IWOKRAMA INTERNATIONAL CENTRE FOR RAINFOREST CONSERVATION AND DEVELOPMENT

# PROCEDURES FOR ESTABLISHING PERMANENT SAMPLE PLOTS FOR FOREST MONITORING IN THE IWOKRAMA FOREST

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# Procedures for Establishing Permanent Sample Plots for Forest Monitoring in the Iwokrama Forest

## 1. Introduction

Permanent sample plots (PSPs) are permanently demarcated areas of forest, typically of one hectare, which are periodically remeasured (Alder and Synnott, 1992).

PSPs are the base of growth and yield studies. They allow for gaining knowledge on forest changes under different situations. Forest management, then, can be based on this knowledge and be continuously adapted to new information. With Iwokrama starting in 2007 the sustainable management of some 108,000 ha of forest for timber production, there is a need of a system of PSPs for both sampling and experimental purposes.

These procedures take into account relevant antecedents of PSPs in Guyana and Iwokrama, international theory on the subject, particularly the above mentioned work by Alder and Synnott, and the recent effort by the Guyana Forestry Commission (GFC) for attaining the standardization of this and other forest research methodology in Guyana. The Draft Permanent Sample Plot Guidelines produced by the GFC (August 2006) were extensively used in some sections.

## 2. Objective of a system of permanent sample plots (PSPs)

The system of PSPs in the Iwokrama Forest will be able to register forest change within existing and regular conditions, such as those found in the unlogged forest and in those areas where regular management plan prescriptions are applied. These are the sampling functions of the PSPs, those that provide most of the data for growth and yield models. At the same time, experimental PSPs will be used for exploring different management regimes, like different harvest intensities, to be applied at field trials at a scale which could also facilitate other monitoring and analyses.

Finally, in line with goals of environmental conservation and sustainable use of the forest biodiversity, the PSPs will also attempt to provide information on other important elements related to these goals, such as non-timber forest products, the presence of invasive alien species, and carbon storage in specific carbon pools of the forest.

## 3. Principles of the PSP system

The PSP system to be established will have the following characteristics:

Plots will consist of one-hectare, 100 m x 100 m square plots divided into 20 m x 20 m quadrats, where all trees larger than 20 cm dbh will be measured. Smaller trees of the pole, sapling and seedling categories will be measured in subplots of the main plot.

Plots will be located in areas to be logged in a near future and in reserve areas where no logging is planned.

Plot location will take into account forest type, giving priority to the forest types that are found in the Net Operable Area (NOA) of the Sustainable Utilization Area (SUA).

The GIS grid developed for the pre-harvest inventory, which divides the Iwokrama Forest in 100 ha blocks of 1,000 m x 1,000 m, constitutes the geographical framework for plot location.

Both sample plots and experimental plots will be established. Experimental plots will have the same characteristics as other plots, and will be located on blocks (100 ha) where a uniform treatment will be given to the forest throughout the block.

## 4. Sample plots and experimental plots

By definition, sample plots are established to test existing, regular conditions. Those conditions are basically two in the Iwokrama Forest, unlogged forest and forest logged under the management plan prescriptions (ITI, 2007). Following these prescriptions, some 20 cubic meters per ha are harvested in one intervention within a 60-year cycle. This volume may be lower for the two forest types covering lower area in the NOA (Ibid.). Forest types and their areas in the NOA are shown in Table 1.

*Table 1. Forest types in the NOA of the Iwokrama Forest*

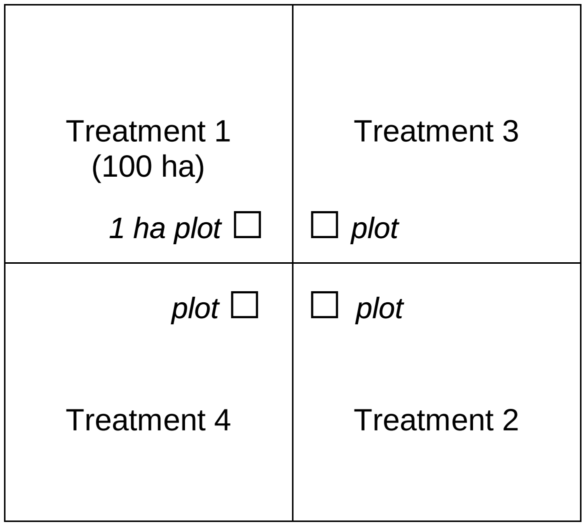
| *Forest type* | *Area in NOA (ha)* |
|---|---:|
| Mixed Greenheart, Black Kakaralli, Wamara Forest (MGK) | 56,650.3 |
| Mora, Manikole, Crabwood, Trysil Forest (MMC) | 30,768.0 |
| Mixed Greenheart, Sand Baromalli, Soft Wallaba Forest (MGB) | 15,859.2 |
| Wallaba Forest (WF) | 5,714.3 |
| *Total* | *108,991.8* |

Experimental plots will be also established to explore other treatments. These new treatments will be applied on large scale field trials of 100 ha, allowing for carrying out other types of studies on the area. Experimental plots will have the same size and characteristics as other plots.

The 20 $m^3$/ha to be extracted in each intervention is in line with the guidelines of the GFC (2002) Code of Practice for Timber Harvesting (CoP). This is a general conservative estimate which does not discriminate between forest types, site qualities and logged and unlogged forests. Unlogged forests like the Iwokrama Forest contain high volumes of commercial timber in comparison to forests that have gone through logging interventions in the past. At the same time, this rule of thumb has been strongly influenced by the purpose of ensuring sustained productivity of a restricted number of species, particularly Greenheart. This suggests that, within a certain range, higher extraction levels may be sustainable and consistent with the permanent objective of maximizing forest benefits by promoting diversification and the utilization of lesser known commercial timber species. Experimental plots will be established on areas where harvest intensities of 17 $m^3$/ha, 20 $m^3$/ha, 23 $m^3$/ha and 26 $m^3$/ha will be applied.

The location of the experimental plots within the larger 100 ha blocks, where a uniform treatment will be applied, may look as shown in the figure below:

*Figure 1. Location of experimental plots within contiguous 100 ha blocks.*




This location of plots and treatments may allow for analyzing results of the experimental plots within a randomized complete block design if, in the future, replications are carried out. In this first stage, which covers the execution of the ITTO-funded project Implementation of the Sustainable Forest Management Program at the Iwokrama International Center, only one set of four experimental plots can be established. This set will be located on the largest forest type in the NOA, the Mixed Greenheart, Black Kakaralli, Wamara Forest (MGK).

The sample plots will be located on the four NOA forest types, two plots on each forest type. On each forest type, an unlogged and a logged plot will be established.

In all cases, “logged” plots will be established and measured prior to the logging operation, allowing for registering changes. This is also the case for the experimental plots.

Thus, a total of twelve (12) plots will be established, four experimental plots and eight sample plots.

Plots will be located in areas to be logged in a near future and in reserve areas where no logging is planned. Plots in the first type of areas will be established in the NOA. Plots in reserve areas may be located within reserve areas of the SUA or in the Wilderness Preserve (WP).

*Table 2. Forest types and number of PSP*

| *Forest type* | *Sample plots* | *Experimental plots* |
|---|---:|---:|
| Mixed Greenheart, Black Kakaralli, Wamara Forest (MGK) | 2 | 4 |
| Mora, Manikole, Crabwood, Trysil Forest (MMC) | 2 | - |
| Mixed Greenheart, Sand Baromalli, Soft Wallaba Forest (MGB) | 2 | - |
| Wallaba Forest (WF) | 2 | - |
| *Total* | *8* | *4* |

## 5. Plot location and buffer zones

From a fixed base point, an access line on a precise bearing should be cut to locate one corner of the plot. Longitude and latitude coordinates are registered with a GPS unit for the fixed base point and the plot corner. The fixed base point should be permanently marked with a post. For this point, grid intersections of the GIS developed for the Iwokrama Forest or ground features can be utilized. The access line should be as short as possible. Utilization of the grid system should keep line length below 500 m.

The access line should be cleaned and well defined on the ground. Trees up to 5 cm dbh along the line may be felled if needed. Off-sets due to large trees or other causes should be clearly marked. The end of the line marks the plot corner.

A preliminary survey of the location should be carried out before starting the establishment of the plot. Locations with features that make the plot difficult to measure, or with the presence of roads, swamps, deforested areas or other characteristics that would affect the objective of the plot, should be avoided. This subjective decision is admissible as these plots are not part of a forest inventory. Adjustment of the plot location may be done by moving the plot back or forwards along the access line in fixed multiples of 100 m.

All plots are planned within areas subjected to the same treatment as the plot treatment. This includes the experimental plots, which will be established on large scale field trials of 100 ha. The distance from the plot border to any different treatment or management situation shall be at least 100 m. This buffer area will be appropriate for preventing lateral effects of different treatments on the plot.

## 6. Plot layout

The square 100 m x 100 m plot is laid out at the end of the access line. The plot is normally aligned to the cardinal points, using true bearings. The first two boundary lines are cut from the end of the access line. Each boundary is measured using a 30 m or 50 m tape.

Plot corners, as well as the start of the internal quadrants on the plot borders, should be marked with 4 cm (1.5") PVC pipes, with some 60 cm of exposed length. If for any reason small wood poles are temporarily used, they must be cut from outside the plot; subsequently, PVC pipes should be used for replacing those poles. Thirty six PVC stakes are needed per plot. Twenty five of them mark the 25 quadrat SW corners, and are numbered from 1 to 25 with the quadrat number facing south. The other eleven stakes, not numbered, mark quadrat corners on the northern and eastern sides of the plot.

Any required cleaning of the plot boundary should be done on the outside of the plot. No vegetation should be removed from the plot, and no trees above 5 cm diameter should be cleared or cut near the boundary lines.

Borderline trees may be assessed later at the time of tree measurements. The alternative of slashing outside trees on the bole to indicate to the measurement team that they should not be measured was discarded, as it was considered that it does not provide significant operative advantages. For plot trees, the center of the stem at the point of measurement (pom) lies within the plot.

Once the two external boundary lines are marked, the first line of internal quadrat boundaries is cut. A supervisor directs the work of the line cutter using compass. The 20 m quadrat lengths are measured and the length of each internal quadrat is checked to ensure the distance is correct. Distance errors above 1% are unacceptable and must be corrected. In all distance measures, slope corrections shall be made for slopes higher than 5%. Quadrat intersections are marked with 4 cm PVC pipes. All the internal quadrat lines are thus completed and marked following the same procedure. Note that the second pair of plot boundary lines is completed with the completion of all quadrat boundaries, and not before.

The main sample plot is, then, a square one hectare plot with each side measuring 100 meters. It is divided into twenty five 20 m x 20 m quadrats for ease of measurement. However, this division in smaller units also allows for the establishment of subplots for measuring trees of smaller size categories. These subplots will be described below in sections 8 and 9.

The quadrats are numbered in sequence, beginning at the south-west corner of the main plot. Numbers 1 to 5 are assigned to the quadrats in the first column, from south to north. Numbering of the second column starts in the same way from the south boundary of the plot (Quadrat 6), and so on.

## 7. Measurement of trees in the main plot

Data will be collected in the field with electronic data collectors, which minimize the possibility of errors and facilitate data processing. Any reference to field sheets in this text should be indistinctly understood as a reference to field sheets or data collectors.

### 7.1 Tree identification, numbering and measuring of stem diameters

The team begins in Quadrat 1 and works north following the numbering order. At the completion of Quadrat 5, Quadrat 6 is started from the south boundary of the plot. This method is continued until the plot is completed.

The team moves north through the plot walking mainly through the center of the plot, having a half part of the plot to each side, and numbering and measuring the trees in that order.

The location of each tree within the quadrat is recorded by registering the distances in the south-north direction (the Y or north coordinate) and in the west-east direction (the X or east coordinate). Both distances are measured to the nearest decimeter. Note that distances are distances within the quadrat.

The tree is identified and measured under the direction of the supervisor. All information is recorded in the hand held data collectors. Diameter measurement is made to the nearest millimeter with diameter tape. All trees equal or larger than 20 cm at the point of measurement (*pom*) are registered.

Trees which do not have a high buttress are measured at breast height, this is, 1.3 m above ground level. This height is measured on the uphill side. A stick marked at 1.3 m should be used for determining the pom. Any loose bark or moss is brushed away before measurement. The *pom* is first marked with chalk. The diameter is recorded by placing the tape perpendicular to the axis of the stem. Climbers should not be cut but the tape should pass underneath them. Additional chalk marks are then made to record the exact position of the tape at measurement. After completing measurement and removing the tape, a circular band is painted around the tree, whose top edge coincides exactly with the chalk marks and the *pom*.

All trees are numbered with aluminum tags. The numbered tags are nailed using 2 or 2.5-inches aluminum nails at 30 cm above the *pom*. Tags should face south, the side from where the crew is advancing. The number tags should hang loosely on the nail. Nails should not be nailed deep, and should be pulled out if necessary in subsequent measurements. Trees that are recruited in later assessments can be given any number as long as these numbers are different to those used when the plot was established.

### 7.2 Measurement of heights

On each of the five central quadrats (quadrats 8, 12, 13, 14 and 18) total tree height and bole height (height at the crown base) are measured on the largest dbh tree and on a second tree of the main category (= or + 20 cm diameter class), the closest tree to the SW corner of the quadrat. Clinometers or hypsometers can be used. Trees with broken tops or with unreliable diameter measurements shall not be used for height measurements; in these cases the following largest dbh tree or closest tree to the corner, according to the case, should be used.

### 7.3 Crown position

Crown position, according to a simple system of crown classification developed by Dawkins (1958, quoted by Alder and Synnott, 1992), has been found consistently related to increment (Alder, 1990, quoted by Alder and Synnott, 1992). Using Dawkins categories, crown position should be registered for every measured tree.

Crowns are classified on the following scale:

5. *Emergent*: Crown plan fully exposed vertically and free from lateral competition at least within the $90^o$ inverted cone subtended by the crown base.

4. *Full overhead light*: Crown plan fully exposed vertically but adjacent to other crowns of equal or greater height within the $90^o$ cone.

3. *Some overhead light*: Crown plan partly exposed vertically but partly vertically shaded by other crowns.

2. *Some side light*: Crown plan entirely vertically shaded but exposed to some direct light due to a gap or edge of overhead canopy.

1. *No direct light*: Crown plan entirely shaded vertically and laterally.

### 7.4 Crown form

Dawkins (1958) developed a classification for crown form that is indicative of both its photosynthetic capacity and the general vigor of the tree (Alder and Synnott, 1992). It should be interpreted according to the crown characteristics of the species. This five-point system has been widely adopted in the management of tropical high forests. Crown form should be registered for every measured tree according to these categories:

5. *Perfect*: The best size and development for the species, wide, circular in plan, symmetrical.

4. *Good*: Very nearly ideal, but with some slight defect of symmetry or some dead branch tips.

3. *Tolerable*: Just silviculturally satisfactory, distinctly asymmetrical or thin, but apparently capable of improvement if given more room.

2. *Poor*: Distinctly unsatisfactory, with extensive dieback, strong asymmetry and dead branches, but probably capable of surviving.

1. *Very poor*: Definitely degenerating or suppressed, or badly damaged, and probably incapable of increasing its growth rate or responding to liberation.

### 7.5 Climbers

The degree of strangulation by climbers should be registered by utilizing the following codes (after Synnott, 1979, quoted by GFC, August 2006):

1. Tree free from climbers.
2. Climbers on main stem only, crown free.
3. Climbers in crown but main stem free.
4. Climbers on main stem and in the crown.
5. Whole crown smothered by climbers, and present on main stem.

### 7.6 Tree comments: Decay indicators and other characteristics

Each measured tree will be assessed for additional characteristics, including decay indicators. A separate study within the Iwokrama Forest attempts to relate decay indicators to actual decay losses.

A two-letter code has been proposed within the GFC for these and other tree characteristics in a recent draft document (GFC, August 2006). For characteristics which are also considered by the GFC, the same code is used. The appropriate code should be entered in the field sheet:

BC Broken top with coppice crown
BT Broken top, no crown present
BU Buttressed tree (buttress above 1.3m height)
CO Coppice
DE Stem defect at 1.3m height
DF Defoliated crown
DU Diameter measurement unreliable, due to climbers or other causes
FC Felling damage in crown
FD Fire damage on tree
FL Fluted bole above 1.3m height
FS Felling damage in bole due to skidding or fallen tree
FU Fungus on bole
PD Probably dead
RB Large rotten branch/es (above 15cm diameter) in crown
RT Rot in stem
SC Scar
SL Stem slashed for rubber collection
ST Stilt roots above 1.3m height
TE Termite nest on stem

## 7.7 Measurements in non-regular cases

Several special cases present problems for applying the regular procedures. They also require a consistent approach to measurement, following common practice for these cases.

### 7.7.1 Buttressed trees

When the tree is buttressed at breast height, the point of mensuration (*pom*) is moved 30 cm above the end of the buttress. A ladder should be taken to the field to assist with these measurements.

### 7.7.2 Fluted trees and stilt trees

Diameter of fluted trees and of trees that have developed stilt root systems above 1.3m height should be taken at a new *pom*, 30 cm above the end of the flute or the root collar, the same criterion followed with buttressed trees.

### 7.7.3 Leaning trees

Trees not standing vertically are measured along the stem, on the side to which the tree leans. For measuring diameter, plane of measurement shall be perpendicular to the stem.

### 7.7.4 Defects

In the case of defects at breast height, stem diameter is measured as close as possible to the end of the defect.

### 7.7.5 Forked trees

In cases in which trees are forked below 1.3 m, stems are measured as separate trees and given different numbers. When the base of the fork affects diameter measurement at 1.3 m height, the same procedure as for defects should be followed, with two *poms* placed as close as possible to where the stem divides.

## 7.8 Missing trees

In subsequent assessments, dead trees and missing trees should be recorded in the field sheet. The codes to be used in these cases should give an indication of the probable causes:

- H Tree felled and harvested
- K Killed during road building or other logging operations
- D Dead by natural causes

## 7.9 Descriptive indicators of site

Descriptive indicators of site are coded notes, analogous to those applied to trees. They are determined from a visual assessment of the quadrat and are recorded for each quadrat. As with the coded tree notes, several indicators may be simultaneously applied. The following indicators of interest for the Iwokrama Forest should be applied, based on a list by Alder and Synnott (1992):

- CC Climber cutting has or is being carried out on the quadrat.
- CT Climber tangle. Large masses of climbers on top of pole sized regrowth.
- DW Dry watercourse
- FI Fire damage evident.
- GA The quadrat intersects a natural gap due to tree fall.
- GU Gully or embankment. A dry gully (as opposed to stream) or embankment intersects the plot.
- LO Signs of recent logging on the quadrat
- LR A logging road or part of the cleared margin of one intersects the quadrat.
- NO No exotic species
- RK Rock outcrop.
- RS River, stream or lake.
- SK Skid trail.
- SW Swamp. Indications of extensive and continuous waterlogging of the soil. Standing water may be absent in the dry season.
- WT Wind throw

### 7.10 Slope position

Slope position at the center of the quadrat should be scored according to the following codes:

1 Hill top or ridge
2 Upper slope
3 Mid slope
4 Lower slope
5 Valley or gulley

## 8. Subplots for poles and saplings

Two subplots will be established within the main plot, for measuring poles (5 cm to 19.9 cm dbh) and saplings (2 cm to 4.9 cm dbh), of 0.12 ha and 0.04 ha respectively.

Pole diameters are measured on a 0.12 ha subplot consisting of three central quadrats of the main plot. They are quadrats 12, 13 and 14. Sapling diameters are measured on a 0.04 ha subplot consisting of the central quadrat (Quadrat 13) of the main plot.

On the three central quadrats 12, 13 and 14, total tree height and height at crown base are measured on the two closest pole trees to the SW corner of the quadrat. Within the central quadrat (13), total height is measured on eight saplings, the two closest saplings to each quadrat corner. Thus, the heights of six poles and eight saplings are measured in the pole and sapling subplots respectively.

As in the case of diameters, height measurements are also continued on the measured trees in subsequent measurements, even if a change of size category (recruitment) occurs. Data are registered in the field sheet of the new category. When saplings enter the pole category, height at crown base is also measured. In these cases, or when mortality occurs, new sample trees are incorporated to the sampling with the same procedure, for ensuring that the heights of a minimum of six poles and eight saplings are measured.

Each quadrat is worked in a systematic way, and working in the same direction as the used for the main plot.

Tree identification, location and measurement are done in general terms in the same way as for the main plot. Diameter tape is also used for subplot trees. While calipers would be easier to use on very small trees, the use of calipers also have some disadvantages and special requirements, and their measurements are not always consistent with tape measurements.

Numbering of pole and sapling trees could start from tree number 1001. This should be considered just as a recommendation.

At remeasurements, new stems arising as ingrowth from unmeasured sizes should be given the coded note IN (ingrowth). Note that this does not apply to individuals that were already measured in smaller categories.

On trees below 5 cm dbh, no nails are used. Numbers are tagged with a loose copper or aluminum wire or resistant plastic loop tied around the tree and allowed to rest at ground level.

Assessments of crown position, crown form, climbers, decay indicators and additional characteristics are done as for the main plot. Crown form is not registered for saplings.

## 9. Regeneration strips

Regeneration (seedlings) will be measured on strips within the central quadrat (Quadrat 13) of the main plot. Seedlings are trees below the sapling category, this is, below 2 cm dbh. Seedlings to be registered should have a minimum height of 30 cm. This is the minimum seedling height utilized for forest monitoring by Embrapa, the Brazilian forest research agency, in the Brazilian Amazon (Embrapa, 2005).

Only height will be measured for seedlings, not diameter. Height should be measured to the highest point of the tree, without straightening.

Crown position should be registered for seedlings as well as for saplings and poles. For saplings and seedlings, the general situation of the quadrat may affect all the individuals in the quadrat. Crown form is not registered for seedlings.

Coded notes applied to larger trees should also be applied to seedlings, as well as climber assessment.

Four 1-m wide seedling strips will be located within the sapling quadrat, starting at distances of 4, 8, 12 and 16 m from the southern boundary of the quadrat. The southern extremes of the strips should be marked with eight PVC pipes. The total area of regeneration to be measured will be, then, 0.008 ha on each plot.

The measurement of seedling locations within strips is fairly straightforward. A tape should be laid along the southern border of the strip, which for the first strip should be at 4 m from the southern boundary of the quadrat. The position of the seedling along the tape (its distance from the western edge of the quadrat) gives its X or east coordinate directly. No Y coordinates are measured for seedlings. Distances are registered to the nearest decimeter.

Numbering of seedlings could start from tree 2001. The ingrowth (IN) code should be noted for new seedlings in remeasurements. “In the case of the seedling class, ingrowth is something of a misnomer, but the note should still be used to clearly identify new stems and assist in error checking of the data.” (Alder and Synnott, 1992).

Seedlings should be tagged similarly to the saplings, with loosely tied labels resting at ground level.

## 10. Monitoring Kufa and Nibi

Two types of hemi-epiphytic climbers, Kufa and Nibi, each of them referring to two distinct species in Guyana, are very important non-timber forest products (NTFP) in the Guyanese forests, including the Iwokrama Forest. Kufa and Nibi furniture has a local market and is also exported to the Caribbean. Host trees of Kufa and Nibi will be identified. For the large tree categories, poles and larger trees, the presence of Kufa and Nibi will be registered.

The following codes will be utilized for each measured tree in those categories:

K2 Host tree, commercial Kufa
K1 Host tree, noncommercial Kufa
K0 No presence of Kufa

N2 Host tree, commercial Nibi
N1 Host tree, noncommercial Nibi
N0 No presence of Nibi

For monitoring purposes in these plots, commercial Kufa and Nibi are defined by those sizes and characteristics of these plants as described in the Code of Practice for Harvesting Kufa and Nibi (GFC, January 2003) for the definition of protected host trees. It is understood that some plants which do not meet these sizes and characteristics might also have certain immediate commercial value.

The Code of Practice (Ibid.) recommends that Kufa and Nibi should be harvested from host trees which are to be felled, and determines that host trees over 60 cm diameter should not be felled when they support either:

- Mature Kufa with more than 3 roots over 2.5 cm (1 inch) diameter, approximately 3 finger widths; or

- Mature Nibi clusters with more than 20 roots over 0.8 cm (5/16 inch) diameter, approximately 1 little finger width.

These sizes and characteristics define the lower limits of commercial Kufa and Nibi for purposes of this study, irrespective of the size of the host tree.

As for other forest attributes to be measured in the plots, it is expected that further measurements and studies with more specific objectives could be carried out by utilizing this information as a basis.

## 11. Carbon monitoring

Carbon is exchanged naturally between the forest ecosystems and the atmosphere through photosynthesis, respiration, decomposition and combustion. Human activities, however, change carbon stocks in forests and other ecosystems, and their exchanges between them and the atmosphere (IPCC, 2000). Considering the importance of natural forests as carbon pools and carbon sinks, as well as the growing commerce on carbon credits within different mechanisms, some of them outside the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), it is appropriate to incorporate some elements of carbon monitoring within the PSP system in the Iwokrama Forest.

Methods that measure stocks of carbon in forests work basically on four carbon pools: above ground biomass, below ground biomass (roots), dead organic matter (litter, snags, coarse woody debris), and soils. Currently, for purposes of estimating carbon in Guyana forests, forest inventories have been the main source of information. They provide a fairly direct indication of above ground biomass. A recent work by ter Steege (undated) has utilized this information, together with biomass equations and root-shoot ratios from neighboring countries and similar soils, for estimating total carbon content in several forest types in Guyana. The same study emphasized the need of data on the dead organic matter pool ("production of large litter, its standing crops, and residence time") in Guyana forests. This would be hampering a proper implementation of carbon models in the country.

Data from PSPs are not a substitute for data to be collected from properly designed inventories. However, PSPs, including those that have not been established with inventory purposes, have other functions and advantages which apply to carbon monitoring. They provide more reliable data on trends in vegetation development than temporary plots do, and they are more easily verified than other methods, since permanent plots can be revisited and remeasured by external verifiers (MacDicken, 1997). They can complement data from carbon inventories, providing information on carbon stocks in specific forest types, and their change through time and in response to concrete human activities. Permanent plots allow efficient assessment of changes in carbon fixation over time, provided that the plots represent the larger area for which the estimates are intended.

Changes in above ground biomass, and indirectly in below ground biomass, can be registered through measurements of the attributes which are the subject of the preceding sections of this document. It is also planned to measure and analyze standing litter crop and herbaceous vegetation for their carbon content, as well as total carbon in soil, in the PSPs. Standing litter crop is the total weight per unit area of litter on the soil surface at the time of sampling. Litter is organic debris on the soil surface, and is usually freshly fallen or slightly decomposed vegetation. Measurement of the standing litter crop does not require monitoring of litterfall.

In this way, the presence and changes of carbon in all the major carbon pools in the forest will be directly or indirectly monitored in both the sample plots and experimental plots.

Appendix I (Carbon Monitoring: Field Procedures for Herbaceous Vegetation, Soils and Standing Litter Crop) describes the methodology to be used for collecting and processing the samples. This methodology is taken from MacDicken, K.G. (1997), "A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock International Institute for Agricultural Development." The guide is a used reference in more recent work on carbon monitoring and has been tested in tropical and temperate forests. It is cited in the References section, together with its web address. Appendix I is a modified version of Appendix 5 in MacDicken's work. Certain small changes were done for ensuring consistency with the type of PSPs to be used in Iwokrama. However, some considerations on methodological alternatives in the original text (such as those on form and type of sampling frames, among others) were maintained, as they provide valuable information on methodological aspects that admit more than one approach.

Methodological aspects which are not totally defined in Appendix I are number, size and location of samples per plot.

Four samples per plot will be taken for herbaceous vegetation, soils and standing litter crop.

Circular sampling frames of 2 $m^2$ (159.6 cm diameter) will be used for collecting herbaceous vegetation and standing litter crop. Soil samples will be taken within the frames and following the instructions at Appendix I.

The first sampling frame will be located inside the plot, its border at a 5 m distance from the northern boundary of the plot. Distance to the northwestern corner of the plot should be randomly selected. The same distance, as well as the 5 m distance to the plot boundary, will be then maintained from the next sampling location to the following corner (northeastern corner), proceeding in a clockwise direction to the next sampling site within the sample plot. From the first sampling location (on the northern side), the second sampling location will be on the eastern side, the next will be on the southern side and the last sampling location will be on the western side of the plot. Sampling locations will not necessarily be repeated in subsequent measurements.

## 12. Alien species

There are no antecedents of alien species becoming invasive within the Iwokrama Forest. However, with the increased use of the main road, larger affluence of visitors, a growing importance of agriculture for the communities within the region, together with the larger and more regular forest disturbances brought by logging, the possibilities for the introduction of alien species in the natural ecosystems increase.

Field sheets will allow for registering the presence of plant alien species of any type within the quadrat. Due to the lack of antecedents, species codes will be assigned at the time such cases are registered. A NO code will be used when no alien species are found.

## 13. Interval of remeasurement

It is agreed that a high frequency of remeasurements, with intervals of one or two years, may not give meaningful results on diameter growth rates for individual tree analysis (Alder and Synnott, 1992). Remeasurement intervals of 4 or 5 years are considered satisfactory for the majority of cases.

Sample plots in the Iwokrama Forest will be measured at the time of establishment and will have a first remeasurement in two years and a second remeasurement at four years. These initial shorter intervals will be useful for developing and confirming field procedures and data processing methods.

Subsequently to the second remeasurement (year four), a decision should be made on continuing remeasurements at two year intervals or establishing a four year interval between measurements. A reason for a shorter interval would be the convenience of shorter intervals for remeasuring attributes such as ingrowth and mortality. If a decision is made for making total remeasurements every four years, a program for remeasuring ingrowth and mortality in shorter periods should be established. However, the costs of relocating and re-entering the plot might not justify the use of different intervals for measuring different parameters in the plot.

For plots that will be logged, including the experimental plots and half of the sample plots, logging will initially affect remeasurement interval. Preferably, in these cases PSPs will be established and measured immediately prior to logging. This may not always be the case, though, as logging schedule on different areas depends on the management plan, and changes for making it more convenient for the PSP program would not be practical, due to road and infrastructure requirements.

Plots to be logged will be measured at the time of establishment, then immediately after logging, and then at the regular remeasurement intervals. The regular remeasurement interval will be applied in the period before logging in the case logging does not take place before several years.

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## Appendix I

### Carbon Monitoring: Field Procedures for Herbaceous Vegetation, Soils and Standing Litter Crop

*(Modified from MacDicken, K.G. 1997. A guide to monitoring carbon storage in forestry and agroforestry projects. Winrock International Institute for Agricultural Development.)*

The carbon content of soil and litter can be measured and analyzed at relatively low cost if the data is collected at the same time the inventory is conducted. This appendix describes sampling and analysis of carbon in herbaceous vegetation, soil and standing litter crop.

In general, data should be collected in the following order:
1. Herbaceous vegetation
2. Standing litter
3. Soil

### A. Procedure overview

1. Go to the northern edge of the plot and select a point 1 m inside the outside edge of the permanent sample plot. This will be the first sampling location for herbaceous vegetation, litter and soils.

2. Lay the quadrat or circular sampling frame on the ground with the outer edge 1 m from the plot boundary. Include in the sample only the vegetation that originates inside the sampling frame. Exclude vegetation over-hanging inside the frame if the plant originates outside the frame, but include vegetation over-hanging outside the frame if the plant originates inside the frame.

3. Clip herbaceous vegetation and small woody vegetation of less than 2 cm dbh, place in the sample weighing bag, weigh, and record the weight. Select a small random sub-sample (e.g., a handful) of this vegetation and place in a numbered sample bag for moisture content determination.

4. Before moving on, collect standing litter from the same sample site, place in the sample-weighing bag, weigh, and record the weight. Mix the sample well and select a small random sub-sample (e.g., a handful) of this litter and place in a numbered sample bag for moisture content determination.

5. Collect a soil core or slice for soil carbon analysis, place this on a plastic tarp, screen with 5-mm mesh, mix well with other cores or slices, randomly select a sample, and place in a numbered sample bag for carbon content analysis.

6. Proceed in a clockwise direction to the next sampling site within the sample plot. From the first sampling location (i.e., North) this will be East, the next will be South and the last sampling location will be West.

### B. Herbaceous vegetation

In permanent sample plots, herbaceous understory vegetation can be sampled using four to six quadrats or circular sample frames per plot. Several types of sampling frames are useful for this type of sampling. The main criterion is that the frames be durable and retain their size and shape over long periods of use. All frames used in a project must be of the same size. Frames with at least one hinge allow the user to wrap the frame around broad canopied plants when necessary. Experience suggests that round aluminum frames with hinges on two sides are more durable than welded square frames, and are also more easily transported.

Cut all vegetation inside each quadrat/circular sampling frame at ground level. Take care to cut at the same height for each sample. Clip herbs within the sampling frame in a vertical column extending from inside the sampling frame, so that samples represent the biomass within the frame's area. Weigh biomass for each quadrat and take and weigh a sub-sample for moisture content, and possibly for determining nutrient concentration.

**C. Standing litter crop**

Changes in standing litter crop can be important. It is easy to measure the standing litter crop, but it requires consistent adherence to pre-defined standards.

Measure the standing litter crop by collecting all litter on the soil surface in each of the sampling frames used for measuring herbaceous vegetation. Samples can be bulked by plot. Make sure to record the number of sample frames collected in each plot. Samples should be weighed and subsamples collected in the same way as for herbaceous vegetation.

*Standing litter crop* is the total weight per unit area of litter on the soil surface at the time of sampling. *Litter* is organic debris on the soil surface, and is usually freshly fallen or slightly decomposed vegetation. Measurement of the standing litter crop does NOT require monitoring of litterfall.

**D. Soil sampling**

In general, soil samples should be taken when the permanent plots are established and measured. Use either a soil corer of 30 cm in length or hand-dug pits of 30 cm in depth. A soil corer may provide greater efficiency where soils are not excessively stony, although a folding entrenching shovel (military type) is usually lighter and more versatile. Due to charcoal's high carbon content, it is important to take special care to remove bits of charcoal from samples at any sites that have been burned prior to sampling.

Soil samples should be collected from the 0-30 cm horizon unless otherwise specified.

To collect soil samples, remove all vegetation and litter from the soil surface prior to sampling. Place the soil core or slice on the plastic tarp and remove coarse fragments using a 5-mm screen. If multiple subsamples are to be taken per plot, screen all samples on the plastic tarp and mix thoroughly to a uniform color and consistency. Place a sample in a clearly labeled sample bag (preferably a cloth or Tyvek oil sand bag). The quantity of soil required may depend upon the laboratory and analysis to be used; discuss sample needs thoroughly with laboratory technicians beforehand, to ensure that samples are properly prepared and labelled in the field.

To convert total or organic carbon concentrations into total quantities, bulk density of soils is required.

The greatest changes in soil organic carbon in non-humic tropical soils are often found between the 0-30 cm and >30 cm horizons.

Bulk density is considered to have relatively low spatial variability, with coefficients of variability of less than 10%. For a uniform soil type, four samples should be sufficient to estimate mean bulk density to within 10% of the true value 95% of the time. The following procedure can be used to determine bulk density with a Modified Uhland soil corer:

1. Identify tin sample boxes and tops, weigh and record as W1 (g).
3. Prepare a smooth surface at a sampling depth of 5 cm.
4. Drive sampler into the soil to fill inner core without compression (use mineral oil if soil-metal adhesion occurs).
5. Trim ends, remove core. If core does not completely fill the cylinder, use glass bead adjustment. If it does fill the cylinder, push contents into sample tin, close tin, mark and record tin number.
6. Place samples in an oven set to 100o C for about 72 hours. After drying, record the weight of the tin + dry soil as W2 (g).
7. Calculate bulk density as: BD (g cm-3) = (W2-W1)/344.77

Soil C content (t ha-1 for the 0-30 cm soil depth) = BD * 300 kg m-2 * C concentration (%) * 10

**E. Deciding what type of soil carbon analysis to do**

Soils can contain two types of carbon: organic and inorganic (carbonate). All agricultural soils contain some organic carbon, but not all soils contain inorganic carbon. In most cases, soil organic carbon will be the most important source of soil carbon, although this is not true in arid soils (Aridisols) and several other soil types. Most changes in soil carbon due to project activities are assumed to be in organic matter, and not in inorganic carbonate.

Many laboratories routinely use the Walkley-Black procedure for determining soil organic carbon, although it is known to have a number of important limitations. However, because it is commonly used, rapid, and simple, this method is recommended for analysis of soil organic carbon where total carbon analysis is not required.

If soils are known to contain substantial quantities of inorganic carbonate and the inorganic carbonate fraction is likely to change (e.g., if an arid soil is irrigated), then total carbon methods are necessary.

The average C content of soil organic matter ranges from 48 to 58%.

**F. Sample preparation**

This section describes procedures for preparing samples of soil, litter and vegetation for analysis after they have been collected in the field.

**Soils**

Soils should be air-dried, but not exposed to direct sunlight. Check with the laboratory for detailed arrangements.

**Litter and vegetation**

*After* weighing the samples, take sub-samples of litter and vegetation to determine moisture content and nutrient concentration. The following guidelines are suggested:

*Moisture content*: Mix the sample and collect one random sub-sample of approximately one handful of litter of vegetation per quadrat/circular sample plot. Bulk these subsamples by permanent plot or transect when using the plotless method. For moisture content, collect at least five sub-samples for each vegetation type. Sub-samples should be weighed in the field then returned to the laboratory foroven-drying at 70-80oC to a constant weight and reweighed to determine dry-matter.

*Nutrient concentration*: This is necessary only if the decision is made to use actual C concentration data for vegetation, or if actual data are to be used to predict carbon pool changes using a computer model. A minimum of five samples for each partition is suggested for C (for carbon calculations only) or C and N analysis (for modelling purposes). This means five core samples of wood (collected at dbh), five foliage and litter samples.