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Supplemental protocol for liana censuses

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Abstract

Lianas affect many aspects of tropical forest dynamics and thus the study of their ecology is critical for a comprehensive understanding of tropical forest ecology. Recently, we initiated a complete census of all lianas ≥1 cm diameter in the 50 ha forest dynamics plot on Barro Colorado Island, Panama using the census protocol developed by Gerwing et al. [Gerwing, J.J., Schnitzer, S.A., Burnham, R.J., Bongers, F., Chave, J., DeWalt, S.J., Ewango, C.E.N., Foster, R., Kenfack, D., Martinez-Ramos, M., Parren, M., Parthasarathy, N., Perez-Salicrup, D.R., Putz, F.E., Thomas, D.W., 2006. A standard protocol for liana censuses. Biotropica 38, 256–261]. This protocol marked an important advance in the study of lianas by providing a standard methodology that can be used for liana censuses worldwide, thereby making accurate comparisons among studies possible. During the course of our census, however, we encountered a number of recurring situations that were critical for accurate and repeatable liana censuses, but were not covered in the protocol of Gerwing and colleagues. In this paper, we present a supplemental protocol that covers these additional situations. Our supplement, combined with the protocol developed by Gerwing et al., provides a more complete set of methods with provisions for situations commonly encountered in liana censuses.
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Keywords: Barro Colorado Island; Census methods; Forest dynamics plots; Lianas; Panama; Tropical forest

1. Introduction

Lianas are an abundant and dynamic component of tropical forests and many different methods have been developed for censusing them. The establishment of detailed and standardized census methods by Gerwing et al. (2006) was a significant milestone for the study of lianas. Researchers are now able to use a standard protocol to estimate liana abundance, diversity, and basal area in forests worldwide, thereby alleviating the concern that differing census methods used by different research groups will lead to datasets that are largely incompatible (Schnitzer et al., 2006). A detailed and standardized protocol may encourage more researchers to include lianas in forest plot studies, which traditionally have included only trees. Because lianas can reduce tree growth, regeneration, and fecundity, as well as alter forest regeneration and successional trajectories (Schnitzer et al., 2000, 2005; Schnitzer and Bongers, 2002; Pérez-Salicrup et al., 2004; Wright et al., 2005), the inclusion of lianas in forest studies may yield important new information on forest dynamics, which are crucial for a comprehensive understanding of tropical forest ecology and the formulation of effective management practices (Pérez-Salicrup et al., 2004; Schnitzer et al., 2004).

In February 2007, we initiated a full census of the 50 ha forest dynamics plot on Barro Colorado Island, Panama (BCI), in which we tagged, measured, mapped, and identified all lianas ≥1 cm diameter using the protocol recommended by Gerwing et al. (2006). Whereas this protocol worked well for most situations, during the course of our census we encountered a number of recurring situations that were not covered by Gerwing et al., but were necessary to consider to achieve an accurate and repeatable liana census. This paper describes the additional census methods that we developed for these situations, as well as providing a full description of the methods used for the liana census of the BCI 50 ha plot.

1.1. Supplemental protocol for censusing lianas

We describe our protocol for 11 situations that were either omitted by Gerwing et al. (2006) or are slight modifications of the Gerwing protocol. We drew Fig. 1 in the same style as the

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Gerwing figure and we labeled our figure to start where Gerwing left off, with the letter H. Our goal is for both figures to be complementary, so that together they can be used as a compact field census guide (Appendix A). In all cases and particularly when a portion of the liana is prostrate on the soil or it roots multiple times, we refer to the rooting point as the last substantial rooting point before the stem ascends (see case "P" below and Gerwing et al., 2006 Fig. 1 case "D").

(H) *When to deviate from the 130 cm measurement point due to branching*: In the case where a liana stem branches at a point less than 130 cm from the roots, but the branch has a diameter less than the minimum diameter cutoff (1 cm in our case), we ignore the branch and measure the principal stem 130 cm from the roots. If the branch surpasses the minimum diameter cutoff, however, then the measurement location is taken 20 cm below the branch, as recommended by Gerwing et al. (see also (Appendix A) "J" below).

(I) *Minimum size cutoff for branched lianas*: If a liana branches within 130 cm of the roots and neither the main stem nor the branch is ≥ the minimum diameter cutoff 130 cm from the rooting point, exclude the liana from the census, even if the stem is ≥ the minimum diameter cutoff below the branch. This protocol is consistent with the BCI tree census methods (Condit, 1998). We acknowledge that in some cases we may exclude lianas that would otherwise be included in the census if the measurement location had been lower on the stem than 130 cm from the roots.

(J) *Branching close to the roots*: If a liana branches within 40 cm of the roots, measure each stem 130 cm from the rooting point along the stem and note in the dataset that they are all branches of a single individual. The protocol of Gerwing et al. was to measure the stem halfway between the branch and roots where possible. We used a slightly modified version of cases "C" and "G" in Gerwing's protocol because we found that the stem was often deformed or difficult to measure if the branch was close to the roots. Thus, to simplify and standardize the measurement location, we always measure each stem at 130 cm if the stem branches within 40 cm of the roots.

(K) *Multiple rooting points*: If the liana loops from one rooting spot to another and there are multiple resprouts or branches ≥ the minimum diameter cutoff 130 cm from each rooting point, which is often the case for such lianas as *Coccoloba parimensis*, measure each stem 130 cm from the roots of each distinct rooting point—following the protocol for branching and measuring multiple stems in "H", "I", and "J" (Fig. 1), and in Gerwing et al. (2006). Label and map the largest stem that ascends towards the canopy as the "principal stem", and label and map each additional multiple stem uniquely with the tag number followed by a letter (see below).

(L) *Ground-to-ground lianas*: Exclude "ground-to-ground" lianas, i.e., those that do not ascend toward the canopy, but rather loop from one rooting spot to another without any resprouts or branches.

(M) *Ground-to-ground lianas with stem sprouts*: In contrast to "L", include "ground-to-ground" lianas if they also have a living resprout or branch that ascends towards the canopy, and either the branch or the principal stem is ≥ the minimum diameter cutoff in diameter 130 cm from the roots. If the branch is ≥ the minimum diameter cutoff and within 130 cm of the roots, the measurement location should be on the ascending branch (case "C" in Appendix A and Gerwing et al., 2006). If the branch is < the minimum diameter cutoff, measure the principal stem 130 cm from the roots, ignoring the branch (case "H" in Fig. 1). However, exclude the liana if the total stem length does not exceed 130 cm. We selected these criteria because the stem is ≥ the minimum diameter cutoff 130 cm from the roots and it is clearly alive (evidenced by a living resprout or branch), and thus it meets our criteria for inclusion. These criteria are also consistent with the BCI methods of tree censuses (Condit, 1998).

(N) *Prostrate lianas*: If a liana is growing prostrate on the soil surface but does not have a stem ≥ the minimum diameter cutoff ascending toward the canopy, exclude the liana from the census (even if it is ≥ the minimum diameter cutoff and rooted within the plot). The distinction between cases "N" and "L" is that we would not measure any part of "N" that is prostrate along the ground; we would measure only the resprouts ≥ the minimum diameter cutoff. In contrast, we would measure the main stem in case "L" if there were resprouts (as in case "M").

(O) *Prostrate branches*: Some common neotropical taxa, such as those of the Bignoniaceae, often have many small branches that originate low on the principal stem and snake along the forest floor but never ascend. Exclude these

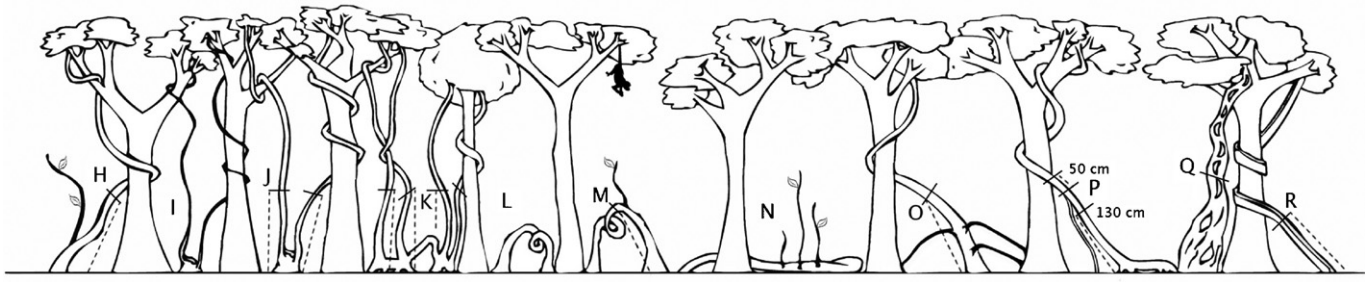

Fig. 1. Supplemental protocol for liana measurement methods not covered in Gerwing et al. (2006). Each letter of the figure is described in the text. Dashed lines indicate 130 cm from the roots, measured along the stem and not perpendicular to the ground. In case P, an additional dashed line indicates 50 cm higher than the last aerial root. Illustration by S. Rutishauser.

branches if they are smaller than the minimum diameter cutoff and measure the principal (climbing) stem 130 cm from the roots (as in Fig. 1, "O"). However, if these branches are ≥ the minimum diameter cutoff, measure the principal stem 20 cm below the lowest branch (as per Gerwing et al., 2006; case "J" may also apply). If these prostrate branches re-root and have climbing resprouts ≥ the minimum diameter cutoff, measure and map the resprouts 130 cm from the last rooting point and tag them using the principal stem number followed by a letter (see below).

(P) *Defining aerial roots*: Gerwing et al. recommend measuring 50 cm above the last adventitious root if that root is >80 cm from the "main rooting" location. We followed this recommendation with one modification: we measured 50 cm above the last *aerial* root if that root was >80 cm from the *ultimate* rooting location. We considered aerial roots to be those that originated from the part of the stem that was suspended in the air (i.e., not prostrate on or buried in the soil). We defined the ultimate rooting location as the last substantial rooting location of the portion of stem that is in contact with the soil surface immediately prior to the ascension of the stem towards the canopy. We deviated from the protocol of Gerwing et al. in this case because it was often impossible to distinguish the "main rooting point" for prostrate stems snaking along the soil surface that had multiple rooting points, some of which were larger than the rooting point furthest from the ascending portion of the stem. Furthermore, we wanted to consistently use the last substantial rooting point before the stem ascended to the canopy (e.g. Gerwing's Fig. 1, case "D"). We defined the *substantial* rooting point as one where the roots were strong enough not to be easily dislodged.

(Q) *Non-uniform* (*anomalous*) *stems*: In the case where the stem is anomalous and not uniform (e.g., separated into multiple strands in the case of *Bauhinia* spp.) from the roots to above 130 cm, measure the stem 20 cm above the point where it becomes uniform. If there is no uniform area on the stem that is within reach, then measure the non-uniform area 130 cm from the rooting point and note this in the dataset.

(R) *Minimum size cutoff for non-cylindrical stems*: In the case where the stem is not cylindrical (e.g., *Maripa panamensis*, *Bauhinia* spp.) include the liana if the mean of its wide and narrow axes is ≥1 cm (or the minimum size diameter cutoff). While the arithmetic mean can be used in the field to rapidly determine if a non-cylindrical stem has a basal area greater than the minimum size diameter cutoff, ultimately the geometric mean should be used to estimate the basal area of stems that are more elliptical than cylindrical (Gerwing et al., 2006; Schnitzer et al., 2006).

1.2. Tagging, mapping and identifying lianas in the Barro Colorado Island 50 ha plot

For each liana in the BCI study, we attach a tag to the principal stem immediately above the ultimate rooting location using loosely tied 12-gauge green grafting tape (Condit, 1998). We deploy the tags in numerical order, which will enable us to increase the speed of subsequent plot censuses. Each column has a set of pre-printed aluminum tags, which have eight digits preceded by an "L". The first two digits indicate the census number, the next two digits indicate the column number, and the last four digits indicate the liana number for that column (e.g., L 01-05-0353). We also tag all multiple branches and resprouts ≥1 cm diameter using the number of the principal stem followed by a letter, which we write on green grafting tape with permanent black ink and tie around each multiple stem (Appendix B). We map the ultimate rooting point of all stems, including independently rooted multiple stems that are connected to the principal stem. We do not map branches from a single stem if they are not independently rooted, allowing us to distinguish these two types of multiple stems. For every stem that we measure, we apply a strip of orange, oil-based spray paint at the measurement location (Sheil, 1995), which will allow us to consistently re-measure at the same stem location in subsequent censuses without having to record data on the point of measurement for each stem (Gerwing et al., 2006). We use the multiple datasheets similar to those described by Condit (1998) to record data in the field.

After the lianas are tagged, mapped, and measured, the botanists complete the survey of each quadrat by identifying the lianas. Lianas are identified in the field by a team of botanists with years of experience in the plant taxonomy in Panama. Because a comprehensive description of the flora exists for BCI (Croat, 1978), identification of most species can be performed using a combination of leaf and stem characteristics, and nearly all of the lianas can be accurately identified in the field. We are also collecting voucher specimens for each species on the plot. In many tropical forests around the world, however, liana identification will be much more challenging and a strategy for determining and recording tropical plant taxonomy is provided by Condit (1998).

1.3. Quality control

Throughout the course of the census, we have incorporated three forms of quality control to ensure that the census team members are not deviating from the established methods. The first quality control check occurs with the datasheets. At the end of the week, the datasheets for that week are examined to check for anomalies or missing data. The second form of quality control is implemented in the field, where one of the two field supervisors uses the maps to locate each liana per 20 m × 20 m quadrat to ensure that the maps are accurate (Condit, 1998). For each liana, the supervisor then visually checks or re-measures the stem measurement location to ensure that the correct stem measurement protocol was followed. The supervisor also checks the accuracy of the diameter measurements by re-measuring approximately 10% of the lianas in each quadrat. The third quality control check is the responsibility of the botanist, who uses the maps to locate the lianas for

identification and thus checks the accuracy of the mapping. The botanist also checks for any irregularities in measurement location.

1.4. Summary

The liana census protocol recommended by Gerwing et al. (2006) provides an excellent guide to census lianas in tropical and temperate forests. Our supplement accounts for additional cases specific to lianas that we encountered on BCI, and it is meant to complement the recommendations provided by Gerwing and colleagues. Combining both census protocols will enable researchers to account for many of the situations that are commonly encountered during liana censuses.

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Appendix A

Additional measurement considerations

A.1. Determining rooting location

(1) In all cases and particularly when a portion of the liana is prostrate on the soil or the liana roots multiple times, the rooting point is the last substantial rooting point (i.e., the roots cannot be easily dislodged) before the stem ascends (see case "P").

A.2. Stem anomalies, uneven terrain, and rooting location

(1) Measure 5 cm below stem anomalies (e.g., bulges, nodes, damage, or stem splitting). If the entire stem is non-uniform and anomalous below 130 cm, measure stem where it becomes uniform (see case Q). If there is no uniform area on the stem that is possible to measure, then measure the non-uniform area 130 cm from the rooting point.
(2) When measuring on a slope or uneven terrain, measure from the uphill side of the stem.
(3) Include lianas that root in the plot only if the last rooting point nearest to where the stem ascends into the canopy are within the plot. If the last rooting point is outside of the plot, do not include that liana.

A.3. Diameter measurements

(1) Cylindrical (or nearly cylindrical) stems:
   a. Stems < 5 cm diameter—use calipers at *widest* axis at the appropriate point of measurement.
   b. Stems > 5 cm diameter—use diameter tape.
   c. If a stem > 5 cm w/calipers but <5 cm with diameter tape, use the diameter tape.
(2) Non-cylindrical, flattened stems:
   d. Measure diameters along their widest (d_1) and narrowest (d_2) axes at the appropriate point of measurement (e.g., 5.2×1.5). The average size of the two measurements must be ≥ 1 cm to include the liana in the census. Use the geometric mean to estimate basal area (Schnitzer et al., 2006)

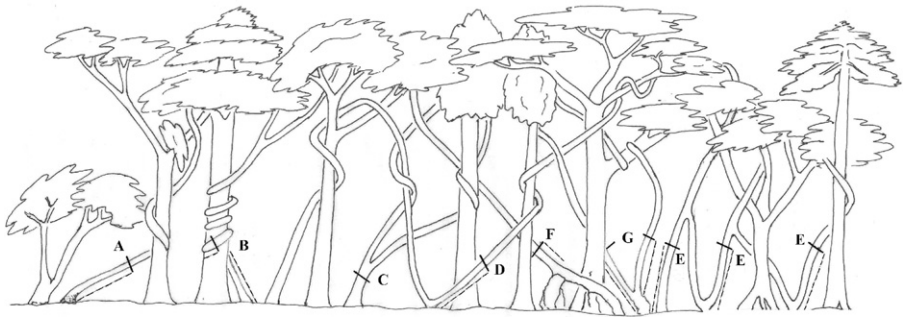
A.4. Multiple-stemmed and rooted clones?

(1) Measure and tag all independently rooted stems—soil excavation should be avoided at all times. If the stems are connected below the soil surface then we consider them to be independent stems.
(2) Multiple stems that are connected to the "principal" stem should be tagged with the same number as the principal stem followed by a letter, with each stem having a unique letter (e.g., 01-05-0353a, 01-05-0353b, 01-05-0353c, etc.). Multiple tags are not pre-printed; on the BCI plot we write the tag numbers on the 12-gauge green grafting tape that we use to tie the tags to the stems.

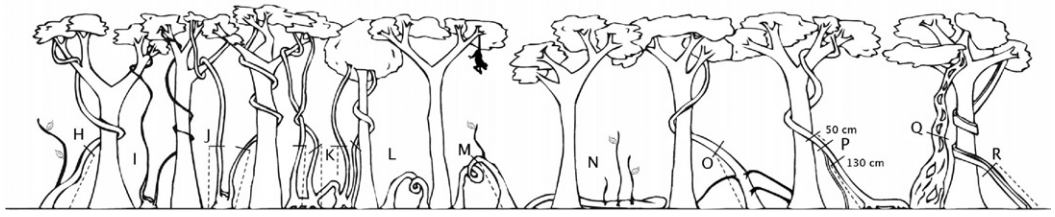
A.5. Which lianas to include?

(1) All lianas (≥ 1 cm), including species with woody or fibrous perennial stems (e.g., *Desmoncus*, *Gnetum*, *Smilax*, *Dioscorea*).
(2) Exclude epiphytes, hemi-epiphytes, and climbing bamboos (see Gerwing et al., 2006; Troy et al., 1997 for treatment of bamboos).

Protocol for determining liana diameter measurement location



(A) Measure the diameter of all lianas (≥1 cm) 130 cm from the main rooting point at the soil surface.
(B) Measure twining lianas 130 cm from the rooting point, along the stem of the liana.
(C) If lianas branch below 130 cm (but ≥40 cm from the roots), measure 20 cm below the branching point.
(D) If lianas loop to the ground and root before ascending into the canopy, ignore the loop and measure 130 cm from the last substantial (cannot be easily dislodged) rooting point along the stem that ascends into the canopy.
(E) If lianas loop to the ground and root (as in D), but the loops have branches that ascend to the canopy, measure each rooted ascending stem of the individual separately and use the multiple stem datasheet.
(F) If lianas have aerial roots >80 cm from the ultimate rooting point of the prostrate stem, measure 50 cm above highest rooted aerial root.
(G) If lianas branch <40 cm from the rooting point, measure each branch of the individual separately at 130 cm above the main rooting point and use the multiple stem datasheet.
(K) Measure each resprout or branch (≥1 cm) 130 cm from the roots of each distinct rooting point.
(L) Exclude ''ground-to-ground'' lianas, those that do not ascend toward the canopy, but rather loop from one rooting spot to another or that are prostrate on the soil without any resprouts or branches, even if they are ≥1 cm diameter.
(M) Include ''ground-to-ground'' lianas if they have a resprout or branch, even if the branch is <1 cm diameter. If the branch is <1 cm, measure the principal stem 130 cm from the roots, ignoring the branch. If the branch is ≥1 cm and within 130 cm of the roots, the point of measurement should be on the ascending branch.
(N) Exclude lianas growing prostrate along the soil if they do not have a stem ≥1 cm ascending towards the canopy.
(O) Exclude multiple branches that originate within 130 from the main roots if they are smaller than 1 cm in diameter.
(P) Measure 50 cm above the last aerial root if that root is >80 cm from the final rooting location of the stem before the stem ascends to the canopy.



(H) Ignore branches <1 cm diameter and measure the principal stem 130 cm from the roots.
(I) Exclude lianas that branch below 130 cm from the roots if none of the stems are ≥1 cm diameter 130 from the roots.
(J) If a liana branches within 40 cm of the roots, measure each stem (≥1 cm) 130 cm from the rooting point. Note that they are branches of a single individual and tag them as multiple stems (see below).
(Q) If the stem is anomalous and not uniform below 130 cm from the roots, measure stem 20 cm above the point where it becomes uniform. If there is no uniform area within reach, measure the stem 130 cm from the roots.
(R) If the stem is flat and wide, include the liana if the mean of its wide and narrow axes is ≥1 cm.

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