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THE HCS APPROACH TOOLKIT

MODULE 4

VERSION 2.0

MAY 2017

THE HCS APPROACH PUTTING NO DEFORESTATION INTO PRACTICE

Forest and vegetation stratification

THE HCS APPROACH TOOLKIT V2.0 MAY 2017

Published by the HCS Approach Steering Group

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MODULE 4

Forest and vegetation stratification



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SECTION A

Outline of the process for making the indicative HCS forest map

By Uwe Ballhorn and Peter Navratil (Remote Sensing Solutions GmbH).

INTRODUCTION

The goal of Phase 1 in a HCS assessment is to create an indicative map of potential HCS forest areas in a development area and its surrounding landscape. This is achieved using a combination of airborne Light Detection and Ranging (LiDAR) data (if available), satellite images and field data. The sections in Module 4 focus on Phase 1: Making the first indicative HCS forest map. They take the reader through the required steps, including pre-requirements, methodology and expected output.

The methodology presented in this module has been tested and refined through pilot tests in development areas in Indonesia, Liberia and Papua New Guinea. The methodology is intended to be applicable for any moist tropical forest on mineral soils, but we have included details of variations to the methodology which

might be necessary to address issues relating to image quality and types of land cover and land use in different regions.

This module is intended for technical experts with experience in remote sensing analysis and forest inventory that can use this document to guide their work and create an indicative map of potential HCS forest areas, without need for further guidance. We thus assume that the reader has an advanced level of knowledge in these analysis techniques, but have provided references to more detailed guidance where it may be helpful.

METHODOLOGICAL APPROACH

The methodological approach for the identification of potential HCS forests is based on three options, where each option represents a level of accuracy and detail, but also of methodological complexity and cost (Figure 1). Progressing from Option 1 to Option 3

represents a decrease of accuracy/detail and an increase in uncertainty, but on the other hand, a decrease of methodological complexity and costs.

The decision on which option to apply should be based on the desired accuracy and detail of the output that is required. Cost should not be the only or the primary consideration. There are also broader benefits that may be gained through choosing Option 1, such as accurate Digital Terrain Models (DTMs) that can be used for plantation planning if LiDAR is used. Further, if it is foreseen that accurate calculations of carbon will be required in the future, Option 1 might be the best since it provides the most accurate calculations of carbon. Alternatively, if the objective of the HCS assessment is simply to identify forest areas for land use planning decisions, then Option 3 may be satisfactory.



As Option 3 has the highest level of uncertainty, this option is the least recommended, but is still allowed in the HCS Approach.

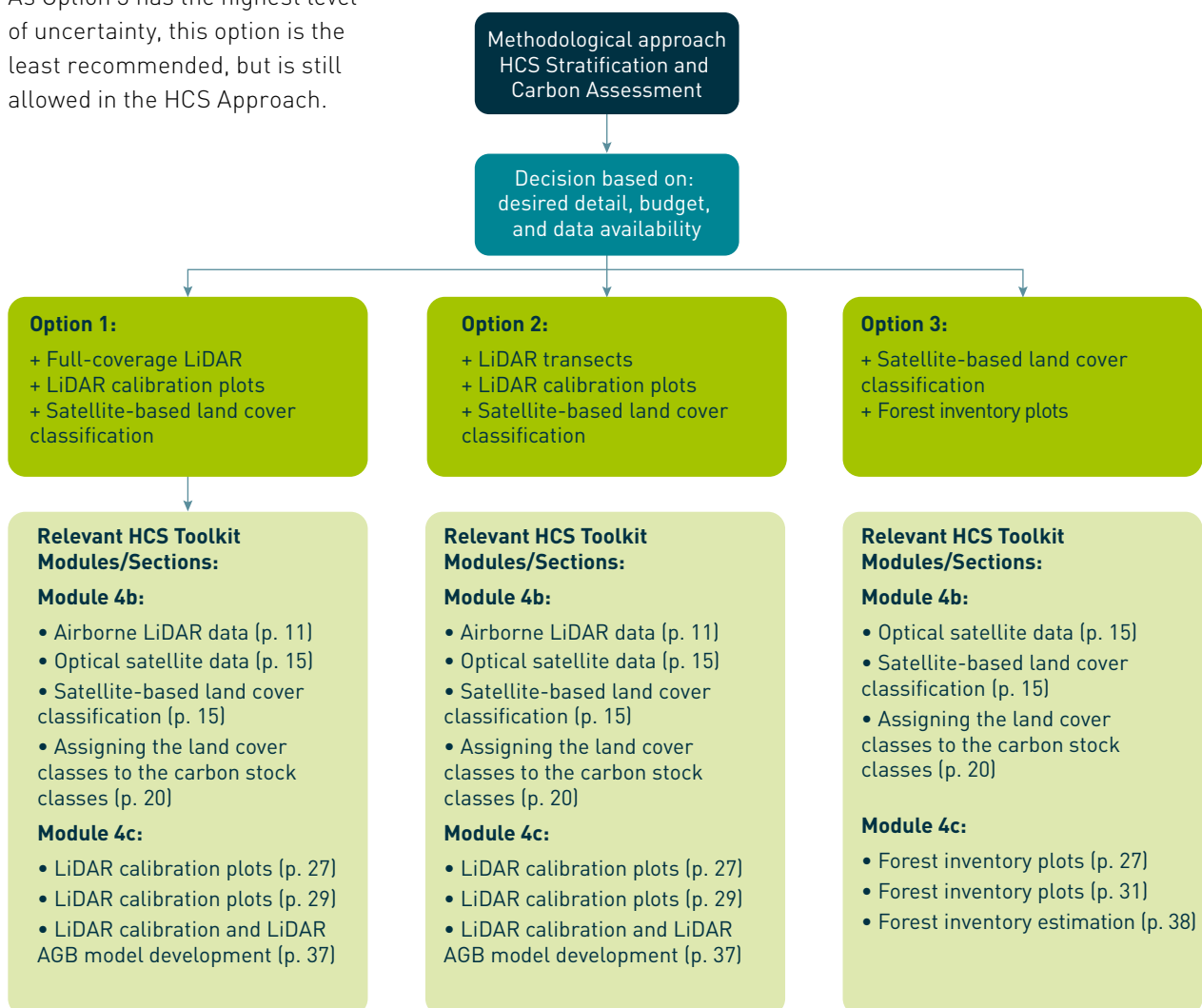


Figure 1: Overview of the methodological approach for HCS Stratification and Carbon Assessment.

Progressing from Option 1 to Option 3 represents a decrease of accuracy/detail and an increase in uncertainty, but on the other hand, a decrease of methodological complexity and costs. Also shown are the relevant toolkit sections describing the necessary tasks for these approaches.



Option 1

The first and most accurate/detailed option is the use of a full-coverage airborne LiDAR data set of the development area, which is calibrated through LiDAR AGB (above-ground biomass) calibration plots collected in the field in order to create an AGB model for the development area. This model is then reclassified into the different HCS classes. In this option, the satellite-based land cover classification is primarily used for the sampling design of the LiDAR AGB calibration plots. Figure 2 describes the workflow of Option 1. The reasons for choosing this option should be explained in the HCS summary report.

Whereas the use of full-coverage LiDAR, LiDAR transects, or no LiDAR, will depend on project-specific considerations (e.g. desired accuracy/detail, budget, data availability) a satellite-based high resolution land cover classification (including ground truthing and subsequent accuracy assessment) is mandatory for all three options. The Area of Interest (AOI) to be mapped by satellites must include the development area and also the broader landscape adjacent to the development area, and is further described in the next section.

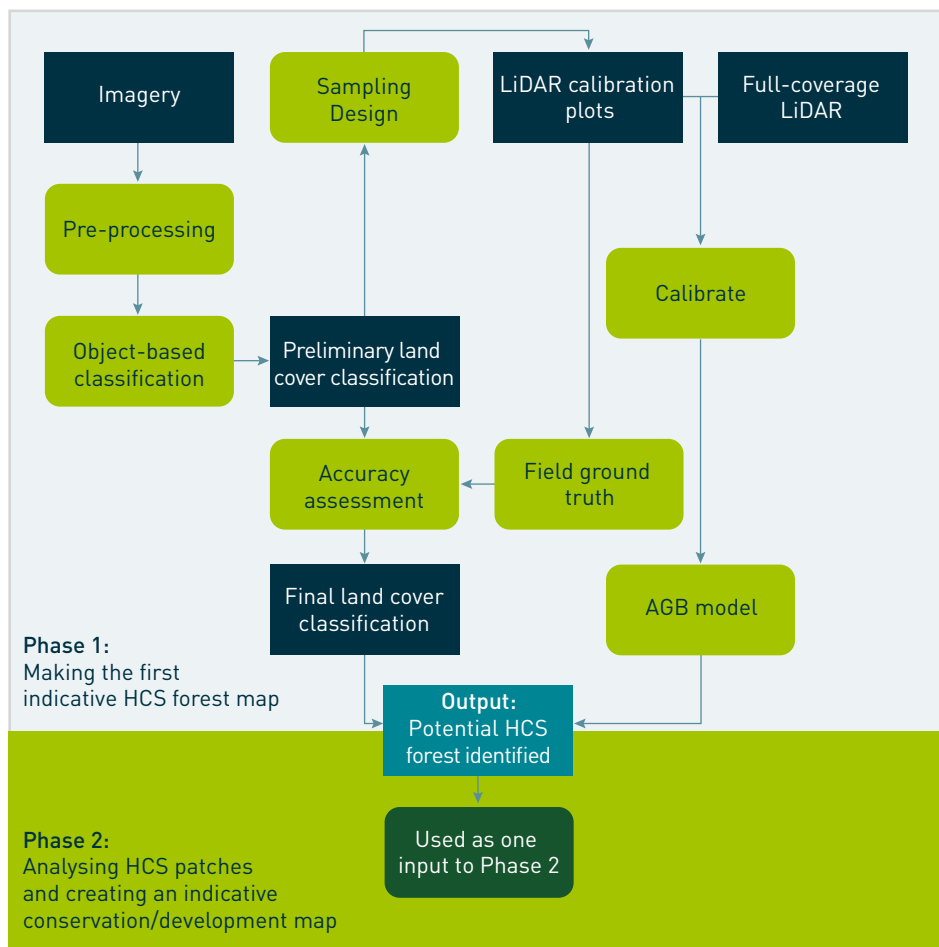


Figure 2: Workflow of Option 1 based on full-coverage LiDAR. Phase 2, HCS forest patch analysis and protection, is described in Module 5.

Option 2



If the acquisition of full-coverage LiDAR data is not feasible, but a higher accuracy and detail than achieved with Option 3 is desired, Option 2 should be selected. Option 2 uses the satellite-based land cover classification in combination with a LiDAR transect sample to derive average carbon values for input to the different land cover and forest classes, and then do the identification of potential HCS forest based on the estimated carbon values of those classes. In this option, the preliminary land cover classification is used for the planning of the LiDAR AGB calibration plots and the planning of the LiDAR transect sampling. Figure 3 describes the workflow of this approach. The reasons for choosing this option should be explained in the HCS summary report.

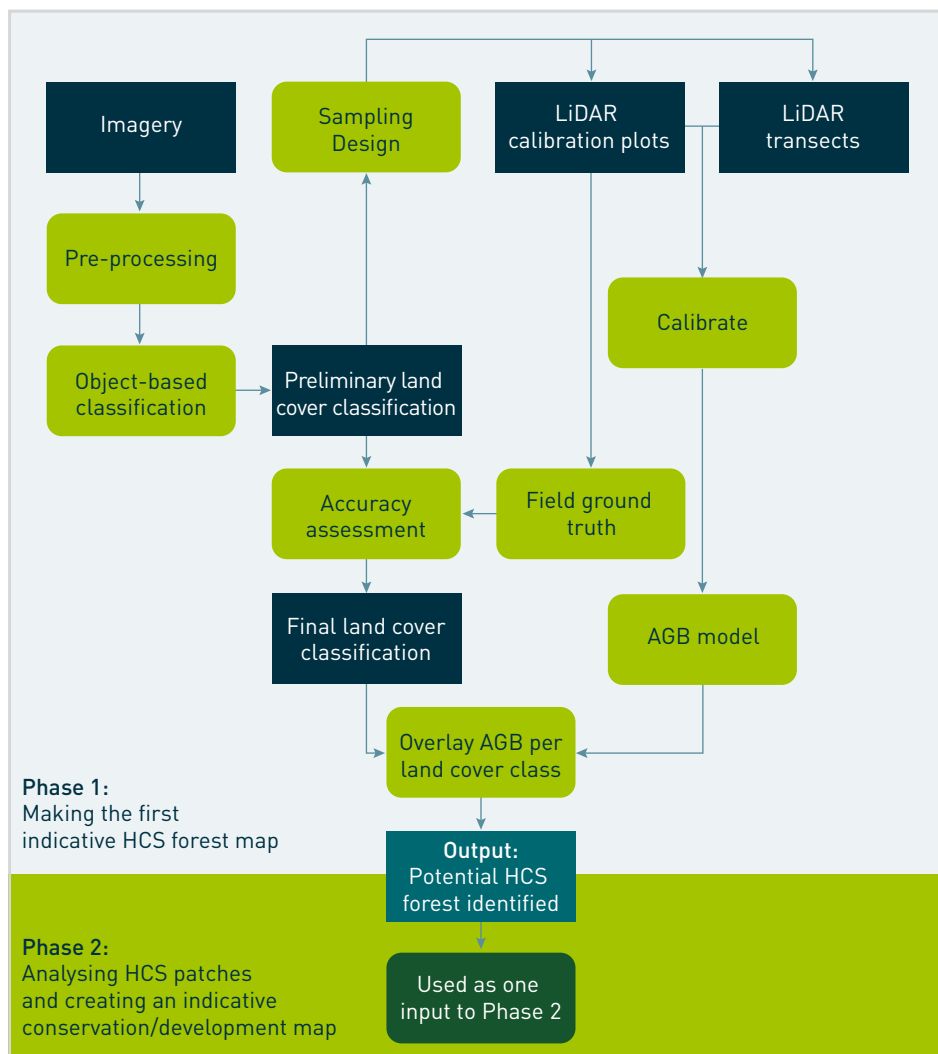
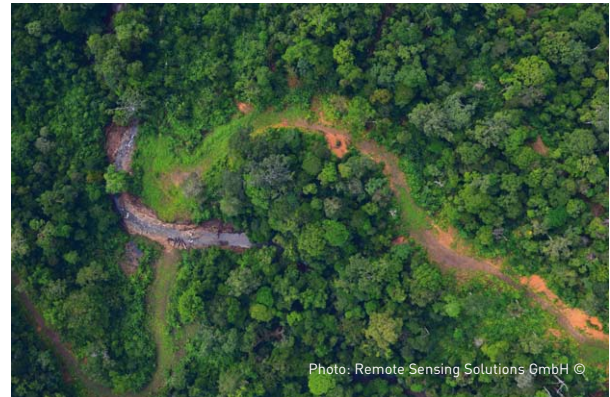


Figure 3: Workflow of Option 2 based on LiDAR transect sampling. Phase 2, HCS forest patch analysis and protection, is described Module 5.

Option 3

If the acquisition of any LiDAR data (full-coverage or transects) is not feasible, a third option is the use of the satellite-based land cover classification in combination with forest inventory data in order to derive average carbon values for the different land cover and forest classes, and then do the identification of potential HCS forest based on the estimated carbon values of those classes. In this option, the preliminary land cover classification is used for the planning of the forest inventory. Figure 4 describes the workflow in Option 3. It is important to note that this option requires a much higher number of forest inventory plots than the LiDAR AGB calibration plots required in Options 1 and 2 in order to assure a sufficiently low level of uncertainty. While Option 3 results in the

lowest accuracy of estimated carbon values and detail of class delineation, it is however sufficient to delineate HCS forest patches at the required resolution. The reasons for choosing this option should be explained in the HCS summary report.

After potential HCS forest is identified (Phase 1), this information is used as input to Phase 2: Analysing HCS patches and creating an indicative conservation/development map.

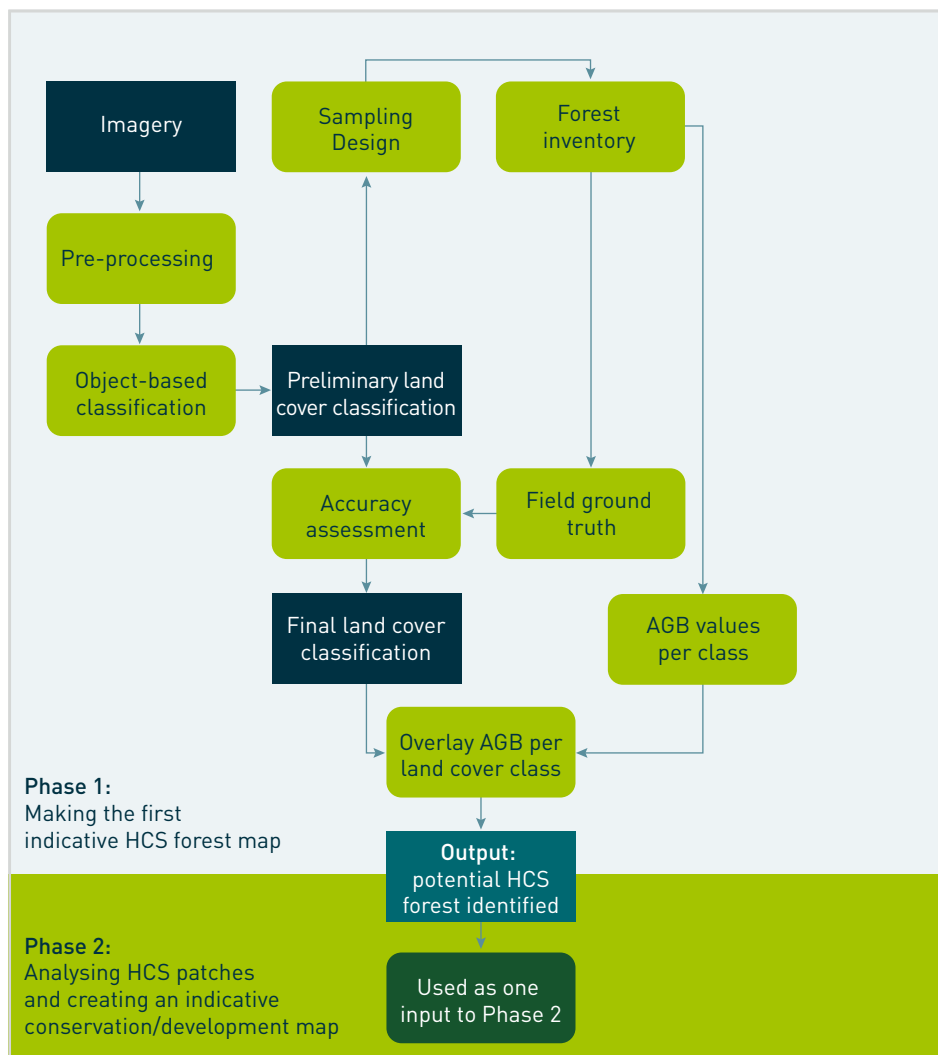


Figure 4: Workflow of Option 3 based on a forest inventory. Phase 2, HCS forest patch analysis and protection, is described in Module 5.



FPIC PROCESSES AND COMMUNITY MAPPING

Because field sampling activities will likely lead to direct interactions with community members, local communities should already be informed about the HCS Approach and process before the collection of ground truthing data, LiDAR calibration or forest inventory plots. Ideally this should occur during the initial engagement with communities through the early stages of the process of Free, Prior and Informed

Consent (FPIC) described in Module 2 of this toolkit. Communities will also need to give consent to any sampling activities being carried out on their lands.

Participatory mapping and community engagement should have indicated areas that communities identify as important for maintaining for their current and future livelihoods, for food security, and for sociocultural needs. These can include both HCS forest areas, for instance those used for gathering non-timber forest products (NTFPs) or hunting, as well as non-HCS areas such as small farms, gardens or agroforestry plots. Note that if these non-HCS areas are identified during the image-based classification or field sampling but were not identified during the participatory mapping process, this could be an indicator that the participatory mapping / FPIC process was not fully completed and needs to be revised before the HCS assessment can be finalised.





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SECTION B

Land cover and carbon stock classification using airborne LiDAR and/or satellite imagery

By Uwe Ballhorn and Peter Navratil (Remote Sensing Solutions GmbH),
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¹ The authors are grateful to Jeremy Ferrand (Forest Carbon), Grant Rosoman (Greenpeace) and Kimberly Carlson (University of Hawaii) for their helpful comments on this section.

INTRODUCTION

This section describes the first step of Phase 1 in a HCS assessment, where land cover is classified into defined classes through the use of airborne LiDAR and/or satellite imagery. The technical requirements of airborne LiDAR and satellite imagery are described, as is the methodological approach for classifying satellite imagery (including ground truthing and subsequent accuracy assessment) into these defined classes. Whereas the use of full-coverage LiDAR, LiDAR transects, or no LiDAR, will depend on project-specific considerations (e.g. desired accuracy/detail, budget or data availability), a satellite-based high resolution land cover classification (including ground truthing and subsequent accuracy assessment) is mandatory for all three approaches (see Module 4a). The intended audience are practitioners with experience in remote sensing (including airborne LiDAR) analysis.



TECHNICAL REQUIREMENTS

Airborne LiDAR data

When it comes to the collection and processing of airborne LiDAR data (more details on LiDAR data is given in box on the next page) in the HCS Approach, the following technical parameters are proposed:

- Discrete-return LiDAR data should be collected.
- A footprint size between 25 cm and 2 m is recommended with a sampling density of at least 4 per square metre.
- It is also possible to collect full-waveform data, although currently it will be simplified to discrete-return data to allow forward compatibility with historic discrete-return data sets. Up-to-date, full-waveform metrics are not yet commonly used, but collecting full-waveform data provides a degree of future-proofing against the likely eventuality of full-waveform data collection becoming routine.

The accurate mapping of above-ground biomass (AGB) using airborne LiDAR can only be achieved if the LiDAR data is carefully calibrated using LiDAR AGB calibration plots collected in the field (see Module 4c). To derive AGB from airborne LiDAR 3D point clouds, a predictive statistical model is developed at each site using in-situ AGB estimates inferred from LiDAR AGB calibration plots established in the field (see Module 4c). Figure 6 demonstrates how the forest structures of different forest types and degradation levels are represented by these LiDAR 3D point clouds.

Airborne Light Detection and Ranging (LiDAR) data

To map above-ground biomass (AGB) it is recommended to use a combination of airborne LiDAR and LiDAR AGB calibration plots (which are collected in the field). Nowadays, the use of airborne LiDAR for this purpose is widely accepted and it is readily available, albeit at some cost, through specialised survey and consulting firms. LiDAR is an active remote sensing technique that is based on the transmission of laser pulses toward the ground surface and the recording of the return signal. By analysing the time delay for each pulse back to the sensor, the height of all reflecting objects can be measured within a range of a few centimetres.

LiDAR systems are usually classified using three characteristics: (a) the type of recording of the return signal, (b) footprint size, and (c) sampling rate and scanning pattern (Dubayah and Drake 2000). Two recording types can be differentiated: the discrete-return system and the full-waveform system.

For discrete-return systems, pulse detection is conducted in real-time on the returned signal so that the system detector splits a continuous waveform into several time-stamped pulses giving the position of the individual targets (Mallet and Bretar 2009). These laser scanning systems are called multi-echo or multi-pulse, and typically collect first and last pulses, although some are able to differentiate up to six individual returns from one pulse. The footprints of these systems are small, reaching sizes of 0.2 m to 0.9 m.

Full-waveform systems, on the other hand, record the amount of energy for a series of equal time

intervals. They give more control to the user as their processing methods increase pulse detection reliability, accuracy, and resolution. A certain amplitude-against-time waveform is obtained for each time interval. To understand these waveforms, pre-processing is necessary, usually through the decomposition of these waveforms into a sum of echoes generating a three-dimensional (3D) point cloud. Most current commercial LiDAR systems are small-footprint systems (0.2 to 3.0 m), depending on flying altitude and beam divergence, and a high repetition frequency.

Airborne LiDAR can thus be used to generate high-resolution, continuous maps of AGB. Figure 5 shows an example of a 10 km long (408 ha) LiDAR transect covering pristine and logged peat swamp forests in Central Kalimantan, Indonesia (Jubanski et al. 2013). It demonstrates how a LiDAR-derived AGB model can continuously detect AGB variability within this transect. This AGB variability cannot be mapped through conventional carbon mapping methods where AGB values derived from forest inventory plots are attributed to similar forest types as classified through multispectral satellite imagery. Further, this approach is robust and allows the reliable identification of the size, location and biomass of small forest patches (small forest fragments), which is a critical issue for the delineation of HCS forests (see Modules 5a and 5b).

In addition, through the provision of a very precise topography, airborne LiDAR also allows for the mapping of landscape features (deep slopes, peatlands, swampy areas, riverine systems, etc.) that are not well mapped by optical imagery. This additional information is very beneficial for plantation planning and management, as well as for HCV assessments.



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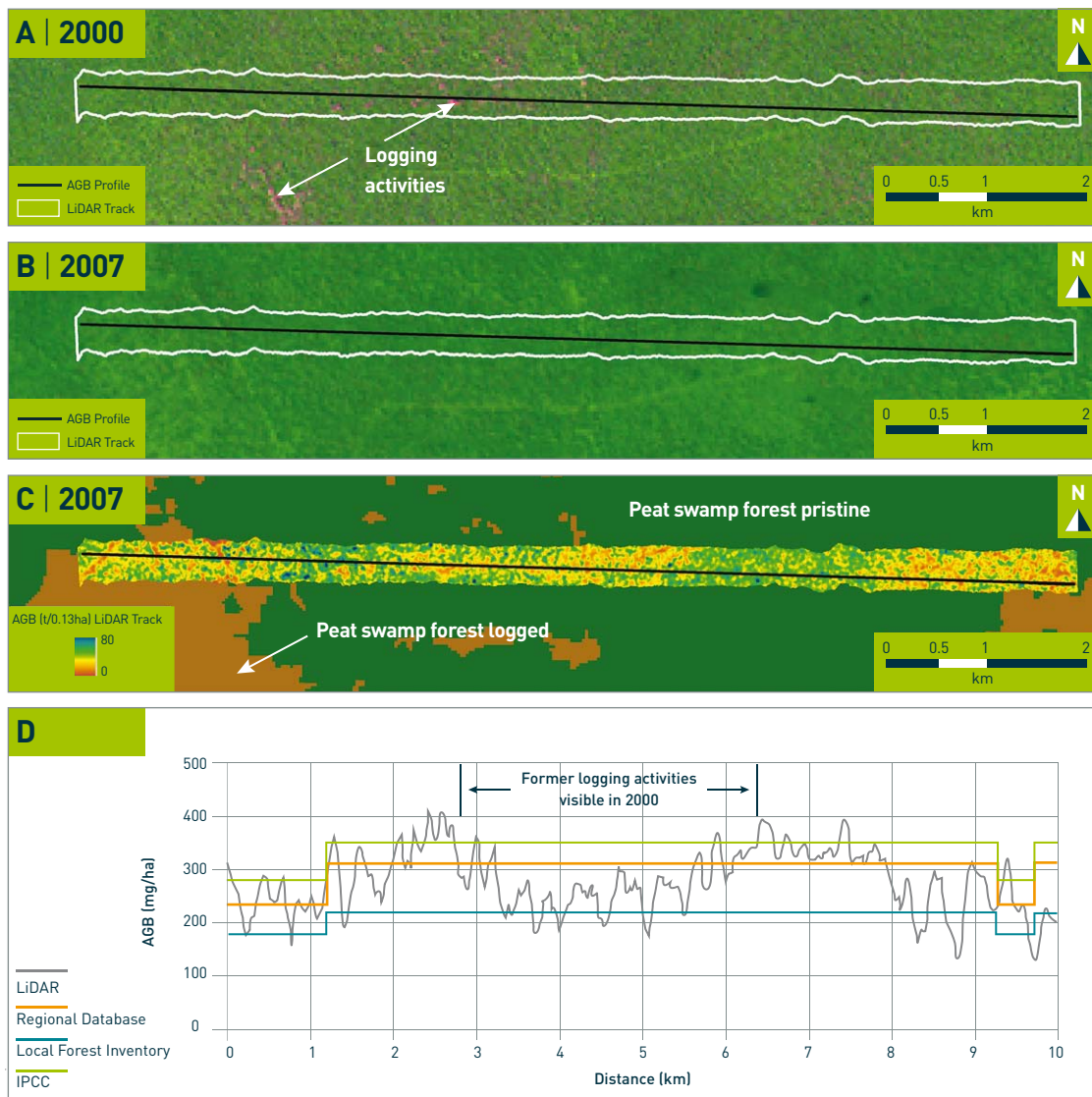
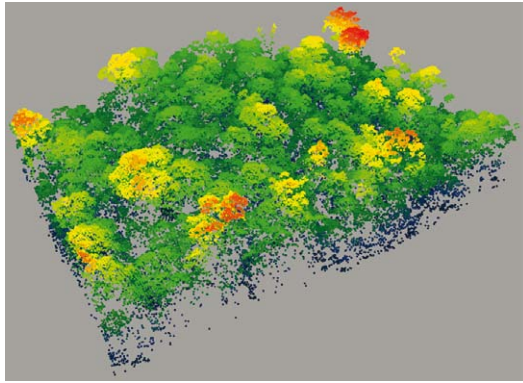


Figure 5: AGB results shown for an airborne LiDAR transect covering 10 km of peat swamp forest in Central Kalimantan (Indonesia).

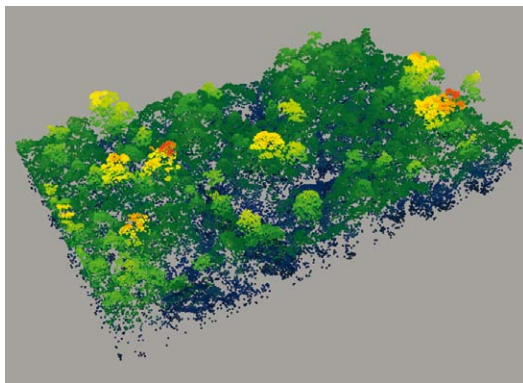
(A) Extent of the LiDAR transect and the location of the AGB profile of (D) superimposed on a Landsat scene from the year 2000 (ETM+ 118-62, 2000-07-16; bands 5-4-3). Green represents forest cover, and logging activities are visible as pink dots near straight line features. (B) Extent of the LiDAR transect and the location of the AGB profile of (D) superimposed on a Landsat scene from the year 2007 (ETM+ 118-62, 2007-08-05; band 5-4-3; gap filled). The logging activities are not visible anymore. (C) LiDAR AGB model superimposed on the Landsat classification (green = peat swamp forest pristine; brown = peat swamp forest logged). (D) AGB variability measured by LiDAR (grey) and the corresponding AGB estimates attributed to the land cover types of the Landsat classification. Site-specific inventory data (local forest inventory) = turquoise; regional literature estimates (regional database) = orange; and IPCC default values (IPCC) = green.

Black arrows indicate the extent of the logging activities in (A). Only LiDAR can continuously detect the AGB variability. Figure adapted from Jubanski et al. [2013].

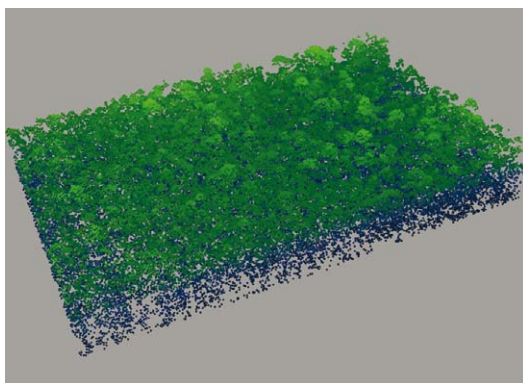
Peat Swamp Forest – Types and degradation



Primary Peat Swamp Forest

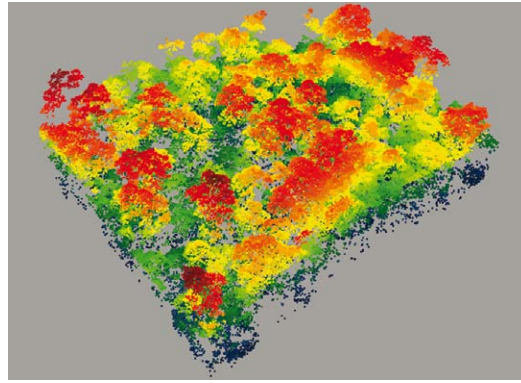


Secondary Peat Swamp Forest

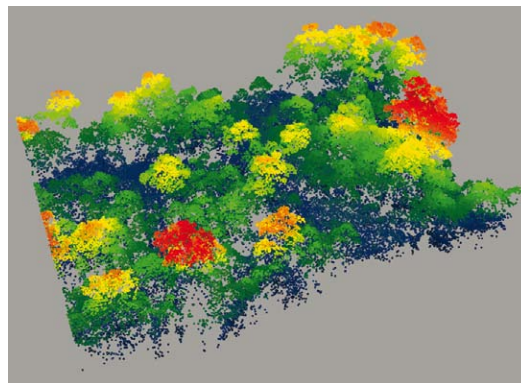


Primary Low Pole Peat Swamp Forest

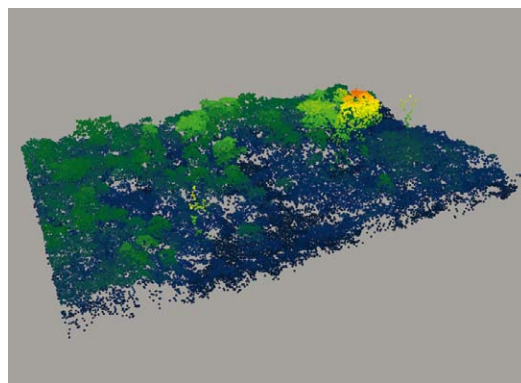
Lowland Forest – Degradation levels



Primary Lowland Forest



Secondary Lowland Forest



Shrubland

Height above ground



Figure 6: Example of distinctive vegetation structure detected through airborne LiDAR data recorded in Kapuas Hulu (left column) and Berau (right column) in Kalimantan, Indonesia.

The differences in forest structure of the forest types and degradation levels are clearly visible in the normalised LiDAR 3D point clouds. The data presented here was recorded and analysed within the Forests and Climate Change Programme (FORCLIME) of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Optical satellite data

The selection of satellite images to be used in the vegetation classification process must ensure that the images provide sufficient coverage of the assessment area while giving preference to suitable temporal and spatial resolutions relevant to the assessment. Specifically:

- Images must be no older than 12 months and have a minimum spatial resolution of 10 m unless this resolution is not available (see final bullet point).
- The data must be of a quality that is sufficient for the analysis with less than 5% cloud cover within the Area of Interest (AOI), with no or very minimal localised haze.
- The availability of data or spectral bands that assist with determining vegetation canopy and height, healthiness of vegetation cover, and vegetation density on the land, must be considered.
- Lower resolution images, like Landsat 8 with 30 m resolution, may be used as ancillary data in combination with the main high resolution images (e.g. to make use of the higher spectral resolution). The use of Landsat as a main image data source is only permitted if higher resolution images are not available or obtainable. However, the images must be replaced as soon as higher resolution data become available.

An overview of optical multispectral satellite image options is provided in the appendix to this section.

SATELLITE-BASED LAND COVER CLASSIFICATION

Determining the Area of Interest (AOI) to be classified

The Area of Interest (AOI) to be mapped must include the development area and also the broader landscape adjacent to the development area. This is because the classification is conducted using relative amounts of canopy cover and carbon stock calculations within a landscape context. For instance, forest patches in a development area that is highly degraded with minimal presence of potential HCS will need to be compared to other larger forest landscapes outside of the development area in order to place them in context.



The boundary of the AOI must be aligned to either administrative or natural boundaries, for instance hydrological catchments or other landscape units. Rationale for the determination of the boundary must be provided.

Preliminary land cover classification

A preliminary land cover map must be created early in the project in order to facilitate efficient planning of the LiDAR AGB calibration plots, LiDAR transects or forest inventory plots (depending on the data option chosen), and to improve the distribution of the sample across the expected range of carbon stock classes (see Figure 7). The preliminary land cover classification uses an object-based classification approach, and the map will be refined at a later stage (see section on final land cover classification below) by incorporating the results of the field surveys (ground truthing, LiDAR AGB calibration plots or forest inventory).

Accuracy of the preliminary land cover classification must reach 70%. As this is a preliminary accuracy assessment, a reinterpretation of samples of the original data (satellite imagery used) in an independent manner is acceptable (no collection of in-situ ground truthing samples is necessary at this stage). The accepted methodologies for calculating accuracy are described later in this section.

In order to improve the classification of the current image, an understanding of the historic change dynamics is beneficial. This allows for a better interpretation of different forest degradation and recovery stages.

Participatory mapping output, like historical land use, existing land use, and land use planning, can be integrated as ancillary data at any stage.

Final land cover classification

The final land cover map will be created from the preliminary classification, which will be enhanced by the incorporation of ancillary information. This may include site information (e.g. vegetation location, vegetation condition, vegetation structure) and physical information (soil type, climate, ecosystem) (see Figure 7). The collection of a sufficient amount of in-situ ground truthing samples is mandatory to assess the accuracy of the final land cover classification (see section on accuracy assessment below). Additional information from the LiDAR AGB calibration plots or the forest inventory (depending on which option was chosen – see Module 4a) should also be incorporated in this accuracy assessment process. The thematic accuracy of the land cover map must be 80% or above.

The final land cover map must also be complemented by ancillary information such as development area boundaries, current land use, infrastructure, peatland extent, riparian zones and HCV areas identified in the HCV assessment.

METHODOLOGY

Object-based land cover classification

Once the images have been selected and pre-processed, the land cover is grouped into relatively homogenous classes in order to delineate, in combination with the LiDAR AGB model or forest inventory plots, potential HCS forest from non-HCS areas. The process primarily consists of analysing the satellite images using Remote Sensing and Geographic Information Systems (GIS) software, which provide tools for land cover interpretation. Several commonly available software packages provide the tools to support the object-based land cover classification, including but not limited to: Trimble eCognition, Erdas Imagine, ENVI, ESRI Image Analysis and OpenSource software (Quantum GIS).

Land cover classification is applied for several reasons:

1. It allows the identification of different land cover classes with various forest and non-forest conditions that can be captured in image analysis (e.g. colour, canopy closure and roughness of the canopy layer).
2. The condition and state of forest regeneration is often (but not always) correlated with forest carbon stock and biodiversity. For example, dense, well-stocked forest is usually associated with high carbon stocks (and also commonly higher biodiversity) than degraded, low-stocked forest.
3. Separating the land cover into classes allows for more efficient sample design for the collection of LiDAR calibration plots or forest inventory (see Module 4c).

The land cover classification must follow the system specific to the country in which the analysis is being conducted. This ensures the map is more easily recognised and understood by local administration and communities, and can also pre-empt any disagreements on forest definition.

Traditional pixel-based classification approaches, which use multispectral classification techniques to assign a pixel to a class, have largely been superseded by object-based approaches when using high resolution images. This is because pixel-based classifications are often incomplete and heterogeneous, particularly when using them with high resolution satellite data mapping spectrally heterogeneous classes such as forest. Improving the spatial resolution of remote sensing systems results in increased complexity of the data. The representation of real-world objects in the featured space is characterised by a high variance of pixel values, hence statistical classification routines based on the spectral dimensions are limited, and a greater emphasis must be placed on exploiting spatial and contextual attributes (Guindon 2000, 1997; Matsuyama 1987). To enhance classification, the use of spatial information inherent in such data has been proposed and studied by many researchers (Atkinson and Lewis 2000).

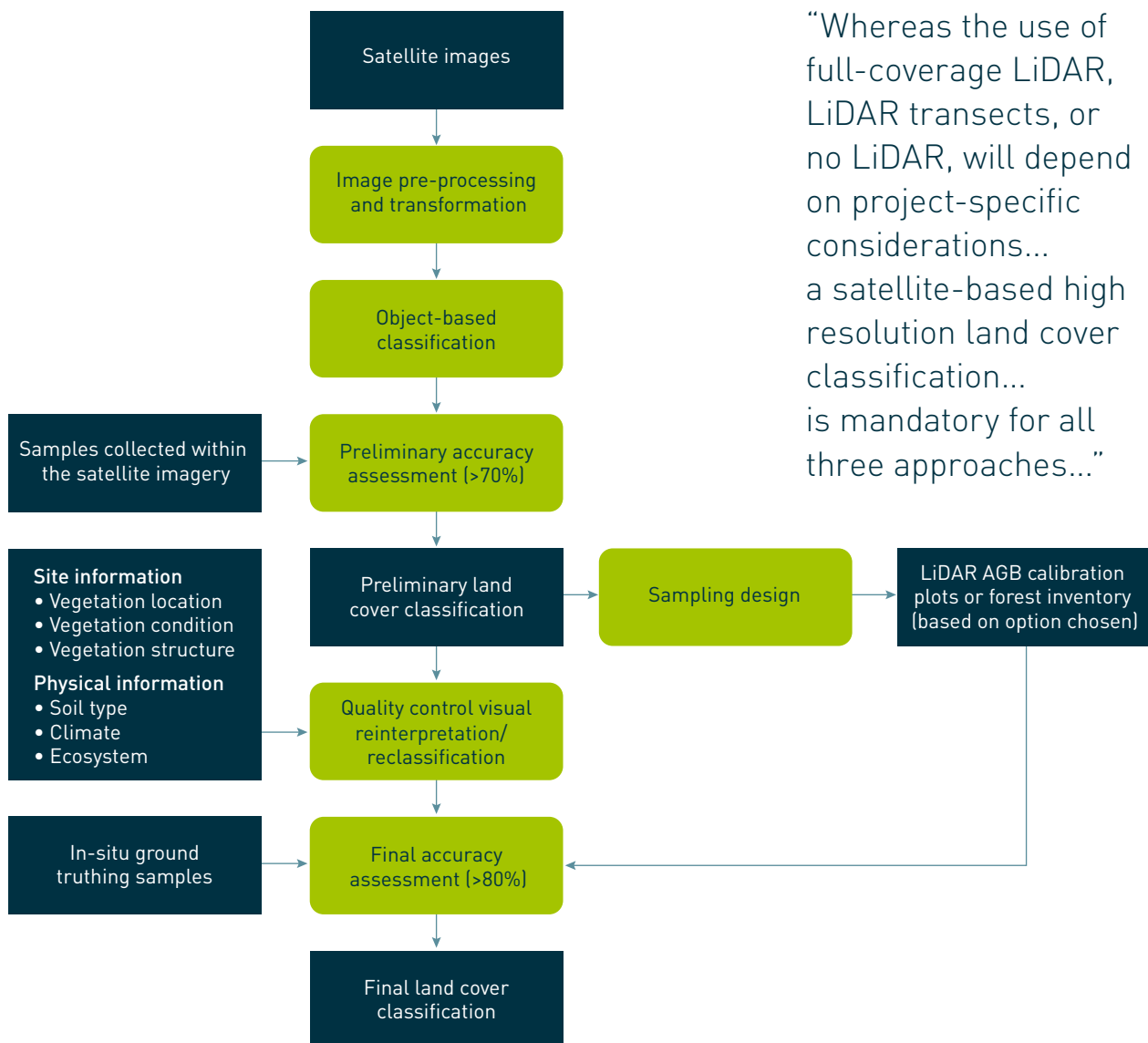


Figure 7: Workflow of the object-based classification procedure

Figure 7 shows the workflow of the classification procedure. In the object-based approach, the first step is the image segmentation or object generation, which combines spatially adjacent pixel clusters with similar spectral properties to image objects. The attributes of the image objects, like spectral reflectance, texture or NDVI, are stored in a so-called object database [Benz et al. 2004].



Sentinel-2 satellite image

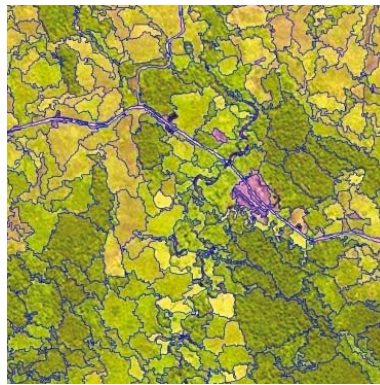
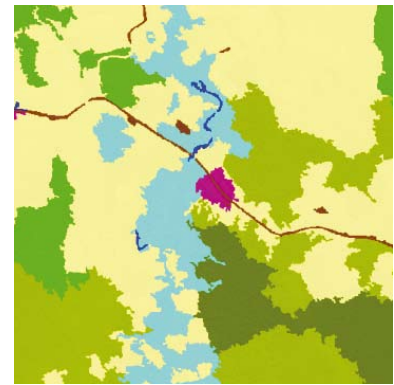


Image segmentation



Classification

Figure 8: Example of the basic procedures of an object-based image analysis. The input image data set (left) is first segmented into homogenous image objects (middle), which are then assigned to predefined classes according to decision rules (right).

The image objects are then assigned to the predefined classes according to decision rules or machine learning algorithms, which can be based on spectral, spatial, geometric, thematic or topologic criteria and expert knowledge. Spectral enhancements will be applied to the satellite images (e.g. the calculation of vegetation indices or Spectral Mixture analysis) in order to enhance classification accuracy. Figure 8 shows an example of the basic procedures of an object-based image analysis.

Visual reinterpretation and reclassification can be used to complement the object-based classification processes in areas with inadequate image quality (e.g. due to fog, smoke, topographic shadows, cloud shadows or clouds) or for classes that cannot easily be classified by automated procedures alone. Further, the interpreter has to be an expert with a background in tropical forest ecology, have local knowledge of the area under investigation, and have a profound understanding of the different remote sensing sensors applied. Interpretation errors or bias can be minimised through a visual quality control by a second interpreter. For areas with incorrect interpretation, corrections are done to match known conditions.

This reinterpretation phase can also bring additional ancillary information into the object-based interpretation results, such as soil types, rainfall distribution, geology, geomorphology or habitats. An understanding of site conditions is key to generating good and accurate classification. The more site-specific information an interpreter has, the less error bias there will be.



Photo: Ulet Ifansasti ©

Accuracy assessment



An independent accuracy assessment and verification of the classification results with reference data is an essential component of the processing chain.

To assess the accuracy of the preliminary land cover classification, a reinterpretation of samples of the original data (satellite imagery used) in an independent manner is acceptable (no collection of in-situ ground truthing samples is necessary at this stage). On the other hand, in order to assess the accuracy of the final land cover classification, a field survey has to be conducted during which field samples (ground truth data) will be collected.

When choosing the amount of samples to be collected in the field for the subsequent accuracy assessment, a balance between what is statistically sound and what is practically attainable must be found. General guidelines suggest collecting a minimum of 50 samples for each land cover class (Congalton and Green 1999). For larger areas (more than about 400,000 ha) it is suggested that a minimum of 75 samples should be collected per land cover class (Congalton and Green 1999).

In addition, the choice and distribution of the samples (sampling scheme) is an important component of an accuracy assessment. Five different sampling schemes are common (Congalton and Green 1999):

- **Simple random sampling:** Each sample unit in the study area has an equal chance of being selected. The main advantages here are good statistical properties that result from the random selection of samples.
- **Systematic sampling:** The sample units are selected at some equal interval over the study area. The main advantage here is the ease in sampling somewhat uniformly over the whole study area.
- **Stratified random sampling:** Similar to simple random sampling, but also uses prior knowledge of the study area to divide it into groups or strata (classes) and then each stratum (class) is randomly sampled. The main advantage here is that all strata (classes), no matter how small, will be included.

- **Cluster sampling:** Refers to the sampling of pixel groups rather than individual pixels. Other than this, it varies little from the other methods. This sampling scheme is frequently used to assess the accuracy of remotely sensed data, especially to collect information on many samples quickly.
- **Stratified systematic unaligned sampling:** Attempts to combine all positive aspects of random, systematic and stratification schemes by imposing additional randomness to a systematic sample.

Available human resources, accessibility in the field and budget/time constraints should all be taken into consideration when deciding which sampling scheme to use.

Finally, the accuracy analysis must provide an accuracy matrix considering user's and producer's accuracies and the overall accuracy. An accuracy matrix compares the land cover information from the reference field samples to the classification results. The overall accuracy shows the percentage of correctly classified reference samples among all reference samples. The producer's accuracy indicates how well the reference site's given cover type is classified. The user's accuracy, on the other hand, indicates the probability that a pixel classified into a given category actually represents that category on the ground.

The overall accuracy of the preliminary classification should be at least 70%, and for the final classification at least 80%.

For further information on accuracy assessments, Remote Sensing Thematic Accuracy Assessment: A Compendium (1994) by ASPRS and Assessing the Accuracy of Remotely Sensed Data: Principles and Practices by Congalton and Green (1999) are excellent references.

ASSIGNING THE LAND COVER CLASSES TO CARBON STOCK CLASSES

Once the images have been selected, pre-processed and a land cover classification conducted, the next step is to group the land cover into homogeneous carbon stock classes in order to indicate, in combination with field inventory data (LiDAR AGB calibration plots or forest inventory plots), potential HCS forest areas. The main purpose of the exercise is to differentiate:

- Low, Medium, and High Density Forest (LDF, MDF, HDF).
- Young Regenerating Forest (YRF).
- Cleared and degraded former forest, including Scrub (S) and Open Land (OL).
- Non-HCS areas such as roads, water bodies, and settlements.

As shown in Figure 9, the potential HCS forest cut-off lies between the Scrub and Young Regenerating Forest categories, where YRF, LDF, MDF, and HDF are considered HCS forest and S and OL are not considered HCS forest. In phase two of the HCS Approach methodology, some YRF may be released for development based on the results of the HCS Forest Patch Analysis Decision Tree.

The land cover types assigned to the carbon stock classes defined through this process can vary between different regions, dependent on the landscape and the type of land cover at the location of the development area. Table 1 shows a general description of what land cover is expected in the different carbon stock classes. Carbon stock classes mandatory for the HCS analysis are indicated in green; however, additional classes that are also of interest can be included as required. Note that the table includes qualitative factors that must be identified during the ground surveys.

“...group the land cover into homogeneous carbon stock classes in order to indicate, in combination with field inventory data (LiDAR AGB calibration plots or forest inventory plots), potential HCS forest areas.”

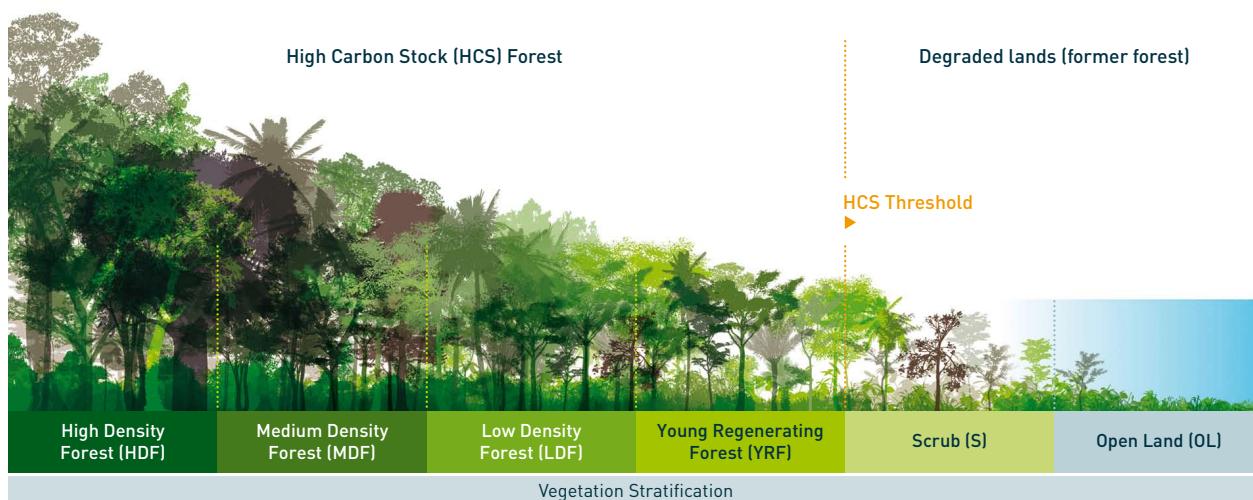


Figure 9: Vegetation Stratification

Table 1: Generic land cover categories

Carbon stock classes	Description
HDF, MDF, LDF	High Density Forest, Medium Density Forest and Low Density Forest Closed to open canopy natural forest ranging from high density to low density forest. Inventory data indicates presence of trees with diameter >30 cm and dominance of climax species.
YRF	Young Regenerating Forest Highly disturbed forest or forest areas regenerating to their original structure. Diameter distribution dominated by trees 10-30 cm and with higher frequency of pioneer species compared to LDF. This land cover class may contain small areas of smallholder agriculture. Note: abandoned plantations with less than 50% of basal area consisting of planted trees could fall in this category or above. Concentrations >50% of basal area would not be considered HCS forest but rather plantations and should be classified separately.
S	Scrub Land areas that were once forest but have been cleared in the recent past. Dominated by low scrub with limited canopy closure. Includes areas of tall grass and fern with scattered pioneer tree species. Occasional patches of older forest may be found within this category.
OL	Open Land Recently cleared land with mostly grass or crops. Few woody plants.
Examples of other Non-HCS land cover categories	
FP	Forest Plantation Large area of planted trees (e.g. rubber, Acacia).
AGRI	Agriculture estates For instance, large-scale oil palm estates overlapping with development areas.
MINE	Mining Area These can be further differentiated between licensed mining areas and overflow, unregulated/illegal mining areas.
SH	Smallholder agriculture and use These areas can be further differentiated among mixed forest gardens/ agroforestry systems, which could potentially serve as wildlife corridors, swidden/rotational gardening systems for subsistence food production, etc.
(Other)	Water bodies such as rivers and lakes.
	Built-up areas, settlements, roads, etc.



The descriptions of each land cover category are relatively clear. On the ground, there is a spectrum of vegetation cover type from forest through to bare land and the cut-offs between vegetation types are sometimes difficult to ascertain in the field. Field assessment should take into account not only the conditions within the plot boundaries, but also in the areas immediately adjacent to the plot, when assigning vegetation classification. When a plot is located across clear vegetation cover boundaries, such as across the transition from forest to pasture land, then the plot should be relocated into one or the other vegetation type.

Based on previous HCS Approach field plot data from Indonesia, the biometric measurements in the table below can be used as guidance in land cover classification:



Land cover classes		Trees with DBH > 30 cm	Canopy closure	Estimated molecular C t/ha	Comments
Forest	HDF	>50	>50%	>150	Dominated by trees with diameter >30 cm. Dominance of climax species, e.g. Dipterocarpus
	MDF	40-50/ha		90-150	
	LDF	30-40/ha		75-90	
YRF		15-30/ha	30-40%	35-75	Dominated by trees with diameter 10-30 cm and with higher frequency of pioneer species, e.g. Macaranga
S		5-15	<20%	15-35	Dominated by low scrub with limited canopy closure. Areas of tall grass and fern. Few trees which are predominantly pioneer species trees. Occasional patches of older trees.
OL		0-5	0%	0-15	

These guidelines need to be validated for other regions such as Tropical Africa and South America.

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APPENDIX: AN OVERVIEW OF OPTICAL MULTISPECTRAL SATELLITE IMAGE OPTIONS (SPATIAL RESOLUTION ≤10 M)

Satellite name	Overview	Spatial resolution
Sentinel-2A/2B	https://sentinel.esa.int/web/sentinel/missions/sentinel-2	multispectral: 10–60 m
SPOT-5 to 7	www.intelligence-airbusds.com/en/4388-spot-1-to-spot-5-satellite-images	multispectral: 6–20 m panchromatic: 1.5–5 m
RapidEye	www.planet.com/ www.planet.com/products/satellite-imagery/files/160625-RapidEye%20Image-Product-Specifications.pdf	multispectral: 5 m
KOMPSAT-2	https://directory.eoportal.org/web/eoportal/satellite-missions/k/kompsat-2	multispectral: 4 m panchromatic: 1 m
KOMPSAT-3	https://directory.eoportal.org/web/eoportal/satellite-missions/k/kompsat-3	multispectral: 2.8 m panchromatic: 0.7 m
IKONOS	www.euspaceimaging.com/products www.digitalglobe.com/resources/satellite-information	multispectral: 3.2 m panchromatic: 0.82 m
Pleiades-1A/1B	https://directory.eoportal.org/web/eoportal/satellite-missions/p/pleiades#sensors	multispectral: 2.8 m panchromatic: 0.7 m
Quickbird	www.digitalglobe.com www.digitalglobe.com/resources/satellite-information	multispectral: 2.16–2.44 m panchromatic: 0.55–0.61 m
WorldView-1	www.digitalglobe.com/ www.digitalglobe.com/resources/satellite-information	panchromatic: 0.50 m
WorldView-2	www.digitalglobe.com/ www.digitalglobe.com/resources/satellite-information	multispectral: 1.85 m panchromatic: 0.46 m
WorldView-3	www.digitalglobe.com/ www.digitalglobe.com/resources/satellite-information	multispectral: 1.24 m SWIR: 3.70 m CAVIS: 30 m panchromatic: 0.31 m
WorldView-4	www.digitalglobe.com/ www.digitalglobe.com/resources/satellite-information	multispectral: 1.24 m panchromatic: 0.31 m
GeoEye-1	www.digitalglobe.com/ www.digitalglobe.com/resources/satellite-information	multispectral: 1.65 m panchromatic: 0.41 m

Temporal resolution	Image capture dates	Free of costs	Available bands	Size of images
5 days	2015 – present	yes	multispectral: 13 bands	swath: 290 km tiles: 100 by 100 km
26 days (nadir) 2–3 days (off-nadir)	Spot-5: 2002 – 2015 Spot-6/7: 2012/2014 – present	no	multispectral: 4 bands panchromatic: 1 band	tiles: 60 by 60 km
5.5 days (nadir) 1 day (off-nadir)	2009 – present	no	multispectral: 5 bands	swath: 77 km tiles: 25 by 25 km
5 days	2006 – present	no	multispectral: 4 bands panchromatic: 1 band	swath: 15 km
5 days	2012 – present	no	multispectral: 4 bands panchromatic: 1 band	swath: 15 km
3 days	1999 – 2015	no	multispectral: 4 bands panchromatic: 1 band	swath: 11.3 km
1 days	2011 – present	no	multispectral: 4 bands panchromatic: 1 band	swath: 20 km
2–12 days	2001 – 2014	no	multispectral: 4 bands panchromatic: 1 band	swath: 14.9 – 16.8 km
1.7–5.4 days	2007 – present	no	panchromatic: 1 band	swath: 17.7 km
1.1–3.7 days	2009 – present	no	multispectral: 8 bands panchromatic: 1 band	swath: 16.4 km
<1.0–4.5 days	2014 – present	no	multispectral: 8 bands SWIR: 8 bands CAVIS: 12 bands panchromatic: 1 band	swath: 13.1 km
<1.0–4.5 days	2016 – present	no	multispectral: 4 bands panchromatic: 1 band	swath: 13.1 km
2.6 days	2008 – present	no	multispectral: 4 bands panchromatic: 1 band	swath: 15.3 km



Photo: Ulet Ifansasti ©

SECTION C

Using field plots to estimate carbon stock and finalise delineation of land cover classes: LiDAR AGB calibration plots and forest inventory plots

By George Kuru and Alex Thorp (Ata Marie Group Ltd) and Uwe Ballhorn and Peter Navratil (Remote Sensing Solutions GmbH).¹

¹ The authors are grateful to Sahat Artonang (Daemeter), Mike Senior (Proforest), Anders Lindhe (HCVRN), Grant Rosoman (Greenpeace) for helpful comments for this section.

INTRODUCTION

As described in the previous section, the first step in Phase 1 of a HCS assessment is to use airborne LiDAR and/or satellite imagery to stratify the land cover into the defined classes. The next step is to collect LiDAR calibration plots in order to derive a LiDAR above-ground biomass (AGB) model, or to sample these classes in the field and assign them average carbon values by measuring vegetation within forest inventory plots. This section explains how to plan and set up the LiDAR calibration or forest inventory plots, conduct measurements, calculate AGB, derive the LiDAR AGB model and finalise the vegetation classification (in order to indicate potential HCS forest areas). The following guidance is intended for practitioners who are experienced in using statistical analysis to inform sampling techniques.

LiDAR calibration plots

To derive AGB from airborne LiDAR 3D point clouds, a predictive statistical model must be developed at each site using in-situ AGB estimates inferred from LiDAR calibration plots established in the field (see Module 4a; Options 1 and 2). These calibration plots must be distributed across the full range of forest types and degradation levels typical for the site (e.g. old-growth forest and secondary/disturbed forest, dryland and swamp forest, riparian forest, scrubland, existing plantations, etc.). To assure this distribution, the location of these calibration plots is derived from the satellite-based vegetation classification described in Module 4b, and plots should be located throughout the whole project area. At least 50 plots must be established to train the model used to derive AGB from the LiDAR 3D point cloud height and structure metrics.

Forest inventory plots

When choosing Option 3 (see Module 4a), the assessment of tree biomass within potential HCS forest classes is based on forest inventory plots. The largest proportion of field samples are distributed in those classes defined as Young Regenerating Forest (YRF) and Low Density Forest (LDF). Although Scrub (S) and Open Land (OL) are likely to contain very low levels of carbon, the HCS assessment process does seek to sample a limited number of field plots to confirm this assumption. Other classes, such as existing plantation areas (e.g. oil palm and food crops), and areas not to be developed including community areas, peatlands, and HCV areas, are generally not assessed as it is expected that these areas are separately demarcated unless required for carbon accounting.

The appropriate number of samples to measure in each class is difficult to predict at the beginning of the field assessment unless locally available data on variability is available. In the absence of such data, sufficient field time must be budgeted to increase the sample size as necessary to achieve the precision targets. It should be recognised that it is costly to return to the site at a later date to undertake further sampling.

The recommended precision targets for the HCS assessment are as follows:

- Forest carbon stock inventories must be planned for the purposes of attaining carbon stock estimates at a 90% confidence interval of the total carbon stocks. Once in the field, an adaptive process may be needed to refine the sample size to achieve the 90% level of confidence.
- Variability within one vegetation class (for instance, within the HDF category) may exceed the 90% precision target, provided that in the final analysis the classes are statistically different from one another.

The number of plots planned must be sufficient to meet the precision targets for each major class in each region. A simple equation for estimating the number of samples is:

$$N = t^2 s^2 / E^2$$

Where:

N = samples to estimate mean to $\pm E$.

t = t-value from Student's t-test table for 90% confidence interval.

s = standard deviation estimated based on existing data sets from similar forest types (government forestry departments often have relevant data).

E = probable error, expressed as a percentage of the estimated mean value.

The resulting number must be rounded to the nearest whole number. For example, to survey a HCS vegetation class with an estimated carbon stock level of 57 tonnes/ha and an estimated standard deviation of 35 tonnes/ha with an allowable sample error of $\pm 10\%$ of the average carbon stock and with 90% confidence limits, the number of sample plots is calculated as follows:

$$N = t_{st 0.9}^2 * s^2 / E^2 = 1.66^2 * 35^2 / (57 * 10\%)^2 = 62.6$$

Rounded to N=63.

Equipment needed for the field work

Plot tree measurement data should be manually recorded in field books. An example of a field book layout is shown in Appendix 1 of Module 4c, along with an equipment list for inventory teams. The equipment required is the same for LiDAR AGB calibration or forest inventory plot collection.

Selecting the survey team

A single survey team is generally made up of between 6–8 people as follows (note that survey team composition is the same for LiDAR AGB calibration or forest inventory plots collection):

Position	No. of persons	Description and role
Team leader	1	Graduate forester with inventory experience Responsible for team organisation and performance, in particular the following: <ul style="list-style-type: none"> • Navigating to transect starting point • Keeping field book • Operating GPS • Tree height measurement • Capturing plot photos • Data management and handover
Species identification technician	1	Botanist Core role is identification of tree species in plots. Must be able to identify the majority of trees to species level and less common species to genus level.
Measuring assistant	1	Experienced technician Core role is to measure diameters and label trees. It is preferable, but not essential, for the assistant to be familiar with local tree species names.
Plot cleaner	1	Role: responsible for cleaning vines and climbers off trees to enable easier diameter and height measurement.
Hip chain operator	1	Role: responsible for measuring transect length and location of plot centre points along the transect.
Compass man	1	Role: responsible for ensuring transect lines are cut on the correct pre-determined compass bearing.
Line cutter	1–2	Role: responsible for clearing the transect line to enable rapid mobilisation to plot points.

The number of team members required will vary depending on skill levels, as well as conditions in the forest. The team leader will decide the composition of the team.



For efficient measurement, the team needs to be able to mobilise to the measuring site quickly and spend a whole day working uninterrupted. Logistical support for the whole team, including local guides and suitable transport, is therefore imperative. Where access is difficult, it may be more efficient for teams to set up a camp. In this case, camping equipment will need to be supplied and a cook must be added to the team.

Multiple teams should be employed for large surveys. A logistics manager should be appointed to ensure teams receive the necessary logistical support, and an inventory data manager engaged to carry out data entry and general data management. Joint training exercises should be held at the start of the inventory period to ensure that all team leaders understand and implement procedures in the same way.

PLOT DESIGN GUIDELINES

LiDAR calibration plots

At least 50 LiDAR calibration plots must be established. These must be distributed across the full range of forest types and degradation levels typical for the site. To assure this distribution, the location of calibration plots must be derived from the satellite-based vegetation classification (see Module 4b) and be situated throughout the entire project area. The method for setting up LiDAR calibration plots is described below.

Navigating and setting up LiDAR calibration plots

The location of the LiDAR calibration plots is determined using GIS software. The coordinates of each individual plot must be uploaded into GPS devices.

Field team leaders must be provided with the following information for each LiDAR calibration plot:

- Map showing access routes and plot points.
- Plot centre point coordinates (uploaded into GPS devices).
- A list of plots to be measured.

Plots must be set up according to the following steps:

1. Navigate to the initial access point using GPS.
2. Traverse the land to the centre point of the first plot using GPS.
3. Identify the actual plot location using GPS.
Each plot must be carefully geolocated to at least 5 m accuracy.
4. Repeat Step 2 for each subsequent plot planned for measurement.

Plots must not be moved for any reason. If a plot cannot be measured due to safety concerns it must be noted as 'not measured' and the sampling must resume at the subsequent plot centre point.

LiDAR calibration plot size and shape

The recommended LiDAR calibration plot design is two concentric circles from a centre point, with a total area of at least 2,500 m² or 0.25 ha. Circular plots are preferred to rectangular plots because they minimise the potential for error caused by slope factors and physical obstacles that may skew plot boundary lines (see Figure 1).

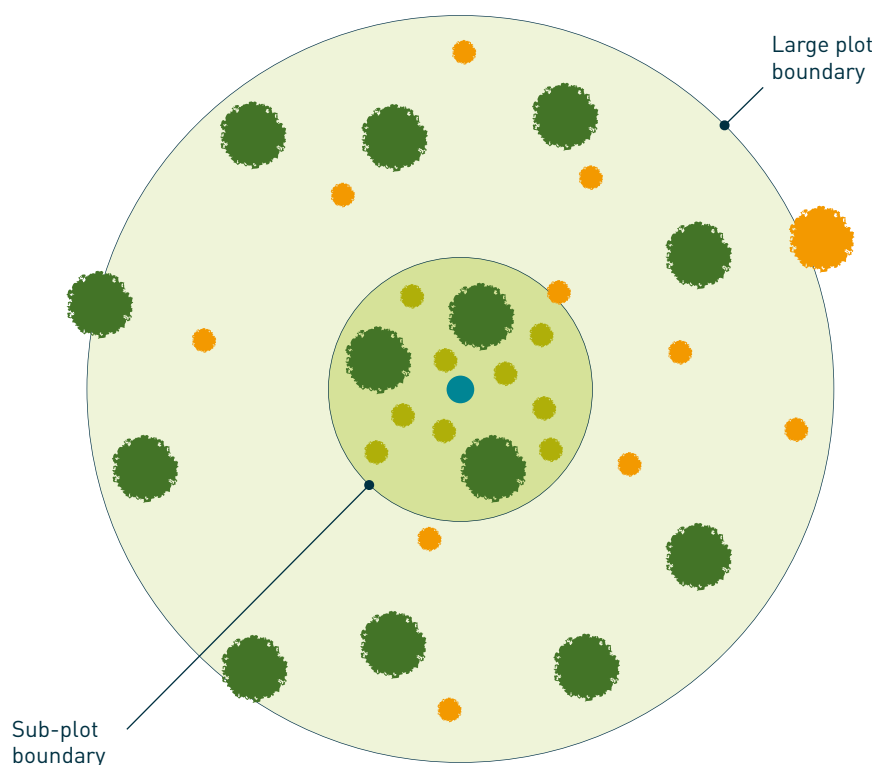
“Because field sampling activities will likely lead to direct interactions with community members, local communities should already be informed about the HCS Approach and process before the collection of ground truthing data, LiDAR calibration or forest inventory plots.”

LiDAR calibration plot demarcation

1. Place a pole at the centre of the plot. Label the pole with flagging tape. Record the plot ID on the flagging tape. Standing trees must not be used as plot markers.
2. Capture the GPS waypoint at the centre point of the plot and write the waypoint number in the field book. Each plot must be carefully geo-located to at least 5 m accuracy. Waypoint numbers should be the running number produced by the GPS. Do not edit this number.
3. From the centre point, the first sub-plot is measured by using a measurement tape or a precision rangefinder to a horizontal distance of 6 m. A second plot is then established by measuring a horizontal distance of 30 m with a precision rangefinder.

4. The following identification information must be recorded in the field book for all LiDAR calibration plots:

- Development area name.
- Date.
- Field team leader name.
- Plot number.
- GPS waypoint number for plot centre point.
- Visual assessment of the HCS class in plot based on HCS definitions provided.
- Soil/underfoot conditions (e.g. organic/peat soil, mineral soil, marine clay soil, standing water, etc.).
- General description of the plot and surrounding area, including evidence of fire, logging, and other human activity (e.g. rubber or other agriculture crops).








Plot	Plot radius (m)	Plot sample area (m ²)	Tree DBH measured (cm)
Sub-plot	6	~113	2–9.9
Large Plot	30	~2827	10 up
Trees DBH 2–9.9 cm	Trees DBH 10 cm up	Plot centre	
Measured 	Measured 		
Not measured 	Not measured 		

Figure 10: LiDAR calibration plot layout

MODULE 4 FOREST AND VEGETATION STRATIFICATION

SECTION C: USING FIELD PLOTS TO ESTIMATE CARBON STOCK AND FINALISE DELINEATION OF LAND COVER CLASSES: LIDAR AGB CALIBRATION PLOTS AND FOREST INVENTORY PLOTS

Forest inventory plots



Plots can be located randomly or systematically within a class. Random sampling is a statistically more thorough and robust approach, but is generally slower than systematic sampling and can be more expensive. Systematic plot location is usually cheaper and easier to implement in the field, allowing a greater number of plots to be measured within a given time frame. Plots can be located along a grid formation, or completed along transect lines spaced evenly across the class without any bias. A combination of systematic and random sampling can also be used for increased accuracy. The methods for setting up forest inventory plots systematically and randomly are described below. Both sampling designs are accepted in the HCS Approach.

Navigating and setting up systematically-located forest inventory plots using transects

Field team leaders must be provided with information for each transect, including:

- Map showing access routes and transect starting point.
- Transect starting point coordinates (uploaded into GPS devices).
- Transect compass bearing.
- Transect length in kilometres.
- The distance between plots.
- A list of plots to be measured.

Transect start points are normally located at convenient positions along roads, rivers, canals or other access routes.

The distance between plots is generally dictated by the scale of the study area. Where large forest areas are being sampled and inventory planners seek broader coverage, this distance will be increased. The distance between plots is usually either 75 m or 100 m, but there is no fixed rule.

Transects must be set up according to the following steps:

1. Navigate to the start point of the nominated transect line using a GPS device, and save a waypoint at the exact location of the start point. Through recent experience, Garmin GPS receivers are preferred as these are single frequency and usually have no problems operating under heavy forest canopy. They are also accurate up to 5 m, which is suitable for this type of survey.
2. Place a pole at the start point. Label the pole with flagging tape. Record on the flagging tape the transect number and its compass bearing.
3. Traverse the land along the planned compass bearing. The transect should be located strictly along the planned compass bearing route. If the field team meets a significant obstacle, such as a cliff or waterway, the survey team should detour around the obstacle if possible. The survey should then be restarted at the nearest possible point along the transect route. Otherwise, the survey team should simply terminate the survey work on the transect.
4. Plot centre points must be located systematically along the transect at the pre-defined spacing. Note that plot locations do not require adjustment for slope along the transect line, provided the plot locations are accurately measured by GPS.

Plots must not be moved for any reason. If a plot cannot be measured due to safety concerns, such as extreme slope, or hanging tree limbs, or if it is within a watercourse (river or stream), it must be noted as 'not measured' and the sampling must resume at the next plot centre point. The observation must also be marked on the plot map.

Navigating and setting up forest inventory plots without transects

Under this method of sampling, random or systematic plot locations are generated using GIS software. Systematic plots are typically located using a grid formation. In either case, coordinates of each individual plot must be uploaded into GPS devices.

Field team leaders must be provided with information for each transect, including:

- Map showing access routes and plot points.
- Plot centre point coordinates (uploaded into GPS devices).
- List of plots to be measured.

Plots must be set up according to the following steps:

1. Navigate to the initial access point using GPS.
2. Traverse the land to the centre point of the first plot using GPS.
3. Identify the actual plot location using GPS.
4. Repeat Step 2 for each subsequent plot planned for measurement.

As stated previously, plots must not be moved for any reason. If a plot cannot be measured due to safety concerns it must be noted as 'not measured' and the sampling must resume at the subsequent plot centre point.



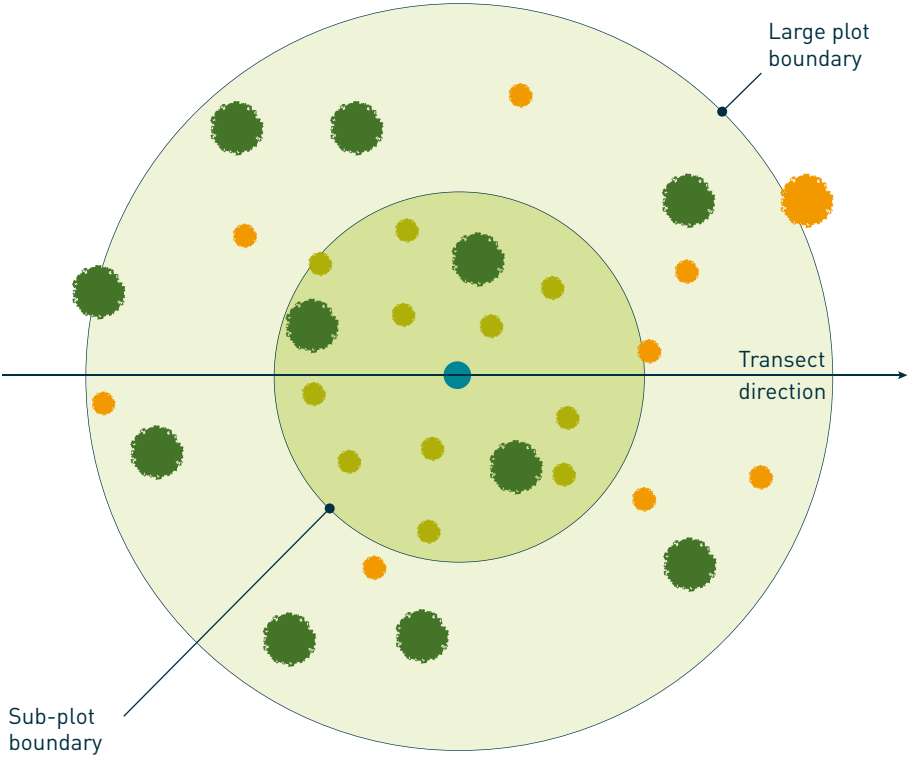
Forest inventory plot size and shape

The same kind of plot is used for random, systematic and transect sampling. The recommended sample plot design is two concentric circles from a centre point with a total area of 500 m² or 0.05 ha. Circular plots are preferred to rectangular plots because they minimise the potential for error caused by slope factors and physical obstacles that may skew plot boundary lines (see Figure 11).

Forest inventory plot demarcation

1. Place a pole at the centre of the plot. Label the pole with flagging tape. Record the plot ID on the flagging tape. Standing trees must not be used as plot markers.
2. Capture the GPS waypoint at the centre point of the plot and write the waypoint number in the field book. Waypoint numbers should be the running number produced by the GPS. Do not edit this number.
3. From the centre point, the first sub-plot is measured using a measurement tape or a precision rangefinder to a horizontal distance of 5.64 m. A second plot is then established by measuring a horizontal distance of 12.61 m with a precision rangefinder.
4. The following identification information must be recorded in the field book for all forest inventory plots:

- Development area name.
- Date.
- Field team leader name.
- Transect and plot number.
- GPS waypoint number for plot centre point.
- HCS class in plot based on generic definitions provided.
- Soil/underfoot conditions (e.g. organic/peat soil, mineral soil, marine clay soil, standing water, etc.).
- General description of the plot and surrounding area, including evidence of fire, logging, and other human activity (e.g. rubber or other agriculture crops).








Plot	Plot radius (m)	Plot sample area (m²)	Tree DBH measured (cm)
Sub-plot	5.64	100	5–14.9
Large Plot	12.61	500	15 up
Trees DBH 5–14.9 cm	Trees DBH 15 cm up	Plot centre	
Measured 	Measured 		
Not measured 	Not measured 		

Figure 11: Forest inventory plot layout

FOREST MEASUREMENT GUIDELINES

The focus of vegetation measurement is on large plant species, which usually comprise the large majority of AGB. Other forest carbon pools are not measured because they are either relatively small in size (e.g. forest understorey) and do not store much carbon, or are difficult and expensive to assess (e.g. below-ground biomass, deadwood and soil organic matter).

Large plant species are defined as those having a diameter at breast height (DBH) greater than or equal to 5 cm. This includes both tree and non-tree species. Breast height for the DBH measurement is defined as 1.3 metres.

Large plant species (referred to as 'trees' for simplicity, but also including non-tree species such as some palms) are measured using the following steps:

- 1. Identification of 'in' trees:** A tree is defined as an 'in' tree if the centre of its stem at DBH is within the boundaries of the plot. Trees on the edge of the plot (borderline trees) must be checked using a nylon rope marked at the correct plot radii (see Figure 12).
- 2. Flagging tape:** Each tree is labelled with flagging tape. The label must indicate the tree number as recorded in the field book.
- 3. DBH measurement:** All trees greater or equal to 10 cm (LiDAR calibration plot) or 15 cm (forest inventory plot) DBH shall be measured in the large plot. In addition to the large trees, all trees greater than or equal to 2 cm (LiDAR calibration plot) or 5 cm (forest inventory plot) and less than 10 cm (LiDAR calibration plot) or 15 cm (forest inventory plot) DBH shall be measured in the small plot (see Figure 13).

4. Height measurement: Depending on the eventual allometric equation used, it may also be necessary to measure total tree heights. Tree heights should preferably be measured using electronic meters such as the Haglof Vertex VI (ultrasound technology) or the TruPulse 200 (laser technology). These calculate height automatically based on readings taken to the top and bottom of the tree, plus, in some cases, a reading of horizontal distance. Once the user is familiar with their mode of operation, these meters are practical to use and measurements can be carried out by one person (usually the team leader). Height measurement with clinometers is also possible but tends to be slow and more prone to error. Where allometrics require an estimate of total tree height, there are two options for generation of height data: measuring a subset of trees and then deriving a diameter-tree height regression from the measured trees, or direct measurement of all trees.

In all cases, the following is important when measuring tree heights:

- Identify the target point before using the meter.
- Ensure a clear line of sight to the target. In some cases, interference from underbrush may impact results (refer to equipment manuals).
- Distance from the tree should be such that the angle to target (e.g. top of the tree) does not exceed 60 degrees.

5. Species: All trees measured in the plot must be identified to genus level and preferably to species level. This information is needed in the allometric equation, and to be able to describe forest composition and structure in a general way. As stated previously, botanists should be part of the field team; local names can be noted in the field book and translated to species names later on. If a genus cannot be identified, photographs and botanical samples must be collected and marked so that experts can identify them later.

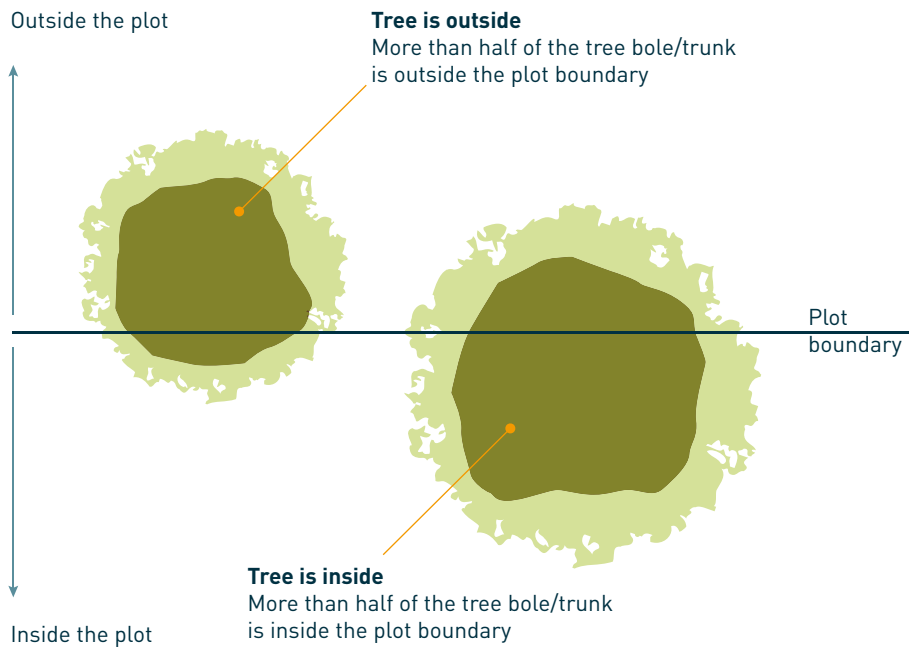


Figure 12: Deciding on borderline trees

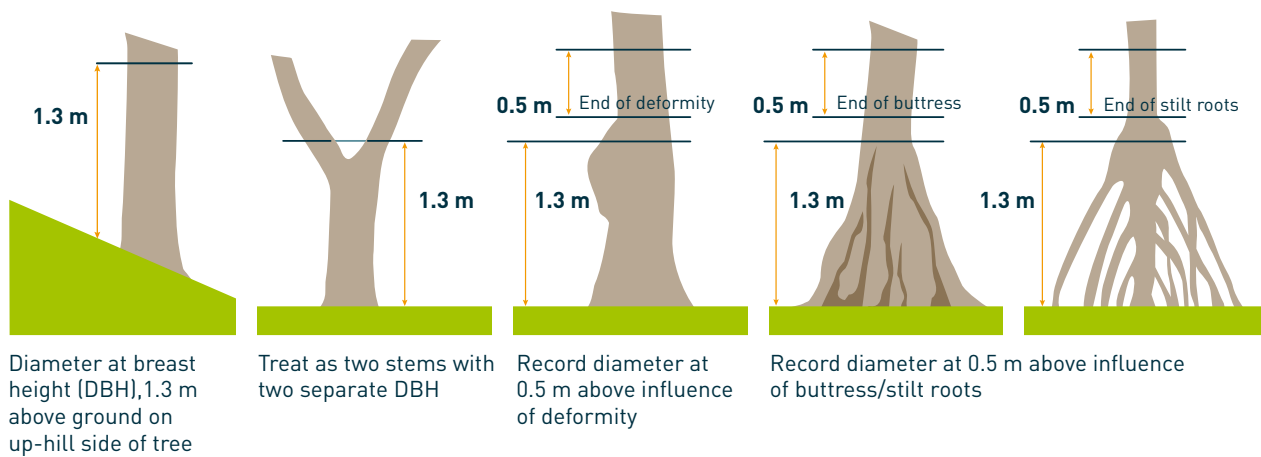


Figure 13: Diameter measurement method



Photo: Remote Sensing Solutions GmbH ©

PLOT PHOTOGRAPHS

For all plots in the forest, five digital photographs should be taken at the centre of each plot. Four photographs will be orientated in turn to the north, south, east and west, and one photo will point directly up to show the canopy density. The photographs should illustrate the basic structure and density of the vegetation at each plot. The GPS tracking function should be kept on at all times during field measurement to enable the photographs to be geo-referenced.

“The focus of vegetation measurement is on large plant species, which usually comprise the large majority of AGB.”

ANALYSIS AND REPORTING

Data entry and management

Team leaders must download GPS track data, waypoint data and photos to personal computers in Ozi/Garmin format every evening, where practical to do so. In addition to data and photographs, team leaders must write a short, two- to three-paragraph description of forest conditions and record other relevant comments. Additionally, statistical calculations should be conducted every night in order to adjust the sampling to achieve the target accuracy levels.

Completed field books, GPS data and photos must be delivered to the inventory data manager, who will then enter the plot data into a spreadsheet and compile all information into a logical format for handover to the GIS team. Team leaders must check the data entered for any inconsistency.

AGB and carbon calculations within the plots

Once the data is entered, each plot is analysed to provide estimates of stems per hectare, AGB and carbon stocks. The following calculations are the same for the LiDAR calibration plots and the forest inventory plots.

Stems per hectare

The average number of stems per hectare is calculated from the plot size. The equation used is:

$$\text{Stems per ha} = (\text{Count of trees in the plot}) / (\text{Plot size in ha})$$

AGB and carbon content

The HCS assessment process uses allometric equations to estimate biomass. Allometric equations help estimate difficult-to-measure tree characteristics by instead measuring correlated attributes of the same tree. For instance, DBH can be measured and then used to determine the biomass of the entire plant above ground.

Many allometric equations are in use around the world; some are specific to one forest type or tree species, while others are more generic and cover a broader range of situations. Allometric equations are typically developed from large samples to improve accuracy. It is important, however, to recognise that these equations have usually been generated for non-degraded forests and that they might not be appropriate for degraded forests where the growing environment has been substantially altered. The Scientific Advisory Committee of the HCS Approach Steering Group is in the process of preparing a list of approved allometric equations for different regions of interest, and welcomes advice and input on this topic.

When using allometric equations it must be noted that:

- The specific gravity measures the dry density of the wood (here the oven-dry weight divided by green volume). If the species is known, the specific gravity must be inferred from databases of established wood densities – for instance, the Global Wood Density Database (Zanne et al. 2000) – and averaged to the genus level if only the genus is known. Otherwise, a default value of 0.55 g/cm³ for tropical tree species and 0.247 g/cm³ for palm species should be used. This is based on average values provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (Volume 4. Agriculture, Forestry and Other Land Use), and the World Agroforestry Centre (WAC) Wood Density Database.



- The carbon conversion factor estimates the carbon of the vegetation biomass. The IPCC standard value of 0.47 can be used.
- The equation for estimating tree carbon mass per ha is:

$$\text{Total Carbon (tonne/ha)} = \Sigma ([\text{Tree Carbon}]) / [\text{Plot size in ha}]$$

- Separate calculations of volume will need to be made when estimating tree volume in sub-plots because the plot size will differ between main plot and sub-plot.

LiDAR calibration and LiDAR AGB model development

To derive AGB from airborne LiDAR point clouds, a predictive statistical model should be developed at each site using in-situ based AGB estimates inferred from the LiDAR calibration plots. At least 50 plots should be established to train the model used to derive AGB from normalised LiDAR 3D point cloud height and structure metrics. To normalise LiDAR 3D point clouds, the terrain elevation at each point is subtracted from its elevation, which results in the height of the vegetation (on the contrary to the height, for example, above ground sea level). This statistical model should itself be derived through correlating these normalised LiDAR 3D point cloud height and structure metrics to AGB estimates at the LiDAR calibration plot location. It is recommended to use metrics such as the Centroid Height (CH) or the Quadratic Mean Canopy Height (QMCH) (Jubanski et al. 2013; Englhart et al. 2013; Asner et al. 2010).

As the estimation of AGB is based on an area approach it is not necessary to accurately extract individual trees, which would be complicated and time consuming.

Forest inventory estimation

Following the calculation of stems per hectare, AGB and carbon stock per plot, these figures should be summarised per vegetation class. The results should be placed into table formats as below.

Summary of statistical analysis of carbon stock results per vegetation class

Land cover class	Number of plots	Stems per hectare	Biomass	Average Carbon Stock	Stdev	E (+/- 10%)	Precision (+/-90% CL)	Plots required to estimate to +/-10%
		/ha	kg/ha	tonne/ha				
Forest								
YRF								
Scrub								
Open Land								

Stand and Stock Table

Land cover class	Number of plots	Stems per hectare by DBH class					Carbon (tonnes per ha) by DBH class				
		Total	5.0-14.9	15.0-29.9	30.0-49.9	50.0+	Total	5.0-14.9	15.0-29.9	30.0-49.9	50.0+
		stems/ha					tonne/ha				
Forest											
YRF											
Scrub											
Open Land											

An ANOVA test should also be applied to determine whether there are significant differences in the carbon estimates per class.

ANOVA						
Source	SS	df	MS	F	F_90% CL	Signif Diff
Model	499,422	4	124,856	105	1.96	Yes
Error	519,794	437	1,189			
Total	1,019,216	441				

This should be followed by, for example, a Scheffé pairwise multiple comparisons test to determine which groups are significantly different.

Scheffé pairwise multiple comparisons test



Scheffé Analysis			
Variables	N	SS	Avg
Pine	16	44,712	148.5
HK	167	371,344	94.4
BT	204	99,278	46.0
BM	45	4,111	10.9
LT	10	348	2.6
	SSE	519,794	
	MSE	1,189	
	p	0.10	
	k	5	
	N	442	
	F(p, k-1, N-k)	1.96	

Pairwise Differences Between Sample Means					
Type	Pine	HK	BT	BM	LT
Pine		54.1	102.5	137.6	145.9
HK			48.4	83.5	91.8
BT				35.1	43.4
BM					8.2
LT					

Scheffé Comparison Values					
Type	Pine	HK	BT	BM	LT
Pine		25.3	25.1	28.1	38.9
HK			10.1	16.2	31.4
BT				15.9	31.3
BM					33.7
LT					

Significant Differences					
Type	Pine	HK	BT	BM	LT
Pine		Yes	Yes	Yes	Yes
HK			Yes	Yes	Yes
BT				Yes	Yes
BM					No
LT					

Canopy density

LiDAR

A further useful parameter for the HCS assessment is crown density. There is a variety of available LiDAR software (e.g. LAStools: rapidlasso.com/lastools/) able to calculate canopy density for different spatial resolutions at different height thresholds.

Forest inventory

Canopy density is typically estimated on the ground as the percentage of light interception by the tree canopy. Light interception is either visually assessed, or assessed using light measurement instruments.

For the purposes of HCS assessment, we recommend that light interception is classified according to four density classes.

Density	Light interception
Bare land	0-10%
Low	10-25%
Medium	25-50%
High	>50%



Finally, potential HCS forest is identified and delineated through the integration of all the data compiled in Phase 1 by a trained expert. This trained expert should have a profound background in tropical forest and landscape ecology, have local knowledge of the area under investigation, and have an understanding of the different remote sensing and GIS methodologies applied. Ancillary information, such as development area boundaries, current land use, infrastructure, peatland extent, riparian zones and HCV areas identified in the HCV assessment, should also be incorporated in this assessment.

The final output is a map of indicative HCS forest areas, including an average carbon value for each vegetation class, as well as a physical description of the vegetation in each class. This map of potential HCS forest is one input to Phase 2 (Analysing HCS patches and creating an indicative conservation/development map).

The second half of this toolkit explains Phase 2, which involves making conservation recommendations for each individual forest patch and integrating these recommendations – with HCV areas, areas important for community needs, riparian zones, peatlands, and other relevant categories of land – in order to create the final conservation and development plan.

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Field book layout

Estate/development area name:		
Field Team Leader:		Date:
Line/Plot:		Waypoint No:
Land Cover:		
Tree	DBH	Species or local name
1	1	
2	2	
3	3	
4	4	
5	5	
6	6	
7	7	
8	8	
etc.	etc.	
General description of the plot and surrounding area: (e.g. evidence of fire, mature rubber trees outside plot, etc.)		



APPENDIX 1: INVENTORY FIELD FORM AND INVENTORY TEAM EQUIPMENT LIST

Inventory team recommended equipment list

Type & Model	Number	Comment
GPS	Garmin GPSMAP (62S, 64S or similar)	1
Height Meter	Haglof Vertex VI or Laser Technology Inc. TruPulse 200	1
Camera	Digital camera	1
Tapes	Diameter tapes – 5 m	1
	Diameter tapes – 1.8 m	2
	50 m tape – TajimaYSR-50	1
	20 m tape – TajimaYSR-20	1
	Flagging tape	20
Hip chain	Chainman II with belt	1
Batteries	AA	As required
	Others as required	As required
Thread	Hip Chain Thread	As required
Compass	SILVA® Starter Type 1-2-3	1
	Bush knives & sharpeners	4
	First aid kits	1
	Backpack	2
	Pencils and pens	1 box
	Waterproof permanent board marker	1 box
	1 KENKO box cutter	2
	1 ruler 30 cm	1
	Stapler and staples	2
	Field books	4
	Ziplock type plastic bags	

APPENDIX 2: ADDITIONAL BIODIVERSITY ANALYSIS TOOLS

Biodiversity indices

Biodiversity indices are a quantitative measure that reflects how many different types of species, genera and families are present in a forest type. Many different indices exist, and we recommend the following indices as easy and robust measures of biodiversity:²

Richness: Simply quantifies how many different types of species, genera and families exist in each corresponding HCS class. Richness is a simple measure so it is a popular diversity index in ecology, but it does not consider abundance. We recommend that the numbers of identified and identified species are listed thus:

Description	Family	Genus	Species	
Forest	41	83	Identified	100
			Unidentified	29
			Total	129
YRF	45	85	Identified	94
			Unidentified	22
			Total	116

True diversity: True diversity, or the effective number of types, refers to the number of equally abundant types needed for the average proportional abundance of the types to equal that observed in the data set of interest (where all types may not be equally abundant). True diversity in a data set is calculated by first taking the weighted generalised mean M_{q-1} of the proportional abundances of the types in the data set, and then taking the reciprocal of this. The equation is:

$${}^qD = \frac{1}{M_{q-1}} = \frac{1}{\sqrt[q-1]{\sum_{i=1}^R p_i p_i^{q-1}}} = \left(\sum_{i=1}^R p_i^q \right)^{1/(1-q)}$$

Where the denominator M_{q-1} equals the average proportional abundance of the types in the data set as calculated with the weighted generalised mean with exponent $q-1$. In the equation, R is richness (the total number of types in the data set), and the proportional abundance of the i th type is p_i .

Forest Integrity Assessment

Assessing and monitoring forest biodiversity is challenging, particularly for smallholders, communities and medium-sized entities. The Forest Integrity Assessment (FIA) has been developed with support from the HCV Resource Network, WWF and Proforest to meet the need for an 'ecological assessment tool for use by non-ecologists'. The tool is available from the HCVRN website (www.hcvnetwork.org).

The FIA tool uses a checklist approach that is designed to overcome the constraints of non-experts. Assessments focus on habitats as indirect proxies for biodiversity, rather than on species, using natural forest types little affected by large-scale human activities as reference.

The FIA tool has been proposed as a useful analysis of biodiversity in patches. The tool would complement carbon assessment work and could be carried out by field inventory teams at little or no additional cost.

² https://en.wikipedia.org/wiki/Diversity_index





FURTHER INFORMATION

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