SEOSAW Field Manual

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Acknowledgements

The production of this field manual was supported by the NERC funded SEOSAW project. It draws heavily on the RAINFOR manual (Phillips et al., 2016). The woody debris (adapted from Waddell, 2002) and stump protocols were developed as part of the ESPA-funded (DFID/ESRC/NERC) ACES project. The work was also supported by a GCRF Impact Accelerator Grant.

Version control

- V0.0 7 Nov 2017 Initial outline by CR
- V0.1 28 Nov 2017 Tidy and edit for input by the SEOSAW partners and Edinburgh Tropical Land Use Team (TLUT)
- V0.5 11 Dec 2017 Accommodate suggestions and comments from TLUT and further reading. Ed Mitchard, Emily Woollen, Thom Brade, Rose Pritchard, Ellie Wood, Kyle Dexter additions.
- V1.0 30 Jan 2018 tided up, added summaries, more input from TLUT, send to SEOSAW group
- V1.5 4 April 2018 - incorporation of comments from SEOSAW
- V2.0 29 June 2018. Heavily revised by NB, edited by CR, following 2nd SEOSAW meeting inputs.
- V3.0 11 Dec 2018. Minor edits and finalisation by CR.
- V3.1 2 Nov 2020. CR edits to improve consistency with newly accepted PPP paper (SEOSAW, 2020). Also new text to reflect learnings from work with UAVs as part of the Cyclex Project. New example data sheets from Thom Brade.
- V3.2 Revision to some codes to improve compatibility with ForestPlots.net

Introduction

This field manual describes a method for establishing plots that is applicable for savannas, woodlands and forests. It is focused on long term (large) plots, but is also useful for one-off (small) plots. Following this manual, and using the associated data sheets will ensure compatibility with others working in southern Africa, and allow integration into global comparisons. The goal is to share experience about what works and what does not, to avoid mistakes being repeated. In many cases there will be more efficient and informative sampling designs possible, that could be used at any one site. However, in most cases, these will not work in the range of savannas, forests and woodlands present in southern Africa, and will have little overlap with global emergent standards. The methods suggested here are a good compromise, that should leave everyone (hopefully only a little) unhappy.

This document will be complemented by data entry forms for Android tablets using the open data kit and excel sheets for data entry. See the SEOSAW website.

1 Contents

2 Summary

Here are the essentials to ensure your work fits with the SEOSAW protocols:

2.1 Plot design

a. Locate plots on homogenous areas, in terms of the soil type and the land use history.
b. Gain the informed consent of the land owners and informal land users before setting up a plot.
c. For long term monitoring, 0.25, 0.5 or 1.0 ha plots are recommended; 1.0 ha squares are preferred.
d. Measure the diameter of all stems above a diameter threshold e.g. > 5 or 10 cm diameter. Measure diameter at 1.3 or 0.3 m height.
e. Mark permanent plots at the corners (or centre for circle plots) with concrete or iron bars
f. Re-measure stems approx. every 3 years, with more frequent visits at the start
g. Complete the 'plot data sheet' for every plot (Appendix 1)

2.2 Tree stems

Table 1 shows the attributes of each stem that should be recorded (NB: <u>stem, not tree – measure all stems, alive or dead, standing or fallen)</u>. These are considered the minimum needed to answer many of the key questions of the SEOSAW partnership. Many others could of course be added. An example data sheet in included in Appendix 2, and excel sheets are available on the SEOSAW website.

Attribute	**Purpose**	**Key recommendations**
Tag ID or Stem ID (if no tags)	Keep track of unique stems	Tag all stems that meet the inclusion criteria. Nail the tag 20 cm above the POM.
Stem diameter	Biomass estimation; growth rates	The Point of Measurement (POM) of diameter should be 1.3 or 0.3 m, along the stem in a straight line. (NOT vertical height). A diameter tape is preferred. Check POM is representative, and move upward if any issues with wounds, forks etc. Record the height of the POM if it had to be moved.
Point of measurement	As above	Always record the height of the POM
Multiple stems	Biomass estimation, resprouting	Record the stem id / tag no. of other stems that start at the same base. Measure all stems that meet the inclusion criteria, even if they have the same base.
Species	Diversity studies, also needed for wood density lookup for biomass estimation	Bring a botanist if you can afford it, take vouchers if you can, use morpho species or local names if not

Alive / Dead and cause(s) of mortality	Mortality and resprouting rates	Measure all stems even if they are dead. Use RAINFOR codes to explain how and why they died.
Standing / fallen	Knowing if a tree is fallen helps explain its absence in subsequent censuses	Include stems that have fallen, as long as they are contiguous to the POM height and rooted in the soil.
Broken	Biomass estimation	Record the height at which a broken stem is severed
Damage	Predicting mortality and growth	Estimate the area of exposed cambium (missing bark) and note the presence of bracket fungus.
Other attributes	See section 5.5	These are quick to record and increase compatibility with global standards
Spatial position (optional)	Useful if tag lost, and for spatial analysis	Record distance in m from the SW corner of the plot (x and y coordinates). On large square plots divide the plot into 10 m strips to help with this
Height (optional)	Improves biomass estimation; allometric traits	If there is a strong DBH-height relationship, measure height on a subset of 100 stems for each site. If relationship is weak, measure all heights.
New recruits	Needed for net carbon balance, and for analysing population dynamics	Record new recruits (i.e. new stems that meet the inclusion criteria) on a separate sheet.
Stumps	Quantifying "missing biomass" and where possible the causes	Measure diameter of all stumps with a diameter >5 cm. Record height of diameter measurement.
Small stems (optional)	Regeneration studies, diversity in small size classes	Count no. of small stems of each species in transects that are 2m wide and 50 m long.
Woody debris (optional)	Quantifying fallen wood biomass for e.g. C stocks and fuelwood assessments	4 line intercept transects; measure all intersecting pieces > 3 cm diameter and 0.5 m long
Soil (optional)	See separate protocol	
Grass, forbs, seedlings (optional)	See separate protocol	

4 Plot establishment

4.1 Engaging with local land users *and* owners

Engage with local land users *and* owners and be attentive that these may be different groups. e.g. the land may be privately or government owned, but local people may harvest woodfuel or NTFPs. At a minimum, engagement would typically involve a community-wide meeting at the start of the plot setup and notifying local authorities of your work. Involving community members in the work on the plots can be beneficial for all and is a good way to ensure that the local community is fully informed of what is being done, and where. This can reduce the scope for misunderstandings about the purpose and nature of the work. Provide information to local land users in relevant local languages in written form so that they can be shared around the community. If possible, undergo ethics approval at your institution

4.2 Location and position

New plots should be located within areas that satisfy the following criteria:

a. Homogenous soil parent material and soil type
b. Homogeneous land use and land-use history
c. Land owners and informal land users have given informed consent for the plot to be established and accessed by researchers
d. Adequate access – although plots near to roads, tracks, paths and settlements are more likely to be disturbed so care must be taken to avoid oversampling these areas, for example by locating plots at least 1 km from these features
e. Long term institutional support – increasing the likelihood that plots will be maintained and re-measured
f. Unlikely to be permanently converted to another land use – although new plots should **not** be specifically located in areas without human disturbance as such disturbances are ubiquitous and need to be understood. It is therefore useful to include plots used for shifting cultivation or harvested for timber, fuel or construction materials.

When positioning plots there can be a tendency to select locations that seem easy work in or that fulfil pre-conceived ideas the about the area. To avoid potential for bias in plot locations, new plots should therefore be positioned randomly, or in a pre-determined pattern, within strata that meet the above criteria. Regularly spaced plots (e.g. on a grid) are advantageous for some analyses.

Determining random plot locations

To randomly locate plots, before going to the field use a GIS to randomly place points within the strata of interest and load these points onto the GPS. Place at least double the number of points, and use only the odd numbered points, saving the even numbered points as reserves in case the odd numbered point does not meet the criteria above.

A tablet with access to high resolution satellite imagery can help to determine whether potential plot locations meet the above criteria e.g. for identifying variation due to soil type and hydrological features, and signs of human use. Suitable software available in 2018 includes MoitionXPro (for iPads) or Gaia GPS (for Android and iOS tablets).

Using a drone to aid plot location

Using a drone can be of great benefit in assessing the suitability of possible plot location in terms of proximity to human disturbance and ephemeral drainage etc that might otherwise require significant field effort to detect or lead to inappropriate plot locations. See Annex 3.

4.3 Shape and orientation

Decisions over plot shape are influenced by the need to fit plots within homogenous strata, the perimeter:area ratio – which influences the number of trees on the boundary of the plot, and the ease of set up.

The SEOSAW network includes circular, square and rectangular plots. Circles have the smallest perimeter:area ratio and can be quick to set up, especially in open areas, but can become difficult to measure if they exceed around 20 m radius. For larger plots, squares or rectangles are easier to set up and are recommended for new plots of 0.2 ha or above. Where possible, square plots are preferable as they have a smaller perimeter:area ratio than rectangles, although rectangular plots may help to fit plots within homogenous strata.

Where possible, North/South and East/West should be used for the principal axes of square and rectangular plots, it may be necessary to adjust these however to enable a plot to be positioned within a homogenous stratum. The bearings of the main axes from the start point of the plot (the Southwest corner or equivalent) and the latitude, longitude and elevation of the start point should be recorded.

Accounting for slope when establishing plots
New plots should be set up to sample a given area of land surface, rather than a planar projection. This requires some flexibility with bearings and distances when closing the final side of square or rectangular plots.
To correct for slope and allow comparison to plots that sample a planar area, the average slope and aspect of the plot, and the altitude of each corner, should be recorded. The planar area can then be calculated later.

4.4 Size

Optimal plot size depends on the aims of the study and the characteristics of the stratum being sampled. Small plots have higher perimeter:area ratio and typically yield biomass estimates that have non-normal distributions, fit less well to remotely sensed observations, and have greater coefficients of variation than larger plots. One hectare has been adopted as the standard size used in many networks in the wet tropics, and is recommended for long-term monitoring plots in the SEOSAW network. In open areas larger plots may be needed to ensure there are >200 stems sampled as sampling fewer stems than this makes estimating mortality very inaccurate.

For non-permanent plots, and plots in areas with relatively homogeneous vegetation structure and high tree density plots of 0.75 ha, 0.5 ha and 0.25 ha are also acceptable. Plots with less than 25 stems inside them are not useful for estimating tree diversity and should be increased in size.

4.5 Timing

Variation in stem water content can affect diameter measurements, so if plots are going to be re-measured, it is best if measurements are made at the same time of year. Tree measurements are usually easier during the dry season when there is less understory vegetation, but it can also be useful to visit plots during the rainy season to collect herbarium vouchers of deciduous species and to increase the chances of finding species in flower or fruit, which increases identification accuracy.

4.6 Visibility

In plots that will be used for long-term monitoring, the corners of square or rectangular plots or the centre of circular plots, **must** be physically marked so that they can be relocated. In some areas, visibly marking the plot location can influence the way the plot is used by people, potentially introducing bias to the sampling. In these cases, trees should not be marked or visibly tagged (buried tags or detailed maps of tree locations can be used instead), and plot location should be marked with cryptic approaches. Materials used for marking plot locations must be durable enough to be maintained between measurement events and not be eroded by corrosion, fire, termites, etc. Adding additional markers, e.g. on a 20 m grid within the plot, and at 10 m intervals around the boundary, can help to reduce inclusion/exclusion errors on re-measurement, and to re-locate trees that lose their tags.

Materials for marking plot locations:

- Treated wooden posts (15 cm diameter) last about 10 years, even with regular burning. These do need to be well dug in, however, which is hard work.
- Concrete posts with reinforcing bar inside them (40 x 10 x 10 cm) can often be fabricated locally and are more durable than wood. If buried with 2 cm protruding from the ground making these are relatively cryptic, and can be relocated with a metal detector. If concrete is not available, iron bars alone can be used, but this is more prone to theft, and will rust.
- Treated steel fencing droppers (1.2 m in length) can be cemented in place to a depth of 0.5 m using holes bored with a soil auger.
- Feno Markers are a more expensive but potentially long lasting option
- Differential GPS can be used instead of permanent posts, but this commits all subsequent users to using expensive equipment. Normal GPS units are not accurate enough to relocate corners – some kind of physical mark must be used.

4.7 Stringing the plot

Once the start point of a square or rectangular plot has been determined the plot boundaries should be carefully measured out using a compass and tape measure, at least two people will be needed for this - one to hold the compass and another to measure the distance and lay string along the boundaries. Any cutting of vegetation within or adjacent to the plot should be kept to a minimum, and avoided whenever possible. Adding strings running the length of the plot at 10 or 20 m spacing can help with orientation while making measurements and mapping tree locations.

4.8 Data recording

For each new plot, a full list of plot data (sometimes called meta data, but really a description of the plot) should be recorded using the SEOSAW plot data sheet (see Annex 1). This information is quick to record (most require a Yes/No answer) and will allow the plot data to be used for a variety of different analyses.

Plot-level data to record includes details of:

- Plot design – size, shape, what was sampled.

- Plot location – longitude, latitude of each corner/the centre. This should be recorded by a GPS set to average the GPS locataion over ~30 mins, and where possible should be repeated on multiple different days to improve accuracy.
- Altitude, slope, aspec
- Sampling carried out within the plot – taxa surveyed and other sampling or measurements made
- Environmental conditions – rainfall, canopy cover, catenal position, and presence of termites
- Land use – legal status, user rights, and occurrence of wood and NTFP harvesting, and agriculture
- Fire – estimated fire return interval and/or time since last burn, fire management, etc.
- Exposure to large herbivores – Elephants, Ruminants, Non-Ruminants, Livestock, etc.

5 Trees and their stems

5.1 What to measure

All stems of all trees (includes climbers, palms and baobabs) should be tagged, measured and identified if:

a. More than 50% of the base of the stem is inside the plot; and
b. They have a diameter ≥ to a defined minimum diameter threshold at the appropriate point of measurement (including dead and fallen stems for which the stem is contiguous from the base to the appropriate point of measurement)

Minimum diameter threshold will be determined by the aims of the study, and the vegetation structure at the study site. Stem diameter ≥ 5cm or ≥ 10 cm are commonly used thresholds. If the intention is to record recruitment (i.e. the number of new stems that have reached the minimum diameter threshold e.g. 5cm), it is advisable to measure all stems with a diameter smaller than this (e.g. 4 cm or 9 cm). This ensures that errors made in determining diameter do not affect estimates of recruitment rates.

This protocol includes (optional) separate sections on measuring poles, saplings and seedlings (stems smaller than the minimum diameter threshold) in sub subsamples of the main plot (section 6).

New plots established in the SEOSAW network should select a minimum diameter threshold for the main plot of either 10 cm, 5 cm or 3 cm according to the aims of the study and the vegetation structure at the study site. The minimum diameter threshold selected should ensure that at least 200 trees are measured within the plot (excluding any measurements made in smaller sub-plots).

5.2 Diameter measurement

5.2.1 Point of measurement

To enable repeat measurements at the same point on a tree, diameter should be measured at a defined point of measurement (POM). Plots in the SEOSAW network should adopt a default point of measurement for use in the entire plot of either 1.3 m or 0.3 m. The point of measurement (POM) is not the vertical height, but is the straight line distance from the mineral soil at the base of the stems to the POM, even if the stem is leaning or bent.

A default POM of 1.3 m should be used unless few stems in the plot reach 1.3 m, in which case a default POM of 0.3 m can be used.

If a default POM of 0.3 m is used, a sub-sample of trees should be measured at both 1.3 m and 0.3 m to enable the use of a conversion factor for comparison with plots measured with a default POM of 1.3 m.

A stick with a mark at 1.3 m or 0.3 m placed at the base of the tree can be used to locate the default POM. Take note of the following circumstances:

- **Forked trees** – Trees that fork below the default POM are only included if the stems present above the fork exceed the minimum diameter threshold at the appropriate POM. These are measured as separate stems.
- **Resprouting trees** –A resprouted stem is only measured if it exceeds the minimum diameter threshold at the appropriate POM
- **Fluted trees** – Trees that are fluted for their entire length should be measured at the default POM.

The POM measurement should be made on a specific side of the tree. Exceptions should only be made the following circumstances:

- **Slopes** – If the stem is on a slope, POM height should be measured on the downhill side of the tree.
- **Leaning trees** – If the stem is leaning, POM height should be measured along the edge closest to the ground

Diameter should be measured at the default POM unless this does not provide a good representation of the diameter of the stem for one of the following reasons:

- **Deformities** – Stems that are deformed at the default POM, for example because of a wound, swelling, bark loss, or branch should be moved to a point 30 cm above the deformity.
- **Forked stems** – Trees that fork at the default POM should be measured at a point 30 cm below the bulge at the base of the fork
- **Buttresses and silt roots** – Trees that are buttressed or have stilt roots at the default POM should be measured 30 cm above the top of the buttress or the highest stilt root.
- **Climbers** – Climbers are included in the survey if they have a diameter greater than the minimum diameter threshold at any point within 2.5 m of the ground. Climbers that fulfil this criterion should be measured in 3 places; i) at 1.3 m measured along the stem from the last point of rooting; ii) at 1.3 m measured vertically above the ground; iii) at the largest diameter within 2.5 m of the ground, including any deformities. These three methods allow comparisons with other workers.

If an adjusted POM does not give a good representation of stem diameter then the POM should be moved further up until a good representation is found. Where a good POM is impossible or impractical because of damage to the whole stem, half diameter methods should be used (See Section 5.2.2).

For all stems the height of the POM must be recorded. The POM can be painted to facilitate re-measuring - although oil based paints can cause callus formation and should be avoided, and bark shedding and fire can degrade paint marks after a few years. Tags can also be used to help relocate the POM. Tags should be located 20 cm above the POM, to speed remeasurement, and avoid the tag influencing the diameter.

5.2.2 Measuring diameter

Diameter at the default or adjusted POM(s) must be recorded for all stems. Diameter tapes should be used for measuring stems with diameter ≥ 5cm. Smaller stems should be measured with callipers.

Diameter should be measured to the nearest 1 mm, and recorded in cm with 1 decimal place, even if this is zero, e.g. 17.0 cm, not 17 cm.

Large trees (10 x the min threshold and above) are very important for biomass estimation, and many aspects of ecology. To provide a double check on the existence of large trees, and guard against errors caused by a missing decimal place, write "large tree" in the notes of all stems > 10 x the diameter threshold e.g. 50 cm DBH for plots with a 5 cm threshold. This is particularly important.

Diameter measurements should be made under any small climbers, epiphytes or roots on the stem (by lifting away from the stem and not cutting), and after cleaning the POM of loose bark and debris. If climbers, epiphytes and roots cannot be lifted away from stem to allow a diameter tape to be passed underneath, half diameter methods should be used.

Half diameter methods
Half diameter methods should be used where it is impossible to measure all the way round the stem e.g. if it is fallen and lying on the ground, or if there are climbers or roots that cannot be lifted away from the stem, or deformities that cannot be avoided. Stem diameter can be estimated by measuring with callipers, or using a diameter tape on only half the circumference of the stem and multiplying the value by two. If these approaches are used it should be noted in the data collection form.

5.2.3 Multiple stemmed trees

Stems can be connected above or below ground, and it will not always be possible to determine if stems are part of the same tree. When a new plot is established, all stems that meet the inclusion criteria should have the stem ID of the largest stem noted as the 'base ID' for all other stems that are part of the same tree as well as their own unique stem ID code.

5.3 Marking and mapping stems

5.3.1 Marking stems

Metal tags can be used to mark stems with their unique stem ID. If metal tags are used these should be attached to the tree so the nail is 20 cm above the exact POM to assist with locating the correct POM when the tree is re-measured, and to prevent any swelling caused by the nail from affecting diameter measurements. If tagging trees is expected to affect the way the plot is used by people or wildlife, an alternative to attaching tags to trees is to bury the tag at the base of the tree just below the mineral soil surface

Marking trees with metal tags
Small metal tags can be purchased or made from roofing zinc (approx 5 x 8 cm) and numbered with a die stamp. Elephants may find the tags less offensive if they are made of non-reflective material or have been sprayed with paint. Tags should be securely attached to stems using a nail. It is best to use aluminium nails of around 5 cm in length. Aluminium causes less reaction from the tree as it does not rust but hammering an aluminium nail into hard wood is not always possible, so steel nails may need to be used in some cases. Nails should be hammered in at a slight downward angle just far enough so that it penetrates the bark and is secure, but has at least 2 cm free to allow space for the tree to grow.
If the plot is divided into strips tagging all the stems in each strip on alternating sides of the stem can help to identify each strip and keep the stem measurements in sequence.

5.3.2 Mapping stem location

A map of stem locations can help locate trees for re-measurement, especially if trees are not tagged, or tags are lost. Location information is also useful for studies of spatial patterns and processes. The preferred way to record x and y coordinates is to divide the plot into 10 m wide strips, with measuring tapes along both long edges. These can be used to measure one coordinate, and estimate the other (diagram). The x and y coordinate should be with respect to the SW corner of the plot. On circular plots, the distance and bearing from the centre should be recorded. A differential GPS can be used instead, but a normal handheld GPS is not accurate enough to locate stems.

5.4 Cut, broken and fallen stems

For each stem note if it has:

- Been fully cut or broken – in which case the height of the cut or break should be recorded,
- Been damanaged. In the case of damage, two metrics are used:
    - The % of the cambium which is exposed, i.e. the bark is missing. This should be estimated on 4 sides of the stem, from ground to 2 m height.
    - The presence / absence of bracket fungus should be recorded as in indicator of rottenness.
- Fallen. Defined as no longer bearing its own weight.

NB If a stem is not rooted in the soil it is not included in the stem inventory, but instead will be recorded as woody debris.

5.5 Other attributes of alive stems

The following attributes should also be noted with a simple Y/N:

- New recruit since last census (i.e. has grown to now exceed the threshold diameter)
- Located on a termite mound
- Hit by lightning
- Presence of climbers in the canopy
- Presence of a strangler on the stem
- Stump. If the stem has been cut or broken lower than the POM then it is called a stump.

5.6 Alive / dead

Each stem measured should be recorded as either alive or topkilled. A stem should be recorded as topkilled if there is no sap beneath the bark at the default POM and no signs of life in the canopy above the default POM. Stems that appear to be almost dead should be noted in the comments, as it will help with the next census if the tree is missing. It can be hard to know if a stem is dead, and sometimes they “come back to life”: thus it is important to record the alive / dead status for at least one more census after the initial declaration of death.

5.6.1 Topkilled stems

Stems that show no signs of life above the default POM should be recorded as topkilled. For stems recorded as topkilled, details of type, mode, and cause of death, and decay class should be noted using the following codes:

Type of death	Mode of death	Cause of death*

R = Topkilled, resprouting T = Topkilled, no sign of resprouting D = Totally killed (i.e. base appears to be dead)	U = Uproooted P = Snapped S = Standing V = Vanished Q = Can't tell X = presumed dead (location not found)	N = Neighbouring tree E = Elephant F = Fire H = Human (cut or ringbarked) L = Lightning M = Termites W = Wind Q = Can't tell

* Note, it will not usually be possible to determine the cause of death with any certainty and unless the cause is unambiguous "Q – Can't tell" code should be used. When cause of death = Human, add details to notes indicating method e.g. ringbarked, chainsaw, machete.

5.7 Species identification

Each stem measured should be assigned a species or morphospecies[1] name. A trained botanist and/or parataxonomist with knowledge of the local flora should be present for the establishment of the plot to identify species using scientific and/or local name. If possible, voucher specimens of all species and morphospecies present within the plot should be collected and duplicates stored in local, national and international herbaria. Voucher specimens can then be used to confirm species names and assign scientific names to morphospecies. Species identifications can be verified and improved as plots are re-measured.

Collection and preparation of voucher specimens In woodlands and savannas, voucher collection of leaf material can often be done by hand. However, some tall individuals and those with fruit or flowers in high places necessitate climbing or the use of clipper poles. In terms of collection protocols, it is important to collect several leaves attached to the stem, except in the case of large compound leaves where sometimes a single leaf (still attached to stem/twig) will suffice. If fruiting or flowering material is available, then effort should be expended to obtain it. In the dry season and/or arid areas, plant presses can dry in the sun (on a roof rack or otherwise). When humid, it is important to dry the specimens using a space heater or plant drying oven (can be constructed with a standard 1 or 2 burner gas stove and canvas or plywood) within several days of collection. Otherwise, the leaves fall off. In remote, humid areas where it is logistically infeasible to take a gas canister, specimens can be stored in plastic bags with alcohol.
Authorities Exporting voucher specimens to at least one international herbarium allows species determinations to be standardised across countries. As per the Nagoya protocol, no international herbarium should accept specimens without associated paperwork and permissions.
Photographs Definitive identification of trees by scientific name usually requires consultation of herbarium specimens. As most people are aware, plants look different when alive vs when pressed flat and glued to a sheet of paper. Thus, while photographs of living leaves, fruits, flowers, bark and trunk slash are all very useful things (which we should endeavour to collect!), photographs of dried herbarium specimens are also very useful in cases where specimens cannot be readily exported to an international herbarium.

[11] Morphospecies are morphologically recognisable and distinguishable entities for which the scientific name is unknown. These can be 'local species names'. Alternatively, even when botanically-informed researchers are involved in plot set-up, there are often individual trees that cannot be identified (e.g. due to a lack of key diagnostic features present in fruits or flowers). In these cases, it is useful to determine which individuals across the plot seem to belong to the same species, even if a scientific name cannot be put on it (e.g. for purposes of calculating alpha diversity).

5.8 Height measurement

Accurately measuring the height of all stems in a plot is time consuming and will not usually be feasible. As an alternative, local height-diameter relationships can be developed to estimate height from diameter measurements, by measuring the height of a sub-sample of trees. The degree to which a diameter-height relationship can be built for a site that is suitable for prediction can be assessed by measuring around 50 trees from across the range of DBH values found in the site (e.g. 10 trees from each of the 5-10, 10-20, 20-30, 30-50 and >50 cm diameter brackets) and testing the r-squared of the resulting relationship. If the r-squared is less than 0.5, then individual height estimates for every tree may be necessary.

Note that height must be recorded for separate stems that meet the diameter threshold, not whole trees.

Estimating tree height with trigonometry

Tree height can be accurately estimated by measuring the angle from the bottom to the top of the tree from a known distance, and using trigonometry to estimate the tree height.

For the most accurate height measurement, stand at a distance approximately equal to the trees height (i.e. for a 20 m tall tree stand 20 m away), to give approximately a 45° angle when looking at the top of the tree. Move around the tree to get the clearest view of the tree base, stem and top. Avoid standing <10m from the tree unless the tree is very small, and be aware that some laser measuring instruments do not give accurate measurements at distances of <10m. On sloping ground avoid standing below the base of the stem. Clinometers, laser range finders (e.g. Nikon Forestry Pro) and ultrasound devices (e.g. Haglöf Vertex Hypsometer) can all be used to produce accurate estimates of tree height. The additional cost of more sophisticated devices generally provides quicker or easier measurements rather than improved accuracy.

If angle to base of stem (*a*), angle to the top of the crown (*b*), and horizontal distance to the centre of the tree (*x*) are measured, height can be estimated with the equation:

$$Height = x(\tan a + \tan b)$$

Estimating tree height by eye

A combination of a 2 meter stick with 10 cm increments marked, and eye, can be used to estimate stem heights. This method is clearly very accurate for trees <=2 m, and reasonably accurate up to 4 m if two people are present, one to hold the stick and one to stand far away. Estimation by eye is also possible for much larger stems (again with two people, one holding a stick of known length next to the stem), but accuracy decreases with height. If time or equipment is limited, estimation as described above is a valid option for many savanna trees, and certainly produces more useful data than collecting no height data at all.

6 Small stems

In general, it is recommended to set the diameter threshold to include all stems size classes of interest. If however, information on smaller size classes is required, a simple count of stems is normally sufficient.

Small stems with a dimeter at the POM of more than zero and less than the threshold should be counted in belt transects – no diameter measurements or tags are needed. The sub sampled area should be a 2 m x 50 m transect. Two such transects should be placed in each 0.25 ha, and counts recorded for each transect. Counts can be recorded for each species, if this extra information is needed.

Stmes that have a high of less than the default POM should be included in the (optional) protocol for survey of understory vegetation (grass and forbs).

Studies with a particular focus on regeneration and the diversity of the understory will want to measure more attributes of the small stems, and may sample more intensively to gain more precision; tagging (normally by attaching a tag around the stem with wire for saplings as nails will do too much damage to small stems) may also be needed. The method here is suggested as a minimum.

7 Stumps

Stumps that are cut above the appropriate POM are measured as stems. At the time of plot establishment all stems that are fully cut or broken below the POM should also be recorded on a separate data sheet. It is not necessary to tag these stumps.

For all stumps and cut stems measured, the following information should be recorded:

- diameter at top of the stem
- height of the top of the stem (where diameter measurement was taken)
- diameter at 0.3 m above the base (if possible)
- decay class (see woody debris)
- species (if possible)
- cause of break – see topkill codes

8 Coarse woody debris

Coarse woody debris is defined as dead tree stems, large limbs, and other large wood pieces either lying on the ground or elevated off the ground, but not rooted in the ground. It does not include live material, standing dead trees still rooted in the ground (included in the stem inventory), stumps (which have their own protocol), dead foliage, separated bark, non-woody pieces, roots, or the part of the tree stem below the root collar.

Coarse woody debris should be measured along perpendicular transect lines forming an x or + across the plot to avoid piece-orientation bias. Each transect originates at the centre and radiates out, so that each plot has 4 transects if laid out in an + or x formation from the centre. Transect design can be flexible, but avoid parallel transects. A piece of debris is measured if:

a. the central longitudinal axis of the piece intersects the transect;
b. the diameter at the point of intersection is > 3 cm, and the piece length is > 0.5 m
c. the piece is not decayed to the point of having no structural integrity (i.e. can be measured).
d. Other rules include:
   I. When a piece of wood is forked or has a very large branch attached to the main bole—and both segments intersect the transect—they are tallied as two separate pieces, if each meets the required minimum dimensions;
   II. A piece is tallied twice if it intersects two different transects or if it is nonlinear and intersects the same transect in two location.

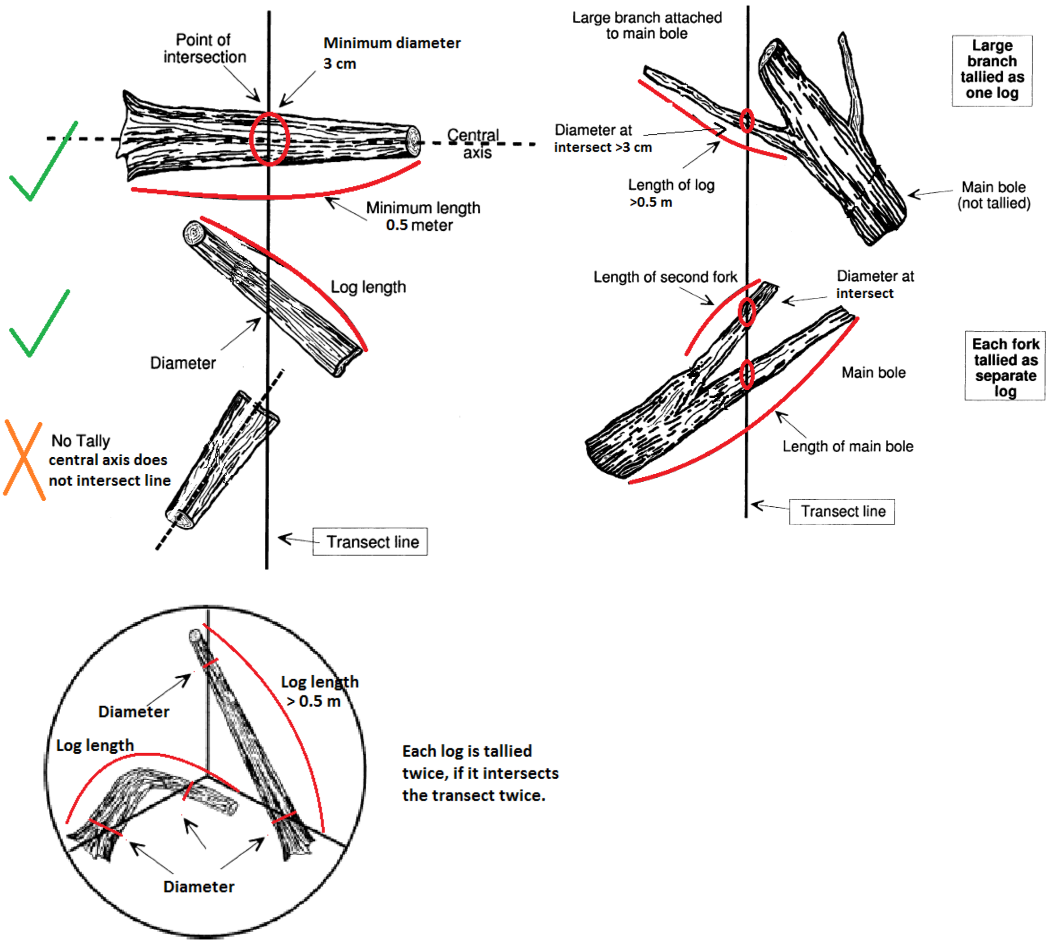

Fig. x: Adapted from (Waddell, 2002)

Measurements taken on each piece are:

1. Diameter at the point of intersection (cm). This can be estimated if you cannot pass the tape around the piece. Callipers are very useful for smaller items; a diameter tape will be needed for larger items
2. piece length (m);
3. decay class (see table 1);
4. and the species of the piece, if possible.

Using the equations set out in Waddell (2002) you can thereby estimate total coarse woody debris density (logs/ha), volume (m3/ha), and biomass (t/ha) in the plot.

Decay class	**Structure**	**Wood texture**	**Wood colour**	**Condition of branches and twigs**	**Biomass reduction factor**
1	Sound, firm	Intact, no rot	Original colour	Branches with fine twigs present	1
2	Heartwood sound, sapwood a bit decayed	Sapwood partly soft. Wood cannot be pulled apart by hand.	Original colour	Branches with some fine twigs present with peeling bark	0.86
3	Heartwood sound, log supports its weight	Large hard pieces of sapwood can be pulled apart by hand	Red-brown, or original colour	Large branches with no fine twigs, branches do not pull out by hand	0.72
4	Heartwood rotten, log does not support its weight	Soft, small, blocky pieces. Heartwood is soft.	Red-brown, light brown, grey-brown	Large branches pull out easily by hand	0.59
5	No structural integrity, no longer maintains shape	Very soft, powdery when dry.	Red-brown, dark brown	Branches not present	0

Table 1. Decay classes. Sources: Modified from Waddell et al. (2002), Maser et al. (1979) and Sollins (1982). Data on the biomass reduction factor come from unpublished data collected as part of a fire experiment in Mozambican miombo (Ryan and Williams, 2011)

9 Plot re-measurement

Re-measure stems approx. every 3-5 years. Consider a shorter measurement period at the start which will help resolve errors in the first census, provide further opportunities for species identification, and also maintain links with the local community.

Re-record the locations of the plot corners at every remeasurement to improve accuracy and update the plot data sheet with any changes in e.g. human use.

Make sure that previous census data are consulted when recording remeasurement data. This helps identify errors. For this reason, it is recommended that for each stem originally measured, a new row is inserted into the re-survey datasheet below previous records (completed example shown in grey in the example below). This allows all data to be maintained on the datasheet without adding columns, ensures consistent recording methodology between surveys and creates data that is formatted ideally for easy data cleaning and analysis (every row is a record, every column is a variable). Recruits should, if possible, be recorded on a separate datasheet that is clearly marked as a recruit sheet and dated with time of survey (but is otherwise identical). A sample datasheet is included Annex 2, Table 1.

The recorder should not use previous measurements to "correct" or even recheck the new measurement unless they indicate a gross error, e.g. a diameter change of more than 2 cm. Adjusting the new measurement with the old one in mind will create biases and must be avoided.

Table 2. Illustrative example of how to record remeasurement data. Note that stems 2 and 3 have the same base (multiple stems), and that stem 3 died between census years. Grey rows indicate the new data from a second census conducted in 2020.

Tag id	Year	Species	Diameter	POM	Base ID	Alive/Dead	Standing/Fallen	Notes
1	2015	B. boehmii	10.0	1.3	1	A	S	
1	2020	As above	11.5	1.3	1	A	S	
2	2015	B. spiciformis	55.1	1.3	2	A	S	Large tree
2	2020	As above	55.2	1.3	2	A	S	
3	2015	B. spiciformis	10.8	1.3	2	A	S	
3	2020	B.spiciformis	10.5	1.3	2	D	S	Elephant damage
4	etc							

To record demographic process (recruitment, resprouting and topkill and mortality), the SEOSAW approach for long term plots is to:

a. Tag all stems where possible
b. Also keep track of all bases that have stem(s). This allows for studies of resprouting.
c. In the simplest case, a base with one stem, the id of the base is the same as the id of the stem (see tag id 1 above)
d. In cases of multiple stems, the base id is the id of the first stem to be tagged. This is maintained, even if the first stem dies. For this reason, tag numbers should never be reused.
e. When all stems have been topkilled, the base should be tagged if there is any chance that it is viable – use the tag from the lowest numbered stem
f. The base id of recruits should be recorded so that resprouting can be assessed

Because of the extra care needed to calculate mortality and topkill rates, it is well worth taking extra time over dead stems. Their alive / dead status should be recorded in at least one census after they are first marked as dead. Stems do "come back to life" – either because they weren't dead in the first place, or because of recording errors. Once a stem has been recorded dead in two censuses, it can be removed from the field sheets used in subsequent censuses.

9.1 Stem measurements

It is helpful to restring the plot before remeasurement, to reduce errors in relocating stems (which may have lost tags etc).

All measurements should be repeated, except the xy coordinates. The species determination should be quickly double checked for gross errors. Remeasuring height is optional.

Locate the POM by measuring from the tag if possible (the POM is always 20 cm below the tag). On untagged plots measure the height of the POM from the ground. Trees often shrink and shed bark, so do not worry if the diameter measurement is smaller than the previous one. Anything that might explain large changes should be noted in the comments.

If a POM becomes bad between censuses (e.g. a deformity has appeared), measure diameter at both the bad, old POM, and a new, good one. This allows for a correction to be made for the biomass increment.

9.2 New recruits

Stems that attain the threshold diameter (recruits) should be tagged and measured and with the data entered onto the "recruit" sheet, or at the end of the stem remeasurement form. The tag number should simply be the next tag number in the sequence for that plot. Whatever else you do, do not reuse a tag that has **ever** been used on that plot. Over time this system will mean that the tag numbering will lose its spatial continuity, but as long as spatial position is recorded, this is not a problem.

The base id of the recruit needs to be recorded, taking particular care to ascertain if the base is shared with another stem in the current or previous census. If it is not shared, then the base id is the same as the new stem id.

9.3 Missing trees

Take particular care to understand the fate of missing stems, and confirm topkill rather than measurement error. For stems that are no longer present, search for the tag in the soil, and try and locate the remains of the roots, or the hole where the roots have been burned out. This helps confirm that the tree is really dead, and not just mis located in a previous census. Any doubts should be recorded in the comments.

Annex 1 Plot data sheet

Table 1. Plot level data to be recorded.

Name	Unit or valid options	Instructions	Notes
Plot Design			
1. Plot name	text/number	A unique name or code	
2. Date of plot establishment	DD/mmm/YYYY	Date that initial tree measurements were finalised	To avoid confusion, write the month using letters
3. Principal investigator		The data owner's name	Include institution and email address
4. Other authors		Other people who have ownership rights to the data (i.e. who would need to be consulted before it were used).	Include institution and email address
5. People to be acknowledged		Names of people who helped create the data, but who would not normally be included as authors to papers, e.g. field technicians	
6. Area of plot	Hectares	Area of the plot in ha, as measured on the ground	If nested, this is the area of the largest plot
7. Planar area of plot	Hectares	Area of the plot in ha, if projected onto a horizontal surface. Ignore this if the plot is on flat ground.	Calculated when back in office
8. Shape of plot		E.g. square, rectangle, circle	
9. Length of x-axis	Meters		If nested, this is the widest plot
10. Bearing of x-axis	Degrees	Bearing of the x-axis measured from the plot start point	
11. Length of y-axis	Meters		If nested, this is the longest plot
12. Bearing of y-axis	Degrees	Bearing of the x-axis measured from the plot start point	
13. Plot diameter	Meters		If a circle was used
14. Min Tree Diameter	Centimetres	What was the threshold of tree diameter that was measured, e.g. >5 cm DBH	

15. N1: Min tree Height	Meters	As above but for height. Leave blank if there was no height criteria	
16. Height method	Text	1= Estimated by eye. 2= Manually by trigonometry (clinometer). 3= Manually by trigonometry (clinometer), carefully trained. 4= Laser or ultrasonic distance to tree, electronic tilt sensor for angle. 5= Laser hypsometer from directly below crown, “last return” filter function. 6= Directly (e.g. climbing, cutting, adjacent tower).	
17. Nested?	Y/N	If you used a nested plot design, then Y	Repeat fields 6 to 15 for each part of the nested plot
What was sampled			
18. Lianas sampled	Y/N/not present	Were lianas (climbers or scramblers, i.e. trees that cannot support their own weight) measured?	
19. Soil sampled	Y/N	Did you collect soil samples? See soil protocol for other details	
20. Saplings and poles sampled	Poles / saplings	Did you count the woody stems that were smaller than the diameter threshold above?	
21. Understory sampled	Grass, forbs, shrubs, seedlings	Did you sample the grasses, forbs and shrubs? Y/N.	
22. Stumps sampled	Y/N	Did you measure the tree stumps that remained after felling or other forms of tree death?	
23. Land use history timeline	Y/N	Do you have any information on the land use history of the plot? Separate form to be developed if Y	
24. Protocol		The file name or description of the methods or protocol that was followed. If not documented please put “not documented”	
Plot location			
25. Latitude of centre / corners and accuracy	Decimal Degrees, accuracy in m	Use decimal degrees in the WGS84 system to	Repeat on multiple days if possible to reduce

		avoid issues with projections	errors. Report average of multiple days.
26. Longitude of centre / corners and accuracy	Decimal Degrees, accuracy in m	Use decimal degrees in the WGS84 system to avoid issues with projections	Repeat on multiple days if possible to reduce errors. Report average of multiple days.
27. Altitude	m above sea level	Record accuracy	
28. Average plot slope at 20m horizontal scale	Decimal degrees	If two people stand 20 m apart on the plot, what is the slope between them in degrees? Choose either a representative area, or repeat several times and average	
29. Aspect	N, NE, E, SE, S, SW, W, NW	Aspect of steepest slope	
30. Allometry: chave14 ok?	Y/N	Is there any reason not to use Chave et al (2014) dbh- biomass allometry for this plot. If there is a problem, please explain.	
31. Recommended allometry		How best to estimate the biomass of each tree on the plot. Is there a local allometric or a specific one you would recommend?	
Environmental conditions			
32. Catenal position	crest, upslope/concave, bottom slope/convex, valley	Estimate Of at what position on the catena the plot lies. This can be very scale dependant, so please estimate in relation to the nearest river that is at least 2 m wide.	
33. Termites	count	If you counted termite nests, how many are there on the plot?	
34. Canopy cover	% of ground under tree canopy	What % of the ground is beneath a tree canopy	Optional
35. Canopy cover method	densiometer, hemispherical photo, point intercept, other	How did you measure this? Add number of measurements	Optional
Current land use			
36. Manipulation experiment?	Y/N	Is any aspect of the plot's land use or env	

		conditions manipulated by scientists?	
37. Experiment ref	Link to set up description	Where can we get details of the experimental set up?	
38. Protected Area (PA) status	Either “not protected” or the name of the protected area	Leave blank if not in PA. Please look up the PA name on http://www.wdpa.org	Include category if known
39. Local community rights	to harvest trees, to harvest NTFPs, both	What are the local community allowed to harvest (for non-commercial use)?	This is the legal (de jure) rights for own use
40. Other usufruct rights		Do other people (i.e. outsiders) have rights to harvest trees; NTFPs or both?	
41. Timber harvesting occurring	Y/N	Is there any evidence of trees being harvested for timber - i.e. for making into planks, or industrial wood products (not including poles)?	
42. Fuel wood harvesting	Y/N	Is there evidence of fuel wood collection (excludes charcoal production).	
43. Charcoal harvesting	Y/N	Evidence of charcoal makers harvesting trees in the plot?	
44. Other woody product harvesting	Y/N	Other evidence of people harvesting woody material or felling trees for e.g. string, beehives, canoes, etc	Includes hives, bark for string etc
45. NTFP harvesting	Y/N	Is there evidence of people harvesting non-wood products, e.g. mushrooms, honey, fruit, etc?	
46. Used for farming in last 30 years?	Y/N/Maybe	Is it likely (P>0.5) that the plot was used for farming (or cleared for another reason) in the last 30 years?	See timeline data sheet for full details
Fire			
47. Estimated fire return interval (years)l	0-Inf	E.g. 1 for annual burning; 2 for every two years, 3 for every three years	Inf =no burn.

48. Fire managed?		Is there any attempt to protect the plot from fire or deliberately burn it? Protected/ deliberately burned: very effectively / somewhat / not at all	
Large herbivores			
49. Exclosure?	No / large / small / large + small	Are browsers excluded from the plot by a fence?	
50. Elephants	Y/N/Not Sure	Are elephants present on the plot?	
51. Elephant density	Ele / km^2	If elephants are present, at what density?	
52. Elephant data source	Free text	Source of elephant density data	
53. Small nonsocial browsers	Y/N	incl. dik-diks, duikers and grysbok, steenbok	(53-57 are based on Hempson et al 2015).
54. Medium-sized social mixed diets	Y/N	E.g. gazelles and oryx	
55. Large browsers	Y/N	giraffe, okapi, Eland, Nyala, Kudu	
56. Water-dependent grazers	Y/N	incl. Roan, Sable, Bluebuck, Waterbuck, Roan, Lechwe	
57. Nonruminants (excluding suids/pigs)	Y/N	zebra, hippos, rhinos	
58. Cattle graze here	Y/N	Do domestic cattle feed in the plot?	
59. Goats graze here	Y/N	Do goats feed in the plot?	

Annex 2: Data sheets

Table 1. Stem level datasheet. Note that an Excel version is available on the SEOSAW website. The same data sheet can be used to record new recruits.

Year	*Plot*	*Subplot*	*X*	*Y*	*Tag No*	*Base Tag No*	*Species*	*POM (cm) e.g "130"*	*DBH (cm) e.g "10.1"*	*Alive/Dead*	*Stand/Fall*	*Mort. Type*	*Mort. Mode*	*Mort. Cause*	*Mort. Decay*	*Height of break (m)*	*Comment (wound = % camb exposed + bracket fungi?*

10 Annex 3. Notes on using a drone to locate new plots (by Thom Brade)

A consumer drone carrying a basic RGB camera can be deployed to great effect when establishing new plots, and these are relatively affordable (~£1000 will buy a very effective drone) and readily available. Quadcopter designs are stable and easy to operate (wind conditions permitting) and are available in compact folding designs easily transportable as hand luggage (which both the drone and the drone batteries should be due to flight checked baggage restrictions). We recommend DJI drones due to wide availability, proven performance and compatibility with several open source software packages that facilitate accurate automated survey.

10.1 Drone field operation - iOS or Android device

Free software can be downloaded onto your mobile iOS / Android tablet or phone and deployed by plugging said mobile device into the drone remote control. This allows fully automated survey in which the a mission can be uploaded to the drone which will then take off, fly the planned mission taking photos at specified points and return to the mission starting point (assuming the mission has been designed within the limitations of drone battery and within the maximum contact range with the controller). Examples of free software used for this purpose are:

- Pix4d Capture (iOS and Android)
- DJI GS Pro (iOS only)

Single batteries on a compact quadcopter can be expected to comfortably perform surveys of areas of 5 ha depending on requirements of imagery (which will determine flight altitude, image overlap extent, drone speed etc.). If a bigger area is required missions can be paused, battery changed and mission resumed with both of these software packages.

10.2 Drone post processing - photographic processing software for further analysis

If you have planned missions appropriately (mission photo overlap and altitude settings) and have access to photographic processing software and relatively high performance computing facilities (recommend machines with 64 GB RAM and SSD write facilities) mission photo outputs can be mosaicked into single large area images for creating areal statistics or for other forms of analysis. Examples of commercial software (require licence) used for this purpose are:

- Pix4d
- Agisoft (Metashape / Photoscan)

Read software manuals before planning any missions. Inappropriate specification of parameters such as photo overlap and altitude of flight for your given purpose and woodland / forest will inevitably lead to issues with output data quality or lead to failure of processing. See for example: https://support.pix4d.com/hc/en-us/categories/200300675-Pix4Dcapture for information on recommended mission settings.