SHORT COMMUNICATIONS

A Standard Protocol for Liana Censuses[1]

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ABSTRACT

A recent increase in published studies of lianas has been paralleled by a proliferation of protocols for censusing lianas. This article seeks to increase uniformity in liana inventories by providing specific recommendations for the determination of which taxa to include, the location of diameter measurement points on individual stems, the setting of minimum stem diameter cutoffs, the treatment of multiple-stemmed and rooted clonal groups, and the measurement of noncylindrical stems. Use of more uniform liana censusing protocols may facilitate comparison of independently collected data sets and further our understanding of global patterns in liana abundance, diversity, biomass, and dynamics.

RESUMEN

El reciente incremento de publicaciones sobre bejucos ha estado acompañado por una proliferación de protocolos para censarlos. Este artículo busca incrementar la uniformidad de los inventarios de lianas dando recomendaciones específicas sobre los taxa que deben incluirse, la ubicación de los puntos de medición del diámetro en tallos individuales, el establecimiento de diámetros mínimos de medición, la forma de tratar a grupos de tallos múltiples y clones arraigados, y la medición de tallos no cilíndricos. El uso de protocolos de medición más uniformes facilitará la comparación de bases de datos colectadas de forma independiente y incrementará nuestro entendimiento de patrones globales de abundancia, diversidad, biomasa y dinámica de lianas.

Key words: biodiversity; biomass; census methods; inventory; lianas.

THE PAST TWO DECADES HAVE BROUGHT INCREASING AWARENESS OF the importance of lianas to species diversity (Gentry & Dodson 1987, Schnitzer & Carson 2001, Burnham 2002), tree growth (Clark & Clark 1990, Pérez-Salicrup & Barker 2000), succession (DeWalt *et al.* 2000, Schnitzer *et al.* 2000), ecosystem functioning (Gentry 1983, Hegarty 1990, Schnitzer & Bongers 2002), biomass (Putz 1983, Gerwing & Farias 2000, Körner 2004), and management (Appanah & Putz 1984, Putz 1991, Vidal *et al.* 1997, Parren & Bongers 2001) of tropical forests. This increased interest in lianas has also resulted in a proliferation of different methods used to census lianas, as each researcher has resolved independently the challenges of sampling plants that frequently form clonal groups, loop through the canopy ascending and descending, and display a variety of stem

shapes (*e.g.*, Parren *et al.* 2005). Some steps have been taken to develop a common liana methodology for the large forest monitoring plots in the Center for Tropical Forest Science network (Kenfack *et al.* 2005). Unfortunately, differences in censusing methods result in substantially different results and confound comparisons among studies (Pérez-Salicrup & de Meijere 2004). For example, estimates of liana abundance, basal area, and biomass all vary with the position on stems where diameters are measured and whether ramets (*i.e.*, clonally-derived stems) or genets (*i.e.*, genetically distinct individuals) are counted (Schnitzer *et al.* 2006).

The goal of this paper is to provide specific recommendations for liana censusing with the hope that their implementation leads to increased comparability across studies. We present our recommendations as the answers to a series of questions that one typically responds to in developing a liana census.

WHICH TAXA AND LIFE-FORMS SHOULD BE INCLUDED IN LIANA INVENTORIES?

Lianas, as strictly defined, are climbing plants that produce true wood (*i.e.*, xylem tissues derived from a vascular cambium) and that germinate on the ground but lose their ability to support themselves as they grow, so they have to rely on external physical support to ascend to the canopy. There are, however, several reasons to elaborate upon this strict definition when deciding on which taxa to include and exclude in liana inventories. First, excluding climbers that lack true wood results in the somewhat arbitrary omission of climbing monocots (*e.g.*, rattans and other climbing palms) that produce woody tissue by apical meristems and that grow and function like lianas with true wood. The woodiness criterion would also exclude climbing genera of "subwoody" dicotyledons that do not have true wood but do have perennial, fibrous stems and reach the canopy (*e.g., Passiflora, Ipomoea, Drymonia, Begonia*, and many Cucurbitaceae). Finally, some liana inventories have included primary hemiepiphytes which begin life as seedlings in tree crowns (*e.g., Ficus* spp., *Clusia* spp., *Blakea* spp.), measuring the diameters of their descending roots, and secondary hemiepiphytes (*e.g.*, some Araceae, and Marcgraviaceae), which begin life as a climbers, become epiphytes when their roots and climbing stems degenerate, and, in some cases, reestablish contact with the ground as new aerial roots are formed (Putz & Holbrook 1985). Inclusion of these latter two groups can greatly inflate the abundance and diversity of lianas recorded at a site (Gentry 1991). In summary, our recommendations for which taxa and life-forms to include in liana inventories are as follows:

(1) Include all climbers that germinate on the forest floor and have true secondary growth (wood) or persistent, fibrous (*i.e.*, "subwoody") stems. If herbaceous climbers (*i.e.*, those lacking true wood or persistent, fibrous stems) are included, they should be identified as nonwoody in the data set and, to facilitate cross-study comparisons, the data should be presented and analyzed both with and without the herbaceous climbers.

(2) Rattans (and other climbing palms) should be included in liana inventories, although they should be distinguished from nonpalm lianas so that comparisons can be made with data sets lacking palms.

(3) When climbing Poaceae (*e.g.*, bamboos) are included, they should be presented and analyzed separately from lianas.

(4) When hemiepiphytes are included, they should be presented and analyzed separately from lianas. The recommendations for measuring liana diameter (below) do not apply to measuring hemiepiphytes.

WHERE ON THE STEM SHOULD LIANA DIAMETERS BE MEASURED?

Our recommendations for locating the point of measurement (POM) on liana stems seek to provide consistency (*i.e.*, any two data collectors would measure the same location on the stem), ecological relevance, accuracy in repeated measurements of stems, and ease of implementation in the field. The measurement points for commonly encountered liana growth forms are illustrated in Figure 1. One commonly used protocol for liana measurement calls for measuring the stems at 130 cm above ground level (*i.e.*, where the stem crosses a horizontal plane 130 cm high). However, because liana stems frequently grow horizontally, the point where a given stem crosses this plane might be many meters from its principal rooting point and can change over time as the liana stem slips downward. On the other hand, measuring liana diameters at a fixed distance along the stem from the rooting point provides a more consistent location that is independent of an individual stem's inclination (ranging from horizontal to vertical). Based on this reasoning, some researchers (*e.g.*, Burnham 2002) have chosen a POM of 20 cm from the rooting point. While setting the POM lower on the stem is likely to increase estimates of liana biomass and stem density, our consensus was that a distance of 130 cm from the rooting point provides a good compromise among ecological relevance, ease of measurement, accessibility in flooded forests, and continuity with past inventories. When lianas slip to the ground or otherwise produce new adventitious roots above the designated POM, a new POM should be marked 130 cm above the highest root. In summary, our recommendations for locating POM on liana stems are as follows:

(1) POM should be 130 cm from the main rooting position (*i.e.*, the point where the stem goes into the soil) with the following exceptions (Fig. 1):

a. Stems with adventitious roots emerging >130 cm from the main rooting should be measured 50 cm above highest adventitious root that is rooted in the soil. As liana stems develop adventitious roots, diameter growth often ceases in portions of the stem between the original rooting point and the adventitious roots but continues above the adventitious roots (J. Gerwing, pers. obs.). A POM above any adventitious roots is likely to measure a section of the stem that is actively growing in diameter;
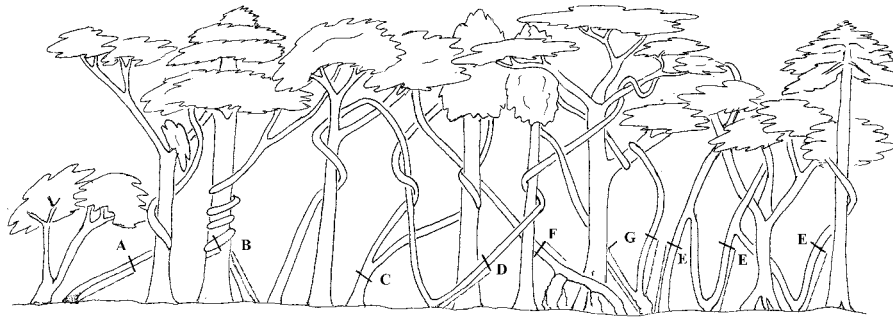
FIGURE 1.   Liana diameter measurement points: (A) lianas that simply ascend into the canopy are measured 130 cm along the stem from the main rooting point; (B) twining lianas are measured 130 cm from the rooting point measured along the stem of the liana; (C) lianas that branch below 130 cm from the rooting point are measured 20 cm below the branching point; (D) lianas that loop to the ground and root before ascending into the canopy are measured by ignoring the loop and measuring 130 cm from the last roots (lianas that loop back to the ground without rooting before ascending and to the canopy are measured like (A), 130 cm from the main rooting point); (E) lianas that, like (D), loop to the ground and root but the loops have branches ascending to the canopy, then each rooted ascending stem with a leafy canopy branch is recorded separately as a clonal stem of the same individual; (F) lianas with rooted adventitious roots further than 80 cm from the rooting point are measured 50 cm past the last root; (G) lianas that branch below 130 cm but with a very irregular main stem or branching close to the ground, measure the branches separately at 130 cm and note that they are multiple stems of the same individual.

  b.   Stems that branch below 130 cm should be measured 20 cm below the branching point. Where the stem is regular but the distance between the branching point and the roots is less than 40 cm, measure half way between the branch and the roots; otherwise, where the stem is deformed and it is not possible to take a single measurement, measure each of the branches at 130 cm above the main rooting point and indicate that they are the branches of a single stem in the data set; and

  c.   Stems with anomalies (*e.g.*, big bulges, nodes, damage, or stem splitting) at 130 cm should be measured 5 cm below the anomaly.

(2)   For studies in which stems will be periodically remeasured, all POMs should be clearly marked with nontoxic paint and stems numbered with aluminum tags affixed with wire or green grafting tape attached loosely to the stem.

(3)   When measuring on a slope or uneven terrain, measure from the uphill side of the stem.

WHAT IS THE MINIMUM STEM DIAMETER THAT SHOULD BE INCLUDED IN LIANA INVENTORIES?

The most appropriate minimum diameter threshold for inclusion of lianas in an inventory will depend upon the study objectives, forest type, and available resources. For example, the few tree-centered inventories that have included lianas have mostly used the same 10-cm diameter threshold for both lianas and trees (*e.g.*, many of the inventories cited in Phillips *et al.* 2002); whereas thresholds of 0.1–2.54 cm have been used in studies of liana diversity, species composition, and abundance (*e.g.*, Gentry 1991, Burnham 2004, Mascaro *et al.* 2004). Among forest types, some studies conducted in seasonally dry and successional forests have opted for relatively small diameter thresholds (*e.g.*, 0.1 cm, Bullock 1990; 0.5 cm, DeWalt *et al.* 2000) because small diameter lianas reach the relatively low canopies of these forests and because these forest types have few large lianas.

In spite of the importance of study objectives and forest type in determining an appropriate minimum diameter for a liana inventory, several lines of evidence suggest that, for inventories that include both trees and lianas, the minimum diameter for lianas should be smaller than that for trees. First, annual liana diameter growth increments tend to be substantially smaller than those of co-occurring trees (Putz 1990, Gerwing 2004). Thus, a given diameter threshold is likely to include only liana stems that are substantially older than trees of the same diameter. Second, because lianas rely on external physical support, they allocate less biomass to stems and more to leaves than trees do (Putz 1983, Gerwing & Farias 2000). On average, a 2-cm-diameter liana has approximately as much leaf mass as a 10-cm-diameter tree and a 10-cm-diameter liana approximates the leaf mass of a 40-cm-dbh tree (Gerwing & Farias 2000). An additional consequence of lianas' reduced allocation to stem support compared to trees is that lianas reach the canopy at relatively small diameters. For example, a study of three forests in Panama along a continuum of wet aseasonal to seasonally dry forest found that the probability that lianas ≥2 cm diameter were in the canopy was greater than 50% in all three forests (Kurzel *et al.* 2006).

Decreasing the minimum diameter cutoff from 2 cm down to 1 cm may result in large increases in both liana abundance and diversity. For example, in wet and dry evergreen forests in India, measured species richness increased by 12 to 29 percent and stem density increased by 22 to 71 percent (Parthasarathy *et al.* 2004), when the cutoff was 1 cm instead of 2 cm. Similarly, in a forest in Ecuador, measured species richness increased by 22 percent and stem density increased by 31 percent (65–150 stems/ha), when 1–2 cm stems were included (Burnham 2004). Based on liana diameter growth rates, biomass allocation, canopy occupancy, and the

accurate representation of the liana community in terms of density and species richness, we make the following general recommendations regarding minimum diameter limits for stem inclusion in liana censuses. We recognize, however, that the minimum diameter limit for any given study may be determined by the central question of that study and recommend the following:

(1) The 10-cm minimum diameter cutoff limit used for trees is not useful for lianas and few liana species reach this size.

(2) The minimum diameter cutoff for lianas should be at least 2.0 cm to include canopy lianas; however, we recommend 1.0 cm as the minimum diameter cutoff for liana inventories to more accurately represent liana species diversity and abundance.

(3) We recommend 0.5 cm as a minimum diameter for studies of liana community dynamics, regeneration, and succession. A 0.5 cm diameter size limit would approximate a tree cutoff of 1 cm in terms of per stem biomass (DeWalt & Chave 2004) and would better capture the dynamics of the liana community (*i.e.*, growth, mortality, recruitment) than the larger size-classes. When lianas <1.0 cm diameter are included in a census, data should be analyzed and reported both with and without the <1.0 cm diameter stems to facilitate cross-study comparisons. Reporting liana data in terms of stems 1–2 cm and >2 cm diameter will facilitate comparison with existing data.

(4) Some species of lianas can grow to 2–4 m tall as freestanding saplings before they begin to climb (Gerwing 2004; D. Thomas, pers. obs.). If freestanding stems, which meet a census' minimum diameter limit, are included, they should be presented and analyzed separately from climbing stems.

HOW SHOULD MULTIPLE-STEMMED AND ROOTED CLONES BE CENSUSED?

Liana clones form in a variety of ways, including by rhizomatous and stoloniferous expansion, layering and sprouting of fallen stems, splitting of climbing stems, and sprouting from roots (Beekman 1981, Peñalosa 1984, Caballé 1994). Without genetic analysis, it is often difficult to determine whether independently rooted stems are independent genetic individuals or parts of a clone in which ramets have lost their connections. Because independently rooted stems that have no apparent connection to other rooted stems, regardless of their origin, appear to be functionally equivalent in their dynamics and effects on trees, they have been treated as separate individuals (*e.g.*, Putz 1984, Schnitzer & Carson 2001) and classified as "apparent" genets (*sensu* Mascaro *et al.* 2004). For dealing with the clonal expansion challenge, we recommend the following:

(1) Each stem that is independently rooted and not obviously connected to another climbing stem included in the census should be treated as a separate individual. Excavation should be avoided because it can affect other studies and will not reliably reveal lost connections between ramets.

(2) Individually rooted, ascending stems within interconnected clonal groups can be identified and tagged using a subseries (such as "1A," "1B". . .), a protocol that is currently employed at the 40-ha plot at Ituri in the D.R. Congo (C. Ewango, pers. obs.).

(3) Where clumping rattans are present, researchers might want to record physical dimensions of clumps, instead of counting and measuring individual stems, to save time in studies conducted over large areas. Further suggestions for censusing rattans can be found in Stockdale and Wright (1996), Troy *et al.* (1997), and Kenfack *et al.* (2005).

HOW SHOULD LIANA DIAMETERS BE MEASURED?

Reporting stem sizes in terms of their diameters gives the impression that the measured stems were cylindrical or nearly so. The reality is, however, that liana stems vary from cylindrical to ribbonlike with many variations of lobes, strands, and other "irregular" shapes in between (Carlquist 1991, Caballé 1993). While some studies have developed species-specific equations to estimate stem cross-sectional area from measurement of maximum and minimum diameters (*e.g.*, Gerwing 2004), this approach is cumbersome for community-level studies. To simplify diameter measurements, while providing reasonably accurate estimates of stem size, we recommend categorizing each stem as either cylindrical or markedly noncylindrical (including stems that are flattened, elliptical, triangular, or otherwise irregular) and applying the following measurement protocol. For measuring liana stem diameters, we recommend the following:

(1) Cylindrical (or nearly cylindrical) stems:
   a. measure stems <5 cm in diameter using calipers along their widest axis at the appropriate POM;
   b. measure stems ≥5 cm using a diameter (or circumference) tape.

(2) Noncylindrical, flattened stems:
   a. measure diameters of all stems along their widest (d_1) and narrowest ($d_{(2)}$) axes at the appropriate POM;
   b. estimate stem diameter as the geometric mean of these two measurements (*i.e.*, $diameter = \sqrt{d_1 \times d_2}$);
   c. include all stems whose mean diameter exceeds the minimum diameter threshold set for the inventory.

(3) If, to simplify the measurement protocol, all stems are measured as if they are cylindrical, this should be indicated in the data collection protocol.

OTHER CONSIDERATIONS FOR CENSUSING LIANAS

In addition to the aforementioned recommendations, there are several other aspects of liana censusing that merit mention. Lianas, in contrast to most trees, can root within the plot boundaries of a given plot but reach the canopy outside the plot or, conversely, root outside the plot and grow into the canopy or subcanopy of

the plot. Furthermore, the stems of many lianas slip or fall from the canopy and then produce adventitious roots from the prostrate stem (Alvira *et al.* 2004). Thus, a simple criterion such as "rooted in the plot," which may be sufficient for tree censuses, is too vague for lianas since the same individual can be rooted in several plots. Our recommendation for determining the inclusion or exclusion of a stem in a plot is to include all stems whose last rooting point before ascending into the canopy fall within the plot.

Lianas are often more challenging to identify than freestanding plants due to difficulties in locating and collecting leaves, let alone reproductive structures, which are typically positioned in the canopy. In general, lianas are identified in the field via a combination of characteristics from the leaf, bark, stem shape and exudate (*e.g.*, sap or resin), smell, and climbing mechanism (Gentry 1993, Hawthorne & Jongkind in press). Given the possibility of uncertainties surrounding species identifications, we recommend replicate vouchering of species with subsequent verification until the species in question can be accurately and consistently identified. At least one voucher per species should include both sun and shade leaves, and, whenever possible, structures that indicate the climbing mechanism. To facilitate collection, a liana census team should ideally include a tree-climber and the capacity to prepare numerous dried voucher specimens. Many errors of identification are likely to occur at the beginning of a survey in a new area. Training sessions for field crews can reduce errors, as can creating photo-identification guides to the common species in advance of the main survey (*e.g.*, The Field Museum 2005).

We hope that our recommendations promote use of more uniform liana censusing protocols that will facilitate comparisons across study sites. Although some research questions may require different methods than those we suggest, we hope that for most studies the protocols that we recommend will simplify and standardize liana censuses worldwide. Reports of increasing liana abundance in old-growth tropical forests (Phillips *et al.* 2002, Wright *et al.* 2004), which may be linked to global climate change (Körner 2004), emphasize the importance of uniformity in liana sampling protocols that will facilitate comparison of independently collected data sets and large-scale meta-analyses, as well as further our understanding of global patterns in liana abundance, diversity, biomass, and dynamics.

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