separately for men and women. For each use, and for

men and women, a bar graph or a scree plot can be created, showing the species classified in descending order of composite salience value, thus setting out the highly salient, salient and less salient species based on the observation of salience thresholds (Quinlan 2005, 2017).

The recommended format for preparing the data to be analysed by FLARES is in Appendix 4.4.

### 2.2.4 Photovoice

Photovoice gives a voice to people with limited power due to age, poverty, language barriers, gender, culture or other circumstances. People involved in Photovoice learn to reflect on their own experiences and to capture these experiences in photos accompanied by narratives that explain how the photos highlight a theme. This process allows individuals to speak out to generate data for research, advocacy or communication purposes, which can eventually be used to reach out to stakeholders and spur positive change.



Photo by Malaika Yanou/GIFOR-ICRAF

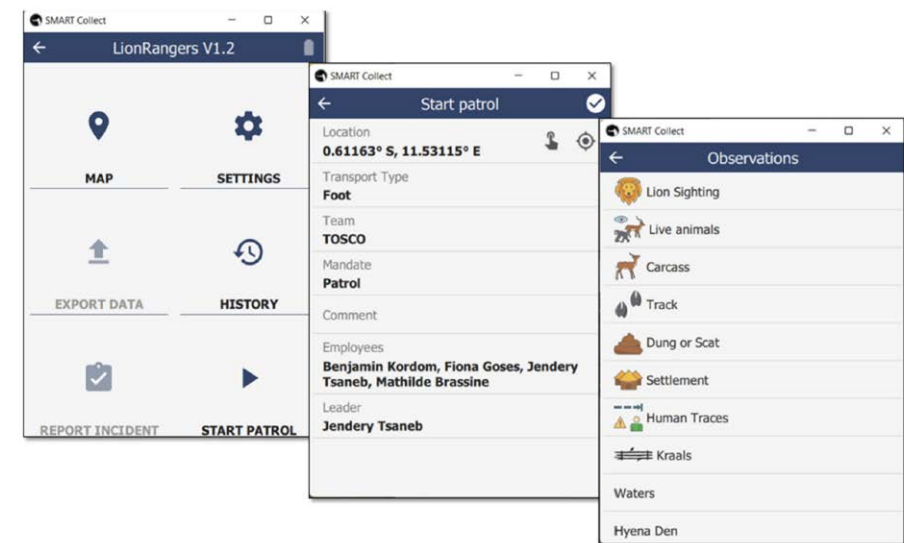
## 2.3 Develop a citizen science approach

Citizen science, also referred to as community science or participatory research, is the practice of engaging the public in scientific research and monitoring (MacPhail and Colla, 2020; Theobald et al. 2015). It encompasses many disciplines from biology to astronomy, and people of all ages, abilities, and backgrounds can participate in these projects. Currently, there are numerous citizen science projects across the world, and they are rapidly gaining recognition for their potential to democratize science and support effective conservation (Couvet and Prevot 2015; Pocock et al. 2019; Skarlatidou et al. 2020).

Citizen science is a powerful tool for collecting information on natural resources and biodiversity trends at both local and landscape levels (Poisson et al. 2020). Data from citizen science projects can help answer questions related to the abundance, distribution, and behaviour of species, their habitats, and ecosystems (Bowser et al. 2020; Callaghan et al. 2020). It can help large-scale projects by increasing the spatial and temporal scope and the rate of data with minimal cost (MacPhail and Colla 2020).

Citizen science also increases awareness, knowledge, and skills among participants. The outcomes can vary depending on the projects, but participation can increase understanding and interest in science. Increasing public engagement and nature-based experiences can also help people connect with nature. Participation provides societal benefits by developing local capacity for biodiversity surveys and by informing and empowering local people to manage biodiversity (Couvet and Prevot, 2015). Thus, citizen science helps identify and prioritise conservation and management actions (Fraisl et al. 2020; Villaseñor et al. 2016). It has been argued that citizen science projects that address real-world problems have greater potential to impact public understanding (Pandya 2012; Senabre Hidalgo et al. 2021). Biodiversity is often not perceived as an immediate priority by communities facing livelihood challenges and limited economic resources, and this can be an obstacle that citizen science initiatives may help address.

Implementing a citizen science approach requires careful and strategic planning. Although it can be an effective tool for scientific data collection and engagement, its success relies on ongoing support and engagement with the participants (Tweddle et al. 2012) and good knowledge of the potential limitations of the data (Snäll et al. 2011; Balázs et al. 2021; Fraisl et al. 2022). Depending on the context, the following three main approaches (Bonney et al. 2009; Shirk et al. 2012; Bonney et al. 2014) can be adopted for conducting citizen science projects, although many consider only two: contributory or co-created. Tools that support such initiative are given in Table 2.



**Figure 5. Rangers' use of SMART for lion conservation (Brassine 2024).** The SMART (Spatial Monitoring and Reporting Tool) platform consists of a set of software and analysis tools designed to help conservationists manage and protect wildlife and wild places (<https://smartconservationtools.org/en-us/>).



### Contributory project model

The contributory model of citizen science (Fraisl et al. 2022) is researcher-driven and focused mostly on large-scale data collection by volunteer participants, who primarily collect data according to clearly defined guidelines. This approach is suitable for engaging diverse participants, raising awareness of an issue, and gathering large volumes of data over a wide geographic area. However, it is driven by scientists' needs rather than the participants. It is suitable for landscape-level monitoring using global citizen science tools such as GBIF, eBird, Zooniverse, or iNaturalist (see Box 10).



### Collaborative project model

This approach also includes projects designed by scientists, but participants are involved in more than one stage of the scientific process, such as developing research questions or analysing data. For instance, a team of local community members, such as a group of school teachers, can be trained to design and implement biodiversity surveys and collect quality specimens of plants, birds, and insects documented by photographs and their classes. An excellent example of such a collaborative citizen science model has been recently developed in Kalimantan, Indonesia, where local communities were actively engaged in biodiversity monitoring design, data collection, and adaptive feedback (Omar et al., 2025).



### Co-created project model

Fully co-created projects are still rare (Senabre Hidalgo et al. 2021). Such projects are designed collaboratively by scientists and local communities who co-create a research programme that builds on participatory social sciences approaches or social concerns expressed by diverse groups of citizens (Bonhoure et al. 2019). The project team should include representatives from different stakeholder groups and work together to define goals and methods to collect and analyse data. The Cybertracker and Sapelli applications are probably the best development tools available today for such co-created projects (see Moustard et al. 2021 and the development of 'Extreme Citizen Science').

None of these models is better or worse than the others. Still, as one of the main principles of ILAs is to make it as collaborative as possible; that is, collaborative and co-created approaches are the approaches of choice for ILAs.

For more details on the various steps for developing and implementing a citizen science project, see the Tweddle et al. (2012) Guide to Citizen Science.

**Table 2. Potential citizen science tools for biodiversity monitoring**

| <b>Apps</b>                                                                                                   | <b>Details</b>                                                                                                                                                                                                                                    |                             |
|---------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b><u>PlantNet (the App)</u></b>                                                                              | For identifying and monitoring plants <a href="https://identify.plantnet.org">https://identify.plantnet.org</a>                                                                                                                                   | Contributory                |
| <b><u>iNaturalist</u></b>                                                                                     | For monitoring varying taxa <a href="https://help.inaturalist.org/en/support/solutions/articles/151000170805-inaturalist-teacher-s-guide">https://help.inaturalist.org/en/support/solutions/articles/151000170805-inaturalist-teacher-s-guide</a> | Contributory                |
| <b><u>ebird</u></b>                                                                                           | For monitoring birds (For eBird best practices see Strimas-Mackey et al. 2023)                                                                                                                                                                    | Contributory                |
| <b><u>zooniverse</u></b>                                                                                      | A popular platform for volunteers to assist professional researchers, including projects on nature, plants and wildlife.                                                                                                                          | Contributory                |
| <b><u>iSpot</u></b>                                                                                           | For ecological observations                                                                                                                                                                                                                       | Contributory                |
| <b><u>WhatSpecies</u></b>                                                                                     | Targeted mainly for youth                                                                                                                                                                                                                         | Contributory                |
| <b>Sapelli (<a href="https://www.sapelli.org">https://www.sapelli.org</a>)<br/>(see Moustard et al. 2022)</b> | Citizen Science. Open-source Android app that facilitates data collection across language or literacy barriers through highly configurable icon-driven user interfaces; easily linked to GeoKey                                                   | Collaborative or Co-created |
| <b>GeoKey (<a href="http://www.geokey.org.uk">www.geokey.org.uk</a>)</b>                                      | GeoKey provides server-side components to run participatory mapping projects                                                                                                                                                                      | Collaborative or Co-created |
| <b>ArcGIS Survey 123</b>                                                                                      | For creating and sharing surveys and analyzing results. Create forms, collect data using web or mobile devices, even when disconnected from the internet. Analyze results on the web or in an ArcGIS app.                                         | Collaborative               |
| <b>Avenza map</b>                                                                                             | Mobile map app (Android and iOS) that allows to download maps for offline use                                                                                                                                                                     | Collaborative               |
| <b>EpiCollect 5 app</b>                                                                                       | A mobile (Android and iOS) & web application for free and easy data collection Take pictures, audio recordings etc                                                                                                                                | Collaborative               |
| <b>ODK (Open Data Kit)</b>                                                                                    | ODK is a open-source suite of tools that allows data collection using Android mobile devices and data submission to an online server, even without an Internet connection or mobile                                                               | Collaborative               |

*continued on next page >>*

&gt;&gt; Table 2. Continued

| Apps                       | Details                                                                                                                                                                                                                                                              |                             |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b>Trailmark Mobile</b>    | Mobile data collection app for Android. Ground-truth spatial data in the field, conduct field surveys to document land use and observations with real-time data, including voice recordings, photographs, GPS tracks.                                                | Collaborative               |
| <b>KoboToolbox</b>         | Free (for NGOs) open-source tool for mobile data collection, management, and visualization                                                                                                                                                                           | Collaborative               |
| <b>ArcGIS Collector</b>    | Mobile data collection app (Android and iOS) to collect data in the field and syncing it with ArcGIS Online and ArcGIS Field Maps                                                                                                                                    | Collaborative               |
| <b>CyberTracker Online</b> | CyberTracker Online is the online version of CyberTracker Classic, a Windows desktop application combine with an Android and iOS CyberTracker mobile application. For mobile data capture and visualization. It supports form design, data management and reporting. | Collaborative or Co-created |
| <b>Device Magic</b>        | Smart data collection app                                                                                                                                                                                                                                            | Collaborative               |
| <b>GeoCache</b>            | GPS tracking and marking location                                                                                                                                                                                                                                    | Contributory                |

Source: Authors; see also Burnett et al. 2023

## 2.4 Compensation, Rewards, and Incentives in Participatory Research

Citizen science emphasizes the importance of community engagement, but it also presents a common dilemma in participatory research: how should local participants be compensated for their time, expertise, and efforts?

Scholars are divided on the practice of paying local communities for participating in research programmes. Based on the social beneficence principle, ethical perspectives highlight a *prima facie* moral obligation to compensate participants (Izquierdo-Tort et al. 2024). Sigouin et al. (2025) emphasize that effective resource co-management, including dedicated funding mechanisms, is essential for building trust, promoting education, and ensuring sustainability in participatory monitoring. Given this ongoing debate in participatory research, three best practices are recommended:

- Clearly document at the beginning of the project which financial category will be used (incentive, reward, or reimbursement), involve communities in choosing the type and amount of compensation, and include all in the FPIC forms.
- Avoid excessive remuneration that could coerce participation, threaten voluntary consent, or cause jealousy among non-participants.
- Recognize that non-monetary benefits, such as capacity-building, are often highly valued and should be part of the compensation package.

Transparent compensation practices will ultimately build trust with local populations, strengthening the sustainability of participatory biodiversity monitoring in ILA.



Illustration by Komarudin

# Conclusion

The guidelines presented here provide a comprehensive framework for practitioners engaged in ILAs, offering a structured approach to assessing and monitoring biodiversity resources within a landscape. Following these guidelines, practitioners can generate high-quality data essential for informed decision making in collaborative and integrated biodiversity conservation, management, development, and policy actions. Utilising these data collection and monitoring protocols will support the following key research questions and outputs necessary for the design and implementation of ILAs:

- How to effectively integrate biodiversity values into policies, planning, and development processes, fostering cross-sector collaboration and mainstreaming values at various scales;
- How to ensure inclusive and equitable participation in decision making concerning biodiversity and resource rights, promoting stakeholder engagement and empowerment;
- How to guarantee the availability of quality information, including traditional knowledge, to decision makers and the public, facilitating effective biodiversity management through awareness, education, and research initiatives?

Adopting these guidelines and protocols will facilitate connections between conventional scientific approaches and traditional knowledge systems, fostering sustainable landscapes that balance ecological integrity with socio-economic development. By incorporating these practices into ILA initiatives, practitioners can enhance landscapes' resilience and long-term sustainability while promoting biodiversity conservation and community well-being.



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# Appendices



Illustration by Sadewa

# Appendix 1. Plot Establishment

## A 1.1 Large landscape survey

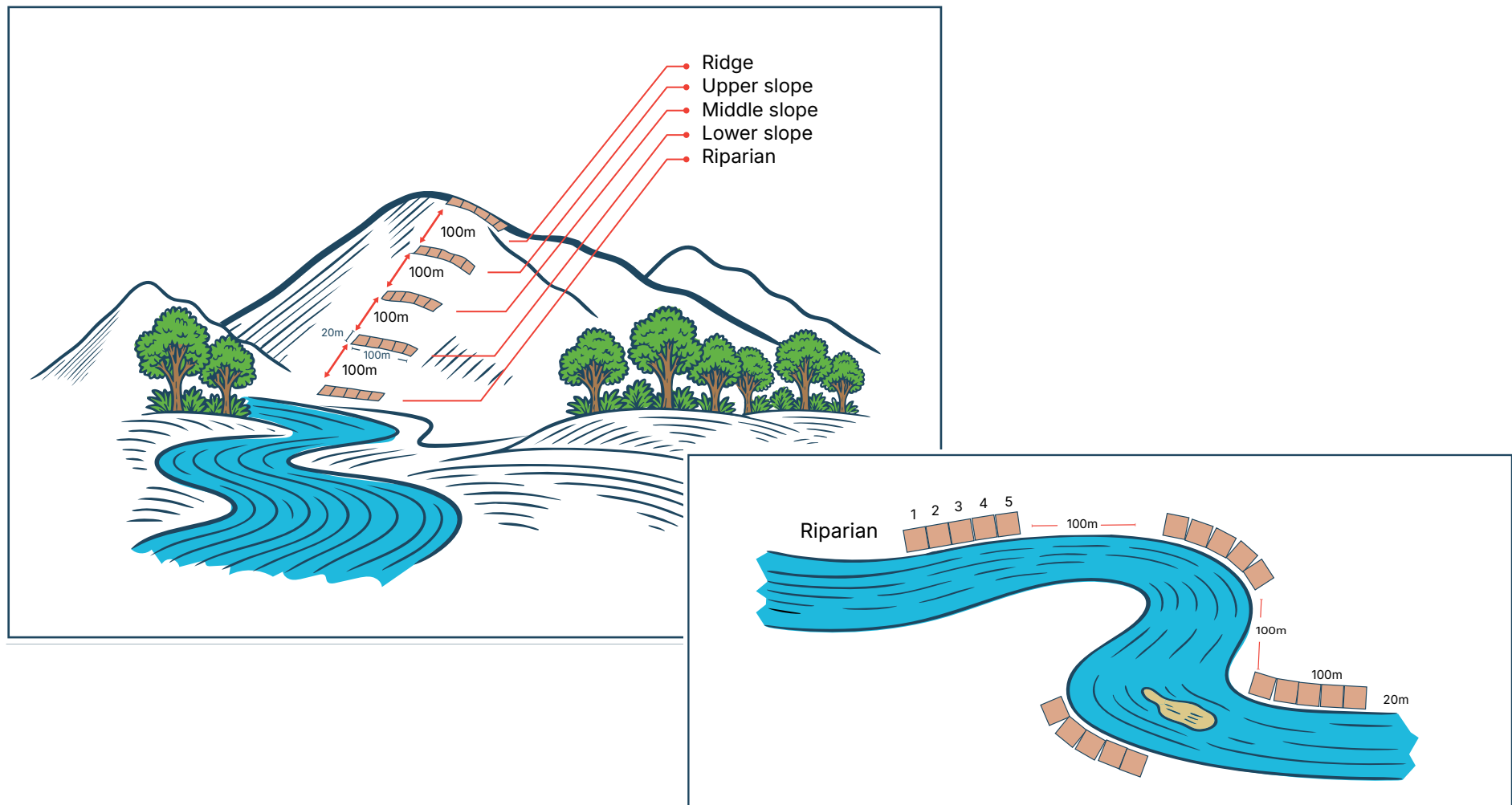
To understand the overall composition of a landscape, it is often more effective to start with a network of small plots (e.g. 0.2 ha, 20×100 m) distributed across the area, usually chosen through a stratified sampling method based on the land unit identified via remote sensing (see Box 4 in the main text). This sampling approach gives a representative overview of the different vegetation types and their spatial arrangement. Once this broader picture is in place, targeted permanent plots of one hectare (100×100 m) can be used to examine specific vegetation types in more detail, allowing for a deeper analysis of their structural features and internal ecological processes, especially in complex systems such as forests.

A good practice is to lay these plots along transects, covering land facets (riparian, lower slope, mid -slope, upper slope, ridge). Each plot, following contour lines, is about 100 m apart, and various transects are separated by at least 200 m (Figure A1). Ideally, this is the work of four persons (including one botanist).

Slope correction is conducted to ensure that the quadrats and final plot correspond to a horizontal projection (Slope correction:  $1/\cos \arctan (\% \text{ Slope}/100)$ ). A correction is made every 10 m if the slope is homogeneous, or 'broken' down following rough topography (see Table A1). Slope correction is optional when <5% slope, but becomes essential for steeper topography.



Photo by Yves Laumonier/CIFOR-ICRAF



**Figure A1.** Landscape network of 100 × 20 m plots encompassing land facets (ridge, upper slope, lower slope) and the procedure for riparian plot design

Source: Authors

Table A1. Slope correction table

| Degree | Radians | D slope<br>for 10m<br>horizontal | D for 5m | Degree | Radians | D slope<br>for 10m<br>horizontal | D for 5m | Degree | Radians | D slope<br>for 10m<br>horizontal | D for 5m |
|--------|---------|----------------------------------|----------|--------|---------|----------------------------------|----------|--------|---------|----------------------------------|----------|
| 1      | 0,9998  | 10,00                            | 5,00     | 17     | 0,9563  | 10,46                            | 5,23     | 33     | 0,8387  | 11,92                            | 5,96     |
| 2      | 0,9994  | 10,01                            | 5,00     | 18     | 0,9511  | 10,51                            | 5,26     | 34     | 0,8290  | 12,06                            | 6,03     |
| 3      | 0,9986  | 10,01                            | 5,01     | 19     | 0,9455  | 10,58                            | 5,29     | 35     | 0,8192  | 12,21                            | 6,10     |
| 4      | 0,9976  | 10,02                            | 5,01     | 20     | 0,9397  | 10,64                            | 5,32     | 36     | 0,8090  | 12,36                            | 6,18     |
| 5      | 0,9962  | 10,04                            | 5,02     | 21     | 0,9336  | 10,71                            | 5,36     | 37     | 0,7986  | 12,52                            | 6,26     |
| 6      | 0,9945  | 10,06                            | 5,03     | 22     | 0,9272  | 10,79                            | 5,39     | 38     | 0,7880  | 12,69                            | 6,35     |
| 7      | 0,9925  | 10,08                            | 5,04     | 23     | 0,9205  | 10,86                            | 5,43     | 39     | 0,7771  | 12,87                            | 6,43     |
| 8      | 0,9903  | 10,10                            | 5,05     | 24     | 0,9135  | 10,95                            | 5,47     | 40     | 0,7660  | 13,05                            | 6,53     |
| 9      | 0,9877  | 10,12                            | 5,06     | 25     | 0,9063  | 11,03                            | 5,52     | 41     | 0,7547  | 13,25                            | 6,63     |
| 10     | 0,9848  | 10,15                            | 5,08     | 26     | 0,8988  | 11,13                            | 5,56     | 42     | 0,7431  | 13,46                            | 6,73     |
| 11     | 0,9816  | 10,19                            | 5,09     | 27     | 0,8910  | 11,22                            | 5,61     | 43     | 0,7314  | 13,67                            | 6,84     |
| 12     | 0,9781  | 10,22                            | 5,11     | 28     | 0,8829  | 11,33                            | 5,66     | 44     | 0,7193  | 13,90                            | 6,95     |
| 13     | 0,9744  | 10,26                            | 5,13     | 29     | 0,8746  | 11,43                            | 5,72     | 45     | 0,7071  | 14,14                            | 7,07     |
| 14     | 0,9703  | 10,31                            | 5,15     | 30     | 0,8660  | 11,55                            | 5,77     |        |         |                                  |          |
| 15     | 0,9659  | 10,35                            | 5,18     | 31     | 0,8572  | 11,67                            | 5,83     |        |         |                                  |          |
| 16     | 0,9613  | 10,40                            | 5,20     | 32     | 0,8480  | 11,79                            | 5,90     |        |         |                                  |          |

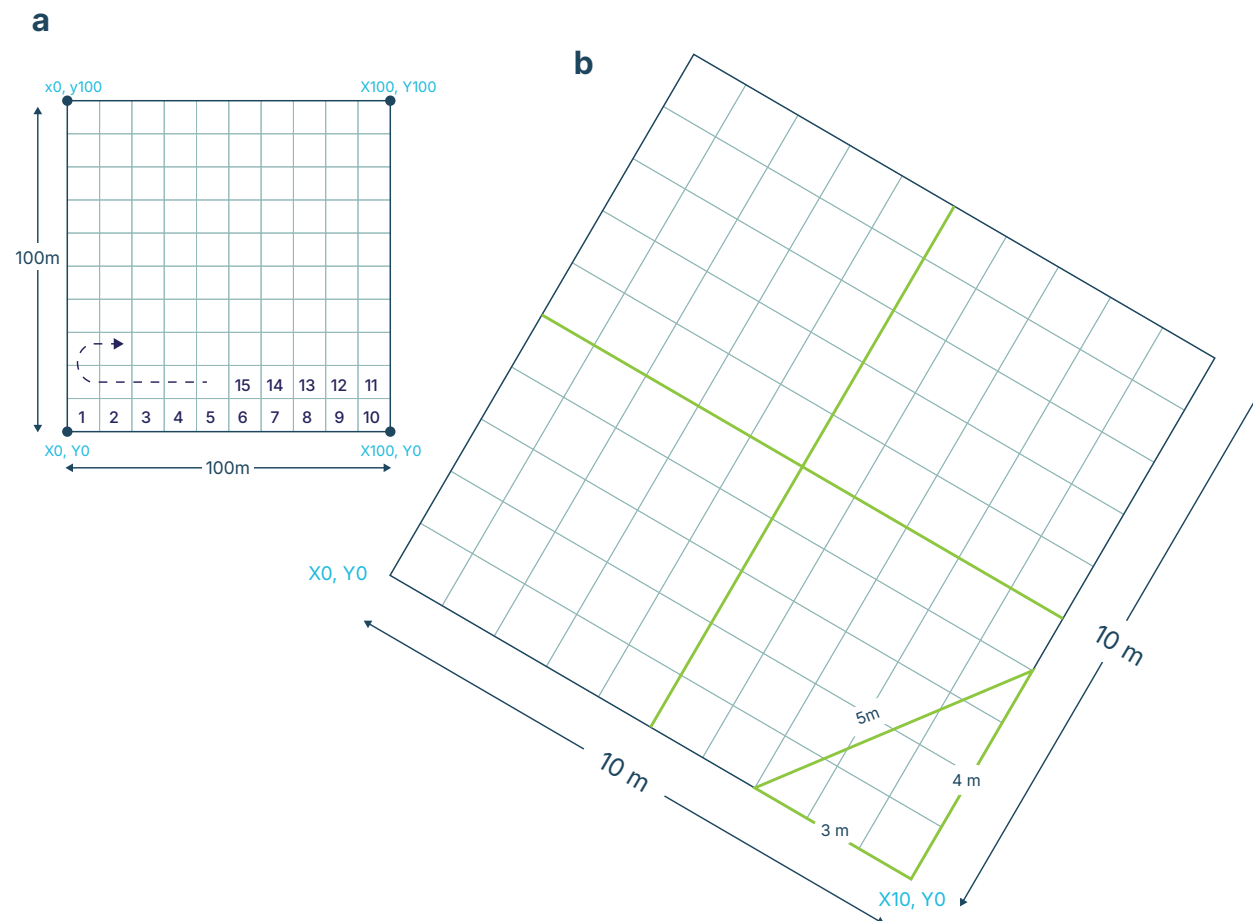
Source: USDA Forest Service. (n.d.). Slope correction table: Elliptical radii for various slopes and 1/100th & 1/50th acre plots. U.S. Department of Agriculture.

## A 1.2 Permanent one-hectare plots

Each 1-ha plot is divided into 100  $10 \times 10$  m quadrats (Figure A2. a). Eventually, each  $10 \times 10$  m quadrat could be further divided into four  $5 \times 5$  m sub-quadrats (to assess undergrowth).

The 1-ha plot is permanently marked on the four corners (at a minimum) with aluminium or iron stakes (to resist fire when working in fire-prone vegetation like tree savannah). Record a GPS point for each corner. The 5,4,3 m technique could be applied to start the first corner at the proper right angle (Figure A2. b)

Each tree is mapped to the nearest centimetre in relation to the quadrat grid in the coordinate plane of the 1-ha plot ( $X_0, Y_0$  to  $X_{100}, Y_{100}$ ). The measured parameters of choice are the diameter at 1.3 m, the height of the tree, the height of the first branch, and crown projection (see Annex 2).



**Figure A2. a) 1-ha plot divided into 100  $10 \times 10$  m quadrats;**  
**b) The 5,4,3 m technique to ensure proper right angle when starting to lay the first quadrat**

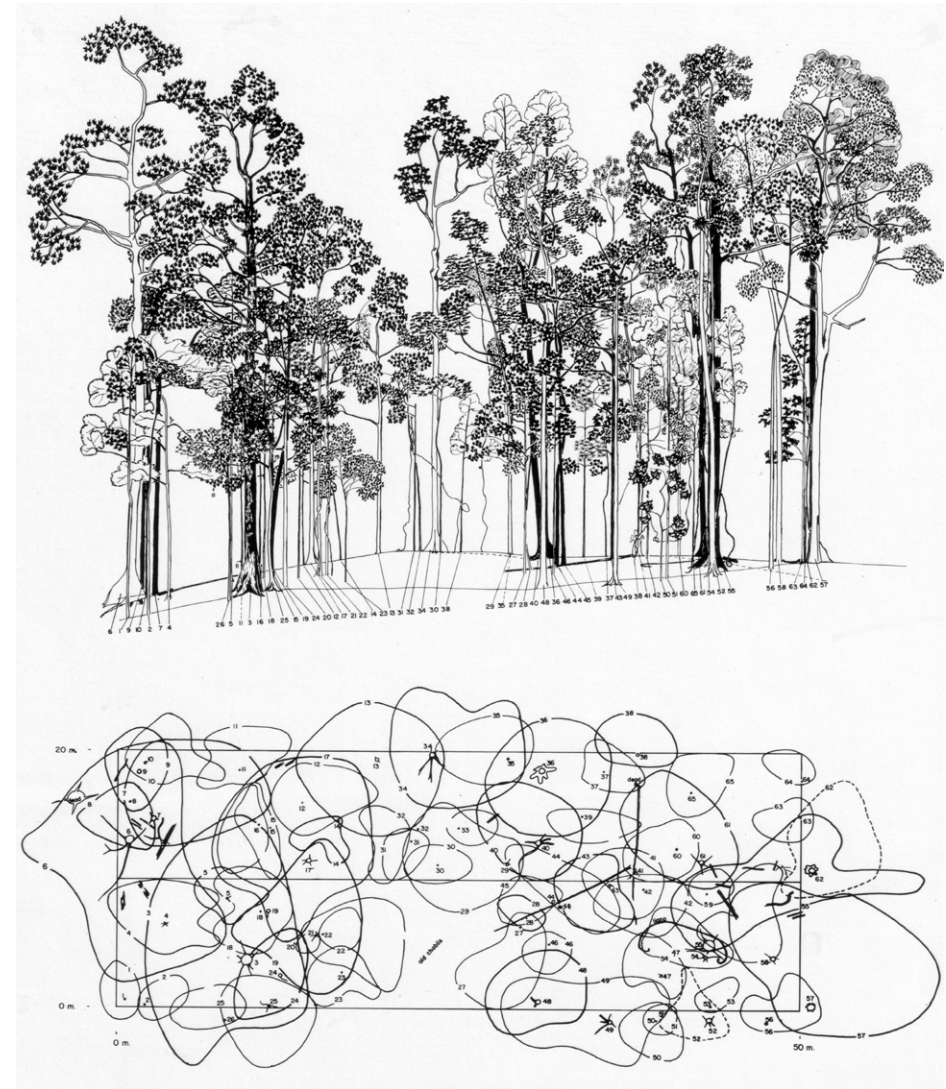
Tree tagging is conducted, preferably with aluminium or zinc and galvanized steel or zinc nails. A line is painted at the point of measurement (PoM) following this procedure: first, an elastic band is put around the tree at 1.3 m above the ground. The diameter is measured adjacent to the bottom of the band. Then, a ring of paint is applied below the band (Photo A1). When remeasured after some years, the diameter measurement will be done at the upper part of the paint ring.



**Photo A1. A ring of paint is applied below an elastic band circling the trunk, after diameter measurement made also just below the band**

Photo by Yves Laumonier

In addition to recording diameter, height, and tree position, mapping the crown projection provides valuable ecological information, offering an alternative lens on dominance that goes beyond the conventional focus on diameter at breast height (DBH) (Figure A3). Incorporating crown height and projection enhances ecological interpretation by capturing structural complexity and can be linked to key parameters such as light transmission through the canopy, Leaf Area Index (LAI), and foliage stratification.



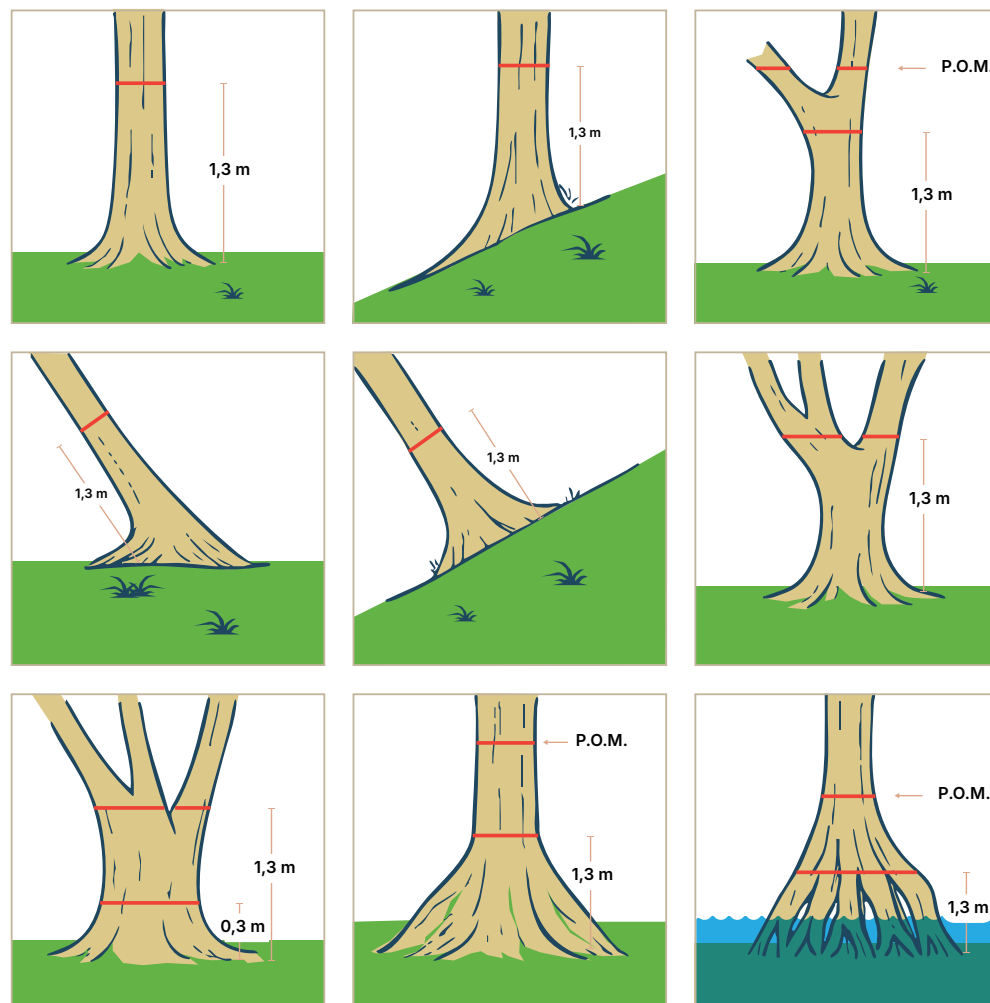
**Figure A3. Tree position mapping (X,Y) and crown projection. Each tree is mapped to the nearest centimetre, relative to the 100 × 100 grid**

Source: Laumonier 1997

# Appendix 2. Tree Measurements

## A 2.1 Diameter at 'Breast Height' (DBH)

Diameter of trees is classically measured at 1.3 m above the ground, following some rules for the point of measurement (POM) as illustrated in Figure A4.

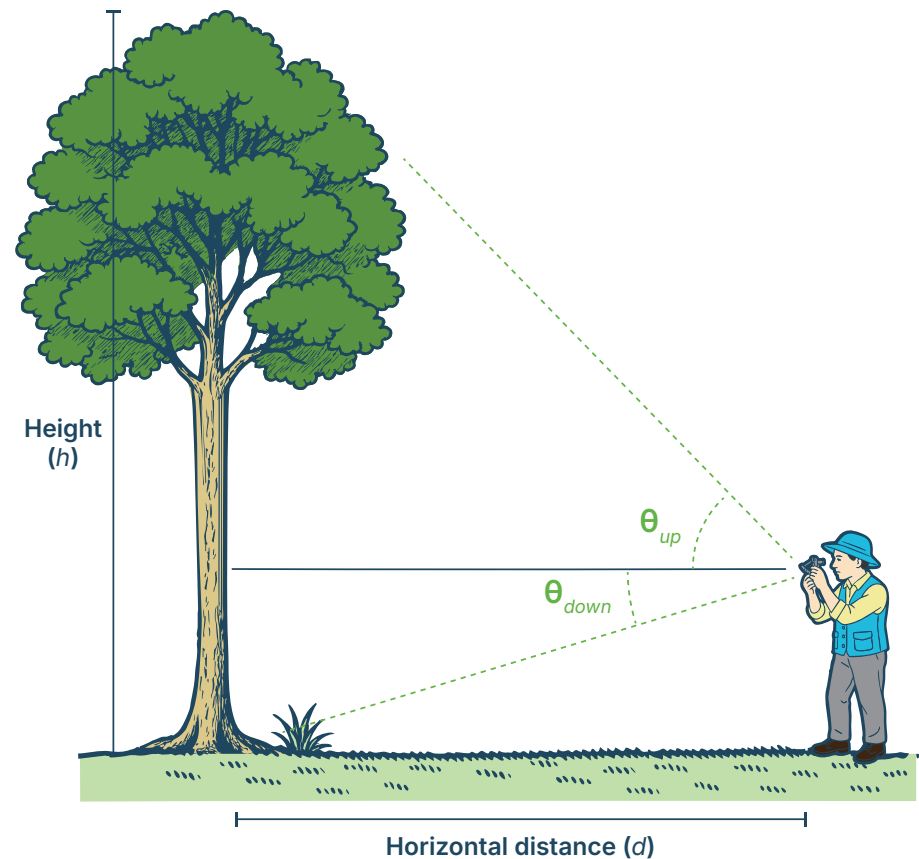


**Figure A4. Diameter, point of measurement (PoM) for various tree base shapes**

Source: Authors

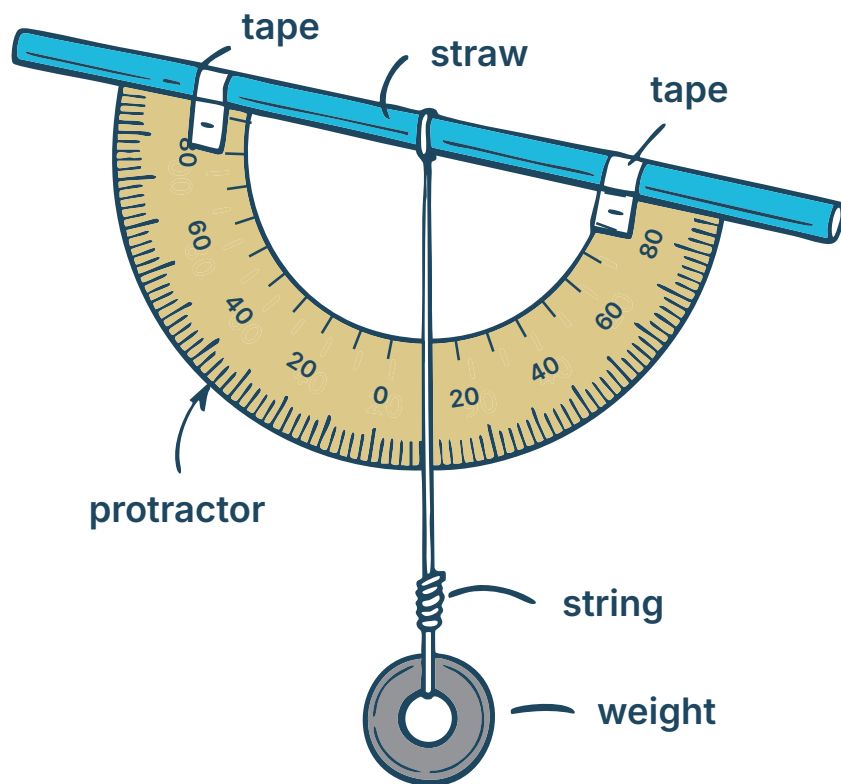
## A 2.2 Tree height

Both total height, and the height to the first branch, are commonly measured with a Haga altimeter or Blume-Leiss hypsometer (Figure A5). In more open environments such as woodlands, a laser rangefinder (paired with a clinometer or an integrated angle feature) provides better accuracy and ease. Increasingly, smartphone apps like Clinometer, Smart Measurement, or Arboreal Height (Android) and Tree Height Measurement (iOS) offer fairly accurate estimates in the field, especially when specialized tools are unavailable. Even a simple protractor can serve as an inexpensive clinometer (Figure A6). Still, it's crucial that users have basic training in proper sighting techniques and angle/distance estimation, and that tools or apps are calibrated or checked periodically against a known reference to ensure the data's accuracy.



**Figure A5. Tree height measurement**

The most employed mathematical technique utilise the tangent of angles and the horizontal distance to measure tree height ( $\text{Height (h)} = d * (\tan \theta_{up} + \tan \theta_{down})$ ). In complicated situations in the field (leaning tree, poor crown shape), the Sine method (Bragg 2007) based on sine and slope is more accurate.



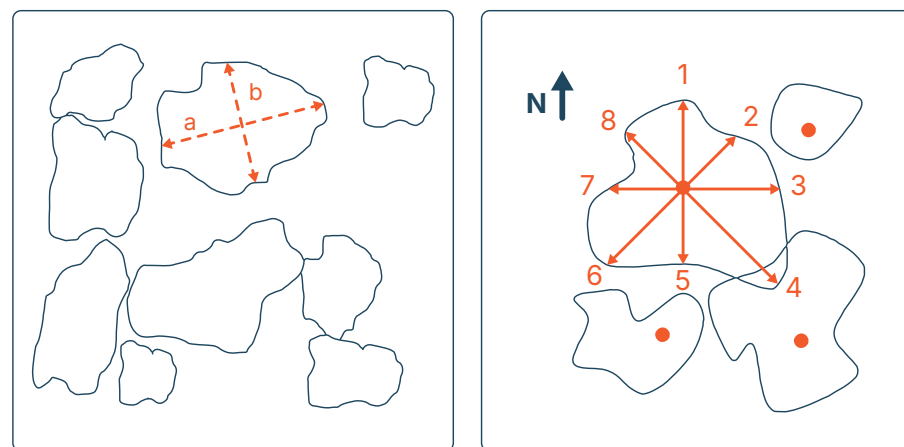
**Figure A6. A basic protractor as a cheap clinometer**

A basic protractor plus straw and string can be used as an improvised clinometer for resource-limited settings.

Source: Authors

## A 2.3 Crown projection

Tree crown size and shape vary with environment, internal forest dynamics, and natural damage like tree falls, dying branches, and crown asymmetry. Ground measurements of tree crowns are challenging and time-consuming. The simplest way to measure crown radii involves bringing a measuring tape from the tree trunk to a person standing below the branch tips in four directions (North, South, East, and West). This method is quite basic and can be improved by using eight directions (N, NE, E, SE, S, SW, W, NW) or by having helpers follow the exact contour of the crown (Laumonier 1997; see Figure 4). When financially possible, an excellent alternative is to use indirect measurement of light penetration through the canopy with hemispherical photography (Trichon et al. 1998; Gourlet-Fleury et al. 2001). Crown volume and shape can now be studied in much greater detail using Terrestrial Laser Scanning (TLS); (see Owen and Lines 2024 for a recent assessment).



**Figure A7. Tree crown projection measurement**

Source: Authors

Table A2. Tree plot Excel template

| Line_code | Plot/<br>Subplot | Tree<br>Nb | X   | Y   | D    | Ht   | Hb   | CA N | CA E | CA S | CA W | Family           | Species                     | Author                    | Local.name     | Herb.ID |
|-----------|------------------|------------|-----|-----|------|------|------|------|------|------|------|------------------|-----------------------------|---------------------------|----------------|---------|
| 1         | 1_1              | 1          | 1,5 | 0,5 | 10,2 | 12,1 | 10,0 | 1,5  | 1    | 1    | 1    | Sapotaceae       | Madhuca motleyana           | (de Vriese)<br>J.F.Macbr. | JELATUN        | NL.1793 |
| 2         | 1_1              | 2          | 2   | 4   | 16   | 16,8 | 12,0 | 3    | 2    | 2,5  | 2,5  | Anisophylleaceae | Combretocarpus rotundatus   | (Miq.) Danser             | ENTAWAR RACUN  | NL.1794 |
| 3         | 1_1              | 3          | 1,5 | 5   | 21,6 | 20,6 | 14,0 | 3    | 3    | 3,5  | 3    | Dipterocarpaceae | Shorea balangeran           | Burck                     | LOAN           | NL.1795 |
| 4         | 1_1              | 4          | 2   | 5,5 | 14,5 | 15,6 | 12,0 | 2,5  | 1    | 3    | 3    | Sapotaceae       | Madhuca motleyana           | (de Vriese)<br>J.F.Macbr. | NYATUK         | NL.1796 |
| 5         | 1_1              | 5          | 2   | 9,5 | 17,6 | 17,9 | 14,0 | 2,5  | 2,5  | 2,5  | 2,5  | Anisophylleaceae | Combretocarpus rotundatus   | (Miq.) Danser             | ENTAWAR KUNING | NL.1797 |
| 6         | 1_1              | 6          | 6   | 9,5 | 21,4 | 20,5 | 16,0 | 2,5  | 3    | 1,5  | 1    | Dipterocarpaceae | Shorea balangeran           | Burck                     | BADANG         | NL.1798 |
| 7         | 1_1              | 7          | 6   | 6,5 | 23,6 | 21,9 | 17,0 | 1,5  | 2    | 1,5  | 1,5  | Penaeaceae       | Dactylocladus stenostachys  | Oliv.                     | AMBUTUN MIANG  | NL.1799 |
| 8         | 1_1              | 8          | 5   | 6   | 14,5 | 15,6 | 14,0 | 1    | 1    | 0,5  | 1    | Dipterocarpaceae | Shorea balangeran           | Burck                     | BADANG         | NL.1800 |
| 9         | 1_1              | 9          | 7   | 5   | 12,1 | 13,7 | 12,0 | 2    | 1    | 2    | 1    | Celastraceae     | Lophopetalum beccarianum    | Pierre                    | TIDAK TAHU 24  | NL.1801 |
| 10        | 1_1              | 10         | 4,5 | 6,5 | 11,3 | 13,0 | 12,0 | 3,25 | 2,5  | 3    | 3    | Clusiaceae       | Garcinia merguensis         | Wight                     | BELANTIK ANAK  | NL.1802 |
| 11        | 1_1              | 11         | 5   | 2,5 | 22   | 20,9 | 15,0 | 2,75 | 3    | 2,25 | 3    | Anisophylleaceae | Combretocarpus rotundatus   | (Miq.) Danser             | AMBUTUN MIANG  | NL.1803 |
| 12        | 1_1              | 12         | 6   | 1,5 | 13   | 14,4 | 12,0 | 2,25 | 2    | 2    | 2    | Celastraceae     | Lophopetalum beccarianum    | Pierre                    | TIDAK TAHU 25  | NL.1804 |
| 13        | 1_1              | 13         | 6,5 | 1   | 12,2 | 13,8 | 12,0 | 3    | 1,75 | 3    | 2,25 | Fagaceae         | Lithocarpus pseudokunstleri | A.Camus                   | AMBUTUN MIANG  | NL.1805 |
| 14        | 1_1              | 14         | 7   | 2,5 | 14,5 | 15,6 | 13,0 | 1,5  | 1,5  | 2,25 | 6    | Anisophylleaceae | Combretocarpus rotundatus   | (Miq.) Danser             | BADANG LOAN    | NL.1806 |
| 15        | 1_1              | 15         | 3,5 | 1   | 10,9 | 12,7 | 12,0 | 1,5  | 1,5  | 1,75 | 1,5  | Sapotaceae       | Madhuca motleyana           | (de Vriese)<br>J.F.Macbr. | JELATUN        | NL.1807 |
| 16        | 1_1              | 16         | 8,5 | 7,5 | 14,2 | 15,4 | 11,0 | 11   | 10   | 12   | 10   | Dipterocarpaceae | Shorea balangeran           | Burck                     | TIDAK TAHU 26  | NL.1808 |
| 17        | 1_1              | 17         | 8   | 7   | 12,6 | 14,1 | 10,0 | 2    | 2    | 3    | 3    | Anacardiaceae    | Mangifera swintonioides     | Kosterm.                  | RENGAS         | NL.1809 |
| 18        | 1_1              | 18         | 7,5 | 7   | 12,3 | 13,9 | 12,0 | 3,5  | 2,5  | 3    | 2,5  | Celastraceae     | Lophopetalum beccarianum    | Pierre                    | KAYU LOLUE     | NL.1810 |
| 19        | 1_1              | 19         | 1   | 10  | 13,5 | 14,8 | 11,0 | 2,75 | 1    | 1    | 3,25 | Penaeaceae       | Dactylocladus stenostachys  | Oliv.                     | AMBUTUN MIANG  | NL.1811 |
| 20        | 1_1              | 20         | 1   | 9,5 | 15,5 | 16,4 | 12,0 | 3    | 4,25 | 3    | 2,75 | Anacardiaceae    | Mangifera swintonioides     | Kosterm.                  | RENGAS         | NL.1812 |
| 21        | 1_1              | 21         | 1,5 | 8   | 18,5 | 18,6 | 13,0 | 2,5  | 3    | 2    | 3    | Dipterocarpaceae | Shorea balangeran           | Burck                     | BADANG         | NL.1813 |

# Appendix 3. Sketch and Drone Mapping Procedures

## A 3.1 Community sketch mapping

The facilitator team (usually two to three or four persons, including a GIS knowledgeable person) divides the villagers into two, three, or more groups depending on the number of participants, with one facilitator per group. Groups are based on gender and age (minimum two groups: men's and women's; or, three groups if adding a youth group).

For each working group:

Ask each group to start by drawing the village resource map: first, put in the locations, such as villages, abandoned villages, graveyards, sacred sites, and restricted access areas. Continue with the location/area of forest products, land types, and soil categories. Re-check the toponymy and common understanding of the base map features. At that stage, some triangulating of local toponymy with satellite images or GPS points can be performed during field tour with some members.

Discuss what should be mapped (e.g. land-use categories and non-timber forest product sites, hunting sites, sacred sites) before starting the sketch mapping process. Following the previous discussions, encourage participants to list and name:

- different types of land and landscape elements (land units)
- different types of land uses
- types of natural resources
- types of soil or drainage (e.g. swamp, wetland areas)
- special features, natural and anthropogenic, such as sacred groves, damaged woodland, waterfalls, graveyards, termitaria.

At that stage, symbols for the map legend should be designed. Each land use type is then sketched as accurately as possible onto the base map. The legend is completed, with a symbol given for each land use category and other important features.



**Photo A2. Discussing sketch resource map of a village landscape in southern Zambia**

Photos by Yves Laumonier/CIFOR-ICRAF

The facilitator team then compiles all maps drawn during the community meeting into one or more 'master maps'. These maps can be updated and corrected each day. The final maps drawn during the community meetings are returned to the village before the team leaves for the next location.

Final maps should be completed with the following elements: **map title** indicating location; **legend** showing all map symbols; **arrow** at the top showing North; **scale** and scale bar.

These maps are displayed at a public place in the village for everyone to see and comment on. Encourage people to add specific features if they wish to.



**Photo A3. Villagers sketching resource maps in West Papua, Indonesia**

Photos by Manuel Boissière/CIFOR-ICRAF

## A 3.2 Drone mission and mapping

**Do not fly drones without first obtaining community permission. All neighbouring villagers must also be informed.** Obtain informed consent from all villagers during or before a general meeting that should include all villagers to explain the drone tool (see main text, section 2.1.1 and Box 10 describing responsibilities under FPIC). At the same time be aware of flight permissions usually needed to be obtained from national civil aviation authorities, especially in protected or sensitive border zones.

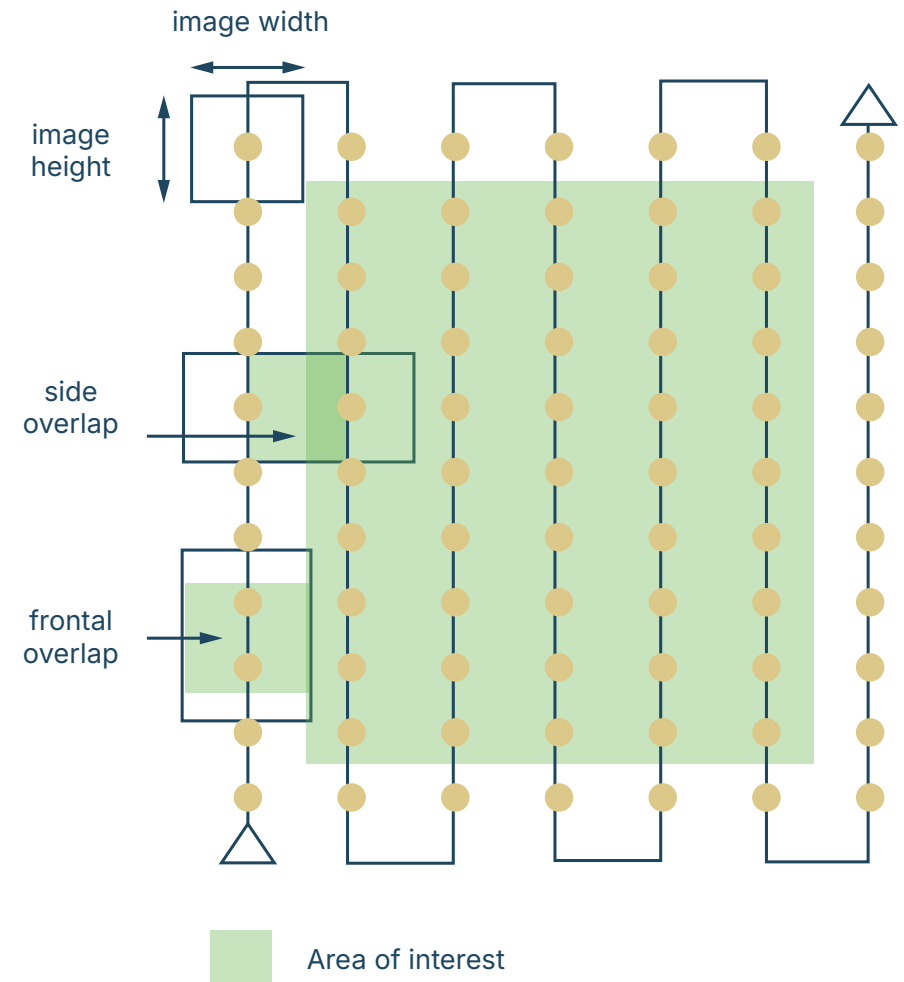
### Questions to be covered for the initial use of drone:

- Where can the drone take off?
- Are the lands that will be flown over individually or collectively owned?
- Who are the owners?
- Might someone feel offended by drones, given the kind of activities they carry out?
- Could using drones trigger aggressive or violent responses from someone?

**Drone mission planning software** includes, among others, Mission Planner (<https://ardupilot.org/planner/index.html>), DroneLink (<https://www.dronelink.com>), and DJIFlightPlanner (<https://www.djiflightplanner.com>). Planning can include, for example, pre-set fly line patterns.

**Fly missions apps** (Drone Deploy, Dronelink, MapMadeEasy, Map Pilot, etc.).

The flying heights range from 120 m to 350 m above ground, depending on topographic conditions and country regulations for using aerial space with drones. Image acquisition should be set up with a front overlap of 75-85% and a side overlap of 70-75%, following a plan of back-and-forth flight lines and the camera pointing straight down (nadir).



**Figure A8. Lawn-mower flight plan, the drone flying back and forth in parallel lines to ensure complete coverage of the area.**

Source: <https://www.aerotas.com/overlap-flight-pattern>



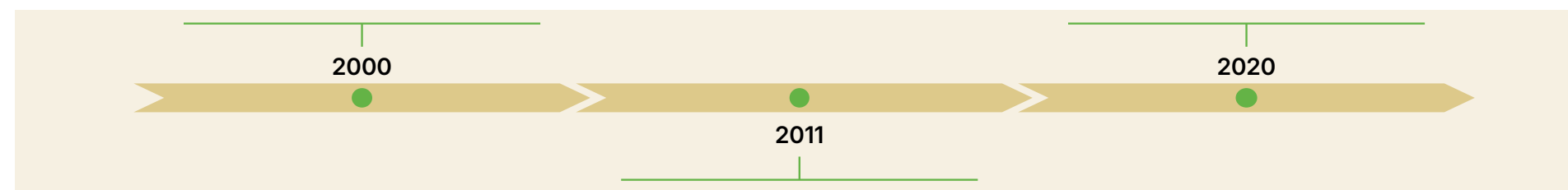
# Appendix 4. Semi-structured interviews, Pebble Distribution Method (PDM) Scoring Exercises and Free Listing

## A 4.1 Timeline

### Data sheet 1

| Data Sheet 1: SETTLEMENT HISTORY, TIMELINE |   |   |                     |              |    |   |             |              |                                 |
|--------------------------------------------|---|---|---------------------|--------------|----|---|-------------|--------------|---------------------------------|
|                                            |   |   |                     |              |    |   |             |              | Village Head/Traditional Leader |
| Respondent                                 |   |   | Date day/month/year |              |    |   | Inputted by |              |                                 |
| Village                                    |   |   |                     |              |    |   | Checked by  |              |                                 |
| Checked by                                 |   |   | Original or Copied? | O            | C  |   | File name   |              |                                 |
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| Name                                       |   |   |                     | Gender       |    |   |             |              |                                 |
|                                            |   |   |                     |              | M  | F |             |              |                                 |
| Age                                        |   |   |                     | Ethnic group |    |   |             |              |                                 |

**Questions:** Please tell us about the history of this village! If the village was moved from (an) earlier location(s), what was the reason to move and what was done with the old/abandoned settlement? Causes of abandonment (e.g., conflict, water shortage, soil fertility decline).



## A 4.2 Land units and vegetation types

### Data sheet 2

| Data Sheet 2: LAND UNITS                  |  |                    |   |                     |              |             |           |   |                       |
|-------------------------------------------|--|--------------------|---|---------------------|--------------|-------------|-----------|---|-----------------------|
| Village head/Traditional leader/Informant |  |                    |   |                     |              |             |           |   |                       |
| Participants                              |  | Group              |   | Date day/month/year |              | Inputted by |           |   |                       |
|                                           |  | Village (Language) |   | Checked by          |              | Checked by  |           |   |                       |
|                                           |  | Facilitator        |   | Original or Copied? | O            | C           | File name |   |                       |
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**Questions:** Please tell us what land units and vegetation types can be found in the village area and where good examples of each are located! (Below is an example of a dry tropical woodland landscape.)

| No | Land and vegetation types | Location of example<br>(Name of place or river) | No | Land and vegetation types<br>(Local name) | Location of example<br>(Name of place or river) |
|----|---------------------------|-------------------------------------------------|----|-------------------------------------------|-------------------------------------------------|
|    | Woodland                  |                                                 |    |                                           |                                                 |
|    | Gallery forest (riparian) |                                                 |    |                                           |                                                 |
|    | Savannah                  |                                                 |    |                                           |                                                 |
|    | Shrub/thicket             |                                                 |    |                                           |                                                 |
|    | Grassland                 |                                                 |    |                                           |                                                 |
|    | Food crop fields          |                                                 |    |                                           |                                                 |
|    | Water                     |                                                 |    |                                           |                                                 |
|    | Secondary woodland        |                                                 |    |                                           |                                                 |
|    | Fallow                    |                                                 |    |                                           |                                                 |
|    | Home garden               |                                                 |    |                                           |                                                 |
|    | Shea parks                |                                                 |    |                                           |                                                 |
|    |                           |                                                 |    |                                           |                                                 |

## Data sheet 3

| Data Sheet 3: FOREST/WOODLAND PRODUCTS    |  |                    |   |                     |              |             |           |   |          |              |
|-------------------------------------------|--|--------------------|---|---------------------|--------------|-------------|-----------|---|----------|--------------|
| Village head/Traditional leader/Informant |  |                    |   |                     |              |             |           |   |          |              |
| Participants                              |  | Group              |   | Date day/month/year |              | Inputted by |           |   |          |              |
|                                           |  | Village (Language) |   | Checked by          |              | Checked by  |           |   |          |              |
|                                           |  | Facilitator        |   | Original or Copied? | O            | C           | File name |   |          |              |
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**Questions:** Please tell us about forest products you know (local names), and the location(s) where they are collected!

[illegible]

## A 4.4 Scoring exercises (FGD-PDM)

### Data sheet 4

| Data Sheet 4: SCORING EXERCISE for LANDSCAPE UNITS/VEGETATION TYPES and USED CATEGORIES |   |   |              |                     |    |   |                     |   |   |                        |              |
|-----------------------------------------------------------------------------------------|---|---|--------------|---------------------|----|---|---------------------|---|---|------------------------|--------------|
|                                                                                         |   |   |              |                     |    |   |                     |   |   | Key Informants-FGD/PDM |              |
| Respondent                                                                              |   |   |              | Date day/month/year |    |   |                     |   |   | Inputted by            |              |
| Village                                                                                 |   |   |              | Writer              |    |   |                     |   |   | Checked by             |              |
| Checked by                                                                              |   |   |              | Interviewer         |    |   |                     |   |   | File name              |              |
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Instructions:

1. Among the following land units on these cards **(taken from Data sheet 2)**, which one do you think is the most important? Please distribute 100 pebbles among the cards to express the importance!
2. For each use category (food, medicines, for example) on the cards, which type of land unit is the most **important?** Please distribute 100 pebbles among the cards based on the importance of this use category!
3. Then, build a matrix with results from Data Sheets 2 and 3. Below is an Indonesian example **to be adjusted for local context and local land unit classification**.

|                             | Overall | Food | Medicines | Light construction | Heavy construction | Charcoal | Tools | Firewood | Basketry | Ornament/tradition/ritual | Marketable items | Hunting function | Hunting place | Recreation |
|-----------------------------|---------|------|-----------|--------------------|--------------------|----------|-------|----------|----------|---------------------------|------------------|------------------|---------------|------------|
| Village                     |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Home Garden                 |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| River                       |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Swamp/wetland               |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Field crop                  |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Young fallow                |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Old fallow                  |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Forest/woodland             |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Total per use category=100  |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Natural forest/woodland     |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Logged-over forest/woodland |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Old Secondary forest        |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Swamp forest                |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Limestone forest            |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |
| Total per use category=100  |         |      |           |                    |                    |          |       |          |          |                           |                  |                  |               |            |

Example taken from an Indonesian site.

Matrix built based on the results of Data Sheets 2 and 3, to adapt for local context, country site.

## A 4.5 PDM Past-present-future importance of used categories

### Data sheet 5

#### Data Sheet 5: PDM PAST-PRESENT-FUTURE

#### Key Informants-FGD/PDM

|                 |   |                     |                     |             |              |
|-----------------|---|---------------------|---------------------|-------------|--------------|
| Respondent      |   | Date day/month/year |                     | Inputted by |              |
| Village         |   | Writer              |                     | Checked by  |              |
| Checked by      |   | Interviewer         |                     | File name   |              |
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#### Instructions:

1. How important were/are/will be forest uses and values 30 years ago, at present, and in 20 years from now? Please distribute 100 pebbles among the cards based on the total importance of the forest at a particular time!
2. How important were/are/will be forest uses and values 30 years ago, at present, and in 20 years from now, per use category? Please distribute 100 pebbles among the cards, first for '30 years ago', then for 'present', and lastly for '20 years from now'!

|                           | 30 years ago | Present | 20 years from now | Total =100 |
|---------------------------|--------------|---------|-------------------|------------|
| Total importance          |              |         |                   |            |
| Food                      |              |         |                   |            |
| Medicine                  |              |         |                   |            |
| Light construction        |              |         |                   |            |
| Heavy construction        |              |         |                   |            |
| Charcoal                  |              |         |                   |            |
| Tools                     |              |         |                   |            |
| Firewood                  |              |         |                   |            |
| Basketry                  |              |         |                   |            |
| Ornament/tradition/ritual |              |         |                   |            |
| Marketable products       |              |         |                   |            |
| Hunting function          |              |         |                   |            |
| Hunting place             |              |         |                   |            |
| Recreation                |              |         |                   |            |
| Total per time=100        |              |         |                   |            |



**Photo A4. Participants in scoring exercise**

Photos by Nining Liswanti/CIFOR-ICRAF

### Scoring exercise, PDM

Typical PDM exercise for four groups of 10 people in Indonesia Borneo: young men, young women (< 35 years old), old men, old women (≥ 35 years old) distributing pebbles indicating their perceptions of the importance of land units, use categories per land units and past, present, future of these categories.

## A 4.6 Free listing

The facilitator asks individuals to name as many species as each person can, for each category – for instance, plants, birds, and other animals (this is done to avoid explaining how to differentiate mammals, reptiles, amphibians, etc.). Within each category, successive free listings can be set up. For instance, for plants, name those that are most salient for food, medicine, firewood, etc.

- People are asked to **“name all the birds you can think of”**.
- Then they are asked the same for plants **“All the plants you can think of”**.
- This is a very broad starter... so the next step can be to do the same while focusing on **narrowing the domain “all the birds you can think of in the forest” or ‘all the medicinal plants you can think of in the forest’**. This is called ‘successive free listing’.
- It can go to specific use “all the plants used for basketry” “all the trees used as timber” etc. (based on the scoring exercise previously).
- The free list, written on paper or orally, will contain items that one individual knows **in the order that they come to his/her mind**. It can also be **recorded on tape**.
- Minimum 15 to 20 respondents randomly chosen in the village (e.g. five young men, five old men; five young women and five old women).
- **There is no pressure**: the person might have difficulties mentioning objects/items; people need time to think about naming various items. The interviewer can, at the end, slowly reread the list and ask if the person can think about more items.
- Avoid influence by other persons on the freelist, e.g. approaching out of curiosity and offering suggestions.
- For the **plant list**, samples should preferably be **collected after the interview, together with the person interviewed, for proper identification**.

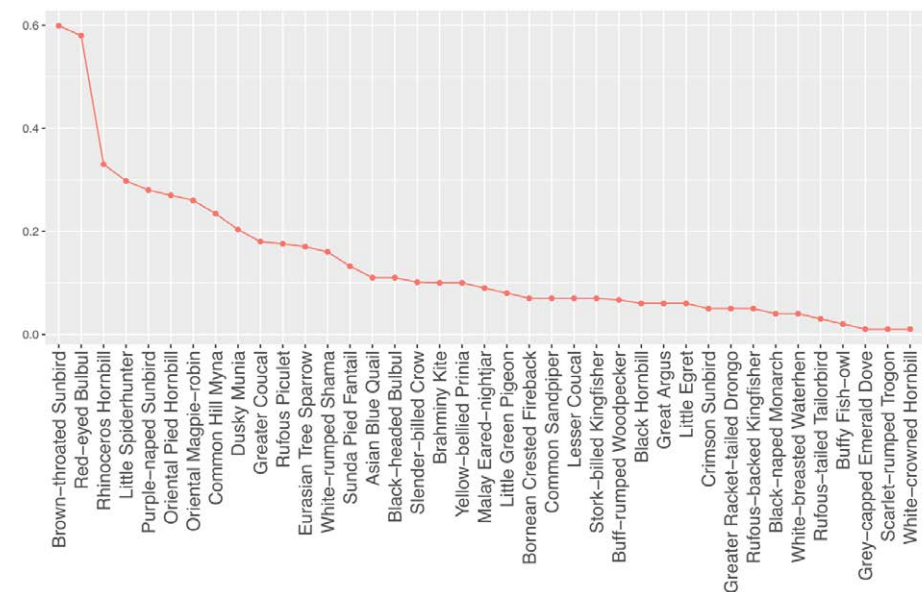
- The form data will be inputted as **.csv** format and will be analysed with **FLARES**. <http://www.anthrocoogs.com/shiny/flares/>
- Salience analysis (or Smith's S index) accounts for **frequency** of mentions, weighted for list position.

For each use category, the most salient and least salient species will be identified for both men and women. The form to fill out is very simple and in Excel format.

| Freelister_1 | Freelister_2 | Freelister_3 |
|--------------|--------------|--------------|
| Ostriches    | Flamingo     | Grebes       |
| Guineafowl   | Turaco       | Nightjar     |
| Flamingo     | Coucal       | Francolin    |
| Sandgrouse   | Grebes       | Flamingo     |
| Crake        | Cuckoo       | Moorhen      |
| Pheasants    | Nightjar     | Plover       |
| Francolin    | Spinetail    |              |
| Lapwing      | Flufftail    |              |
|              | Crake        |              |
|              | Lapwing      |              |
|              | Guineafowl   |              |
|              | Moorhen      |              |

**Figure A10. Recommended format in Excel to be used with the FLARES software; bird species free listing as an example**

Source: Authors



**Figure A11. FLARES Smith's Salience Index chart example**

The Smith's Salience Index combines both how often a species is mentioned and its position in free lists, showing how broadly shared and easily recalled a species is among respondents. Higher values indicate greater cultural salience, meaning that these birds (the Brown-throated Sunbird and the Red-Eyed Bulbul in this case) are part of a culturally 'core' group of species. Simultaneously, breaks in the curve signal shifts to less recognized or more peripheral species. Cultural salience should be viewed as a measure of shared importance and visibility in people's knowledge and practices, rather than as a direct indicator of ecological abundance.

Source: Authors

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