

ForestGEO Dead Wood Census Protocol

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1. INTRODUCTION

After stems die, the wood persists in the ecosystem, either as standing deadwood or woody debris on the ground. Deadwood plays an important role in forest ecosystems, providing significantly different substrate, nutrient source, and microclimate to seedlings as well as habitat to vertebrates and invertebrates. Measurements of dead material on the forest floor can be used to more completely estimate biomass, carbon pools, and carbon fluxes. These methods continue the philosophy of the ForestGEO demography data by tracking the status of individual woody stems after mortality and thereby extending observations to the entire period each woody stem exists in the forest.

Specific deadwood dynamics (i.e., those tied to the original stem tag) are tracked only for the stem not branches. Calculations of dead wood volume, biomass, and carbon are made using allometric equations based on the diameter at breast height (DBH) of the main stem (similarly as for living trees, where the branches also remain unmeasured), and also the decay class of the wood. This approach allows comparability of values derived for living and dead trees. For trees with DBH ≥ 10 cm (the census diameter limit) that die after plot establishment, pieces are tracked by linking them with the original tree and stem identification. For snags or logs ≥ 10 cm DBH that were present at plot inception, those pieces of wood that are not clearly associated with tagged stems are themselves measured, mapped and tagged.

BOX 1: Other dead tree parts (large branches, small branches, leaf litter and duff) are not considered individually, but can be sampled through representative transects. Transect sampling for surface carbon pools is not included in this protocol document. One commonly used protocol is the US National Park Service protocol FMH-19.

Logs from trees ≥ 10 cm DBH should be entered into the database with additional tabular data taken that allows the woody debris to be mapped and its volume calculated. Location data can either be entered directly through the use of a Geographic Information System and automated measurement equipment (a total station or equivalent) or manually by referencing existing field data. The ground position of logs with DBH < 10 cm is not recorded, but the date that they were recorded as fallen (the census date) is recorded.

The ForestGEO deadwood protocol is an extension of the ForestGEO stem census protocol and follows the same philosophy. Dead wood censuses record ‘snags’ (standing dead woody structures) and ‘logs’ (down woody structures). The fundamental characteristics of the originating dead tree (position, species, last living DBH) are maintained in the existing ForestGEO TREE table. Deadwood-specific characteristics are maintained in the SNAG table (Table 1), the LOG table (Table 3), the STATUS table (Table 5) and related definition tables – the SDC table (Table 2) and the LDC

table (Table 4). Records in the TREE table are linked with records of secondary tables via the unique Tree tag and Stem tag keys.

The STATUS table introduces an additional attribute field ‘Advanced Status’ to permit the data from the TREE table to be joined to the dead wood tables.

Each subchapter of object description has the same structure: (i) Definition, (ii) Recorded attributes and (iii) Table of attributes. The data attributes assume that researchers are using the ForestGEO database, or an operational database that preserves most of the integrity checks of the ForestGEO database. The fields of attribute tables need to be populated for cross-site comparisons, therefore the actual field names from this document should be used. It is anticipated that the deadwood data most likely to be shared between collaborators is species, diameter, decay class, and volume of each piece, along with the quadrat(s) in which the piece is found. These data can either be used for forest dynamics studies, or used in calculations of biomass and carbon. Spatial analyses of the effect of dead wood on recruitment and mortality will require sharing of the full spatial data.

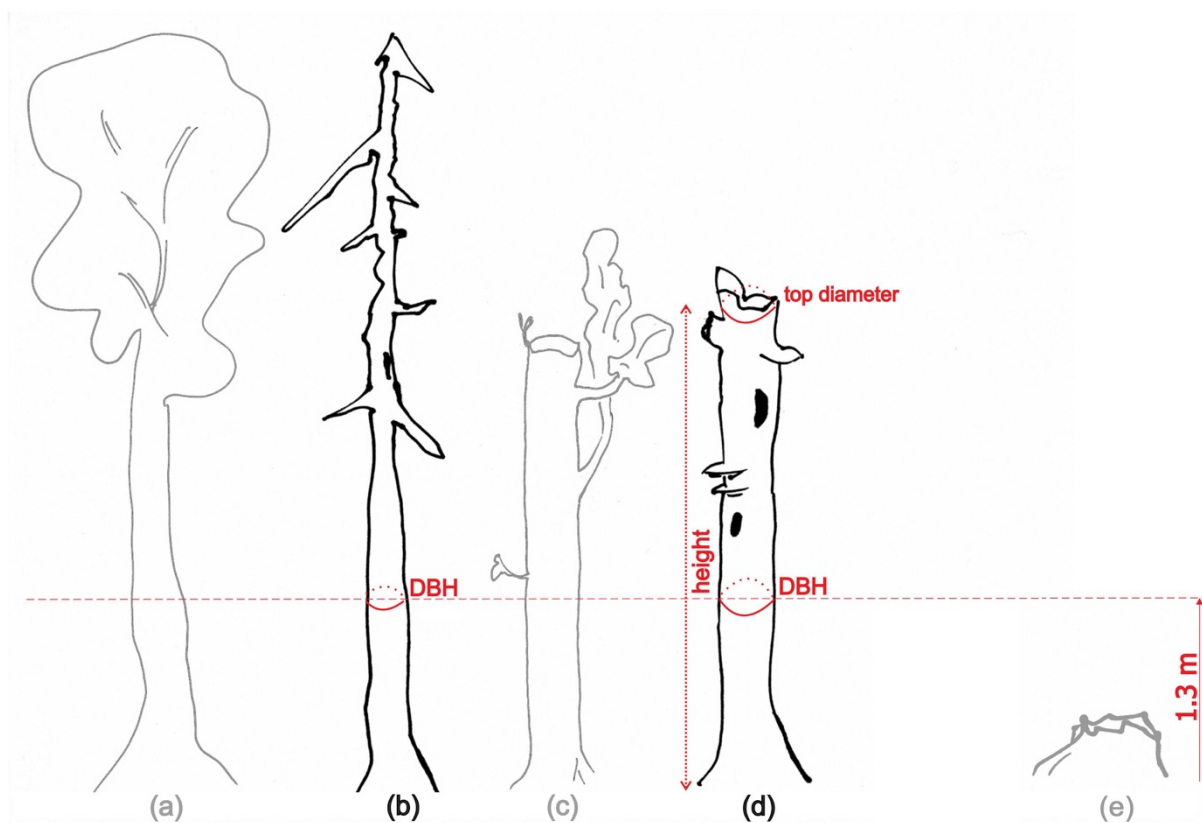


Fig. 1. Types of standing woody structures. Living trees (a) are covered in the ForestGEO protocol. Snags (b,d) are censused for snag-specific information. One type of snag is complete, having died standing (b). Living trees can also experience stem snap (c); stem snap is helpful to note during censuses, but if the tree has green foliage above the standard height of measurement, they are classed as living trees. Snags that have lost their top (d) need an explicit calculation of bole volume. Stumps (e) are dead remains of trees less than the standard measurement height; they carry information about original position of a tree only.

2. OBJECTS

2.1. Snags

Definition

A snag is a standing dead woody stem that has DBH ≥ 10 cm and height taller than the standard height of DBH measurements (Fig. 1b,d). If the snag represents a tree that was alive at plot inception and has since died, the tag is maintained. In this case DBH may be < 10 cm if a small tagged stem shrinks after death. If the tree with DBH ≥ 10 cm is dead at plot inception the tag is pinned on the snag. Snag data is maintained in the TREE table and SNAG table. The TREE table contains the spatial information about the tree, species and DBH. In addition to the existing tree data in standard ForestGEO census presented in TREE table, the snag-specific fields are added to SNAG table.

BOX 2: If the top of the recorded snag has broken off, the down piece is entered and described in the Log table (section 2.2).

Recorded attributes

1) Advanced Status – For standing woody structures following status codes are maintained in the STATUS table:

1. Intact – complete living stem, no traceable deadwood is linked to it;
2. Stem snap (also referred to as ‘broken top’) – a living stem where the top portion has broken off the main stem (possible origin of censused deadwood);
3. Not tracked – Snag of DBH < 10 cm at a time of mortality event;
4. Snag – Snag with DBH ≥ 10 cm;
4. Consumed – this status is assigned to the stems of DHB ≥ 10 cm that were recorded and described in the previous census and completely decomposed (or burned) at the recent census.

Only if the Advanced Status is ‘Snag’, you proceed to other measurements.

2) Position – if the position is not known from the previous census the coordinates of the snag are measured and included into TREE table.

3) Species – information about species is maintained in the TREE table.

4) DBH (resolution = 0.1 cm or 1 mm). Diameter should be measured using the same measurement methods as used for live trees and stored in the TREE table.

5) Integrity (INTEG) – an enumerated list with values for complete (C) or fragmented (F) to indicate whether the snag represents a whole tree (Integrity = C, Fig. 1b) or a fragment (Integrity = F, Fig. 1d). Maintained in the SNAG table.

BOX 3: To maximize the chances of identifying snags with DBH ≥ 10 cm during subsequent censuses, the tag should be hammered all the way to the bark/wood. During every five-year re-census of the plot, the same data (DBH, height, top diameter, and decay class) should be recorded. Diameters of snags can be subject to considerable variability between censuses due to bark separation from wood, swelling due to rain and changes in atmospheric humidity, and gradual loss of portions of the bark (sluffing).

6) Snag height (SH, resolution = 0.1 m). Height of the breakage (Integrity = F) of the main stem should be measured using the same measurement methods as used for live trees. This field is a numeric value with units of meters and resolution of 0.1 m (accuracy will be variable, but likely worse than 0.1 m). Maintained in the SNAG table.

7) Top diameter (TD, resolution = 0.1 cm or 1 mm) If the leader is present (Integrity = C), top diameter is recorded as '0.0' (units of cm) or '0' (units of mm). Any other diameter indicates some breakage of the main stem or leader (Integrity = F). The snag top diameter is ideally measured by using the large end diameter of the fallen top piece. If the top piece cannot be located, the top diameter is approximated, or measured with a laser. Maintained in the SNAG table.

Box 4: The units and resolution of snag top diameter are the same as those for DBH for data consistency, not because they can be measured to this accuracy. For snags where the broken top can be located on the ground, it can be measured precisely.

8) Snag Decay class (SDC, Fig. 2) – this field is a numeric integer value with a foreign key referencing the snag decay class table (containing the definitions). Maintained in the SNAG table.

- 1- Freshly dead (0-5 years for many species); branches of 3rd order are present; the full height of stem is present unless there was damage prior to the mortality event or caused during the mortality event; fully barked (usually ≥ 80 % of stem surface); usually trees that died from suppression, bark beetle outbreak (coniferous), fungal infection (broadleaved), or those killed but not burned by fire. The species is still recognizable;
- 2- Branches of the first order are present; full tree height unless there was damage prior to or during the mortality event; partly barked (usually < 80 % of stem surface; broadleaved trees should be still fully barked); the species can usually still be identified;
- 3- Only short basal rests of main branches; full height unless there was damage prior to the mortality event; bark missing or absent (usually ≤ 20 % of stem surface) in the case of coniferous species;
- 4- No branches or small basal rests; height ≤ 80 % of even height curve (according to DBH); bark missing or absent (usually ≤ 20 % of stem surface) in the case of coniferous species;
- 5- Stumps or short snags; the wood is at a stage of advanced rot.

9) Snag Volume (SVOL) – this field is a numeric value calculated from DBH, SH, and TD. Site-specific, species-specific allometric equations should be used if available. Otherwise, volume should be calculated by modeling the stem as a frustum of a cone in units of m^3 . Maintained in the SNAG table.

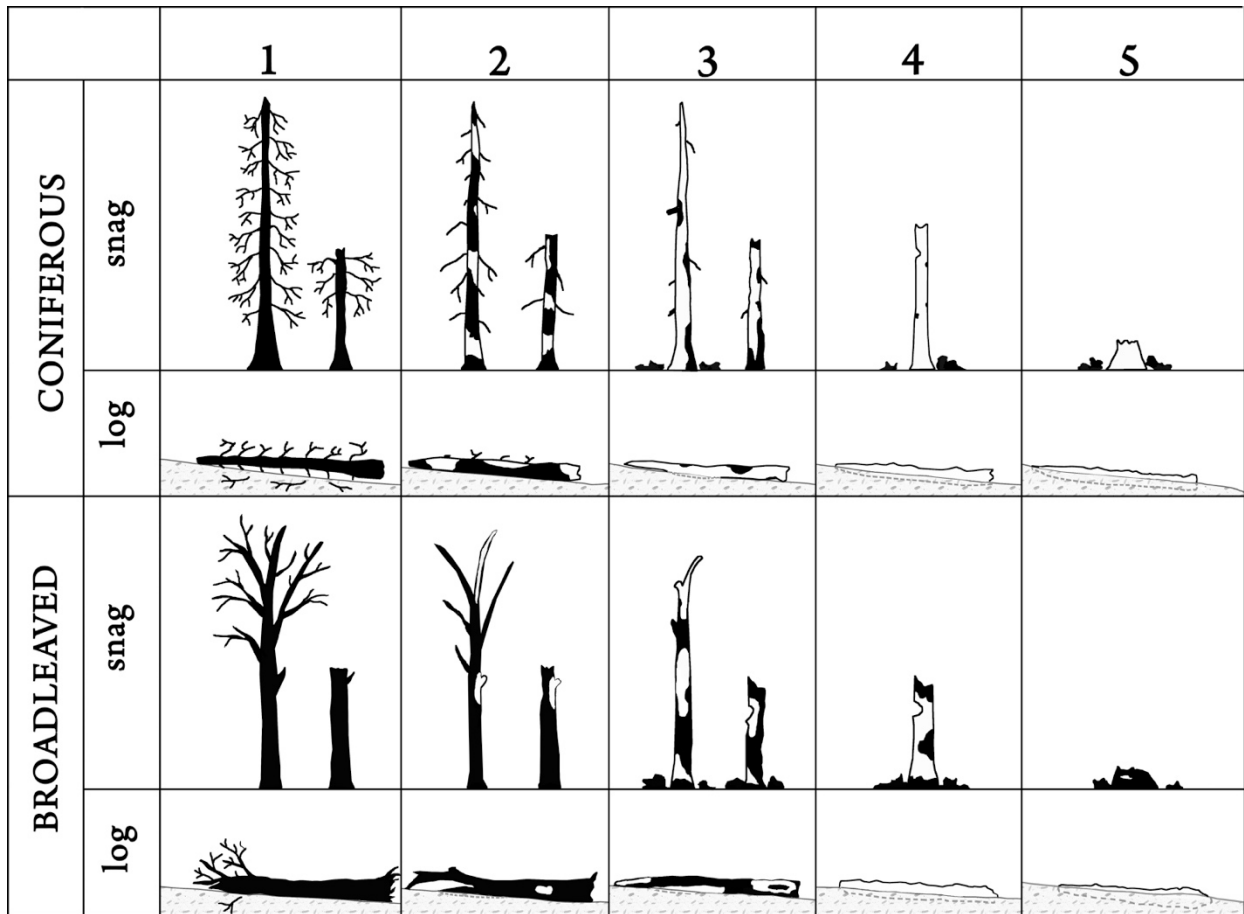


Fig. 2. Decay classes for standing and fallen coniferous and broadleaved trees. For decay classes 1, 2 and 3, the left snag is ‘Complete’ and the right snag is ‘Fragmented’. The fragmented stem would be joined by a piece of log on the ground. When individual pieces of deadwood appear to have characteristics of two decay classes, the class should be determined based on the closest fit to the descriptions.

Table 1. Attributes of the SNAG table. FK = SQL foreign key linked to the appropriate table.

Field Name	Attribute	Type, Code, Dimension	Note
TREE_TAG	Tree Tag No.	VARCHAR	FK Tree table
STEM_TAG	Stem Tag No.	VARCHAR	FK Tree table
INTEG	Integrity	ENUM(‘C’, ‘F’)	
SH	Snag height	DECIMAL(3,1)	
TD	Top diameter	DECIMAL(5,2)	
SDC	Snag decay class	INTEGER	FK SDC table
SVOL	Snag volume	DOUBLE	Null
COMMENT	Field comments	VARCHAR	

Table 2. Attributes of the SDC table. Optional field may include translations of DEFINITION into local languages (DEFINITION2, DEFINITION3, etc.).

Field Name	Attribute	Type, Code, Dimension	Note
CODE	Snag decay class code (1, 2, 3, 4, 5)	INTEGER	
DEFINITION	Text of definitions	VARCHAR(400)	From section 8.

2.2. Logs

Definition

Logs can either be fallen trees that had $DBH \geq 10$ cm at the previous census or current census, or as fragments. In the case of fragments, the mapping limit is related to snag, or base part of the fallen tree. Only small number of down trees fall in a single piece. Usually they are broken into several fragments, especially as decomposition proceeds over time. For that reason, the protocol employs a ‘piece approach’, where each piece of wood has the piece identifier that is entered and described separately. All pieces of a down stems can be virtually merged together using the tree tag and stem tag numbers. The piece of logs associated with the tree base is always a piece A, and subsequent pieces have increasing alphabetic character (B, C, D...) as they are further from the base of the tree. When a tree has multiple leaders that fall to produce logs, the alphabetic characters are assigned arbitrarily with details noted in the comment field. In the course of time the number of pieces of one stem may increase (fragmentation) or decrease (decomposition). The alphabetic identifier of the same piece (or its parts) thus may vary in subsequent censuses. However, increases or decreases in the number of segments are not too common, and in that case, the database should be modified manually so that snag and log pieces continue to be labelled in order (A, B, C, etc.).

Box 5: ‘Piece’ is a part of the main stem of a tree with $DBH \geq 10$ cm. The recorded piece is of a conic section (truncated cone) where the starting and final diameters should be measured. The chips, splinters or flakes from the stem are not recorded. The minimal length of a piece is 1 m. When it is reasonable to specify parts with different Ground contact it is possible to divide one piece into two pieces although they are not spatially interrupted. Then they are treated as two independent pieces and described separately in all attributes. Conversely, cracked pieces may be treated as one piece, if the ground contact is the same and there is no substantial displacement of its different parts.

Species and stem tag are inferred from the originating tree, or, for wood on the ground at the plot inception, from additional field observations. In this case the species may stay unknown (indiscernible), but the stem tag should always be attached to piece A (or in cases where piece A does not reach to the height of measurement, to the piece including the height of measurement) to allow future individual-based re-census. When the pieces of a log have originated from a broken part of snag, the first piece of the log is labeled as piece B and tag remains on the standing snag part. Primary information about the ‘parental’ tree of the log is maintained in the TREE table (position, species, DBH), other log-specific characteristics in LOG table.

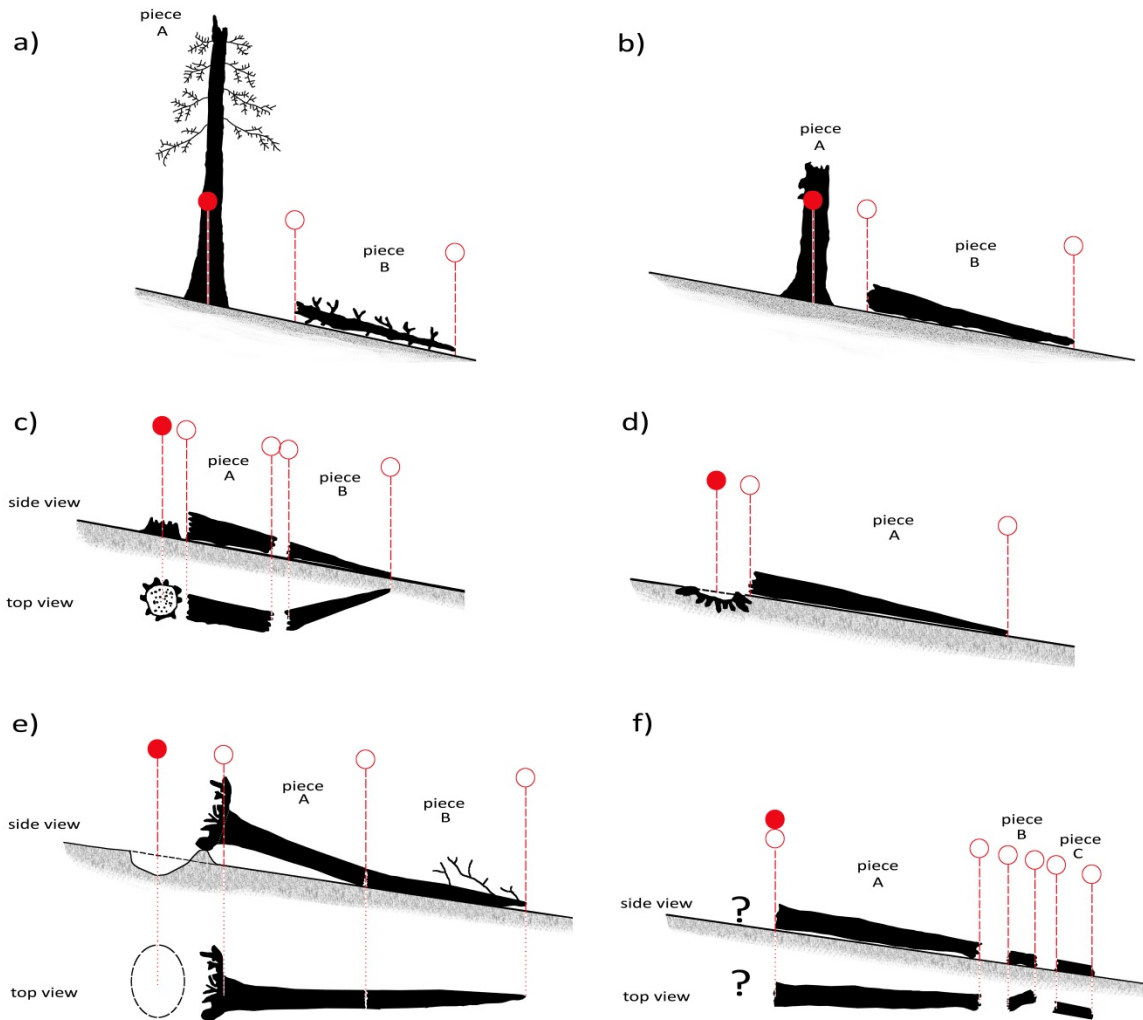


Fig. 3. Geospatial data requirements for logs. Original position of the former live tree (marked by solid circle) and actual position of each piece of the main stem (empty circle) should be recorded: a) piece originating from a live tree (stem snap); b) piece originating from a snag; c) log fragmented in two pieces, originating from stump; d) log and the original position of the stem represented by hole (remaining after decayed stump); e) windthrown stem and its original position represented by windthrow-pit; because of different ground contact of the stem parts they were recorded as two separate pieces; and f) old lying log fragmented in 3 pieces, original position of the stem is unknown – the position of the large end is then used as a proxy of the original stem position.

Recorded attributes

1) Position – coordinates of the original (growth) position of the former live stem (or coordinates of the stem snap associated with deadwood on the ground). For trees that were alive in a former census this position is known, otherwise should be measured. In the field this position may be recognized as stem snap, snag, stump, hole (after decayed stump) or windthrow pit (Fig. 3). For logs on the ground at the plot inception the original position may be unknown, then the position of large end (starting point) of piece A is used as a proxy of the original stem position. This attribute is maintained in the TREE table.

2) Advanced Status – for lying woody structures the Advanced Status mostly informs about the feature that represents its original (growth) position described above. This attribute is maintained in the STATUS TABLE.

1. Not tracked – Log of DBH <10 cm at a time of mortality event;
2. Stem snap – the log (or piece) is associated with the living stem of DBH \geq 10 cm with broken main stem (Fig. 3a);
3. Snag – the log is associated with the snag of DBH \geq 10 cm (Fig. 3b);
4. Stump – the log is associated with the dead woody stem that is shorter than the standard height of DBH measurement. Stumps without connection to Logs are not recorded (Fig. 3c);
5. Hole - if a stem has suffered extensive rot, the stump can break off below the ground surface, leaving a hole (Fig. 3d);
6. Windthrow pit ('WTPit') – a micro-topographical form caused by a single uprooted tree (Fig. 3e);
7. Base of lying stem ('BLS') - for logs on the ground at the plot inception the original position may be unknown, then the position of large end (starting point) of piece A is used as a proxy of the original stem position (Fig. 3f);
8. Consumed – status is assigned to the stems of DHB \geq 10cm that were recorded and described in the previous census and completely decomposed till the recent census.

3) Species – maintained in the TREE table. For highly decayed logs of unknown origin the species may not be identifiable (unknown) or identifiable to genus only.

4) DBH –The preferred method for measuring the diameter of wood pieces on the ground is a diameter tape. However, sometimes a diameter tape cannot be used because the piece is partially buried or covered with other debris. In that case diameter should be measured with calipers, along both the major axis of the wood ellipse and the minor axis of the wood ellipse. Where the wood is cylindrical, or where field crew can average the two diameters, only one measurement is sufficient, and in many cases only one measurement can be made. Maintained in the TREE table.

5) Integrity – this value is an enumerated list, either 'Complete' or 'Fragmented' ('C' or 'F'). Maintained in the LOG table.

6) Piece identifier – this is an identifier allowing multiple pieces of logs to be associated with one originating stem. The piece of log associated with the stem base is always piece A, and subsequent pieces have increasing values as they are further to the top of the tree. The lying piece broken from Snag is assigned as B. Maintained in the LOG table.

7) Piece position – the position of each piece of the log is always determined by at least two points – the start and end (Fig. 3). The start represents the large end of the log, and the end

BOX 6: The principal objective of dead wood size measurements is to compute a volume. If the tree is complete (Fig. 4a), then a DBH measurement can be used in conjunction with allometric equations to calculate volume. Allometric equations of sufficient detail can also be used if the base of the tree is intact and the top broken (Fig. 4b). When the fallen wood is fragmented into several pieces, the volume of each piece needs to be calculated (Fig. 4c). In all cases, the volume can also be determined by measuring the length and end diameters of the pieces. The volumes are computed in census data post-processing.

represents the small end of the log. The piece position can be recorded either as simple coordinates, or as shapes in a Geographic Information System (GIS). Log pieces can be located relative to existing trees, using an azimuth-distance method such as is used for new recruitment, or the standard location system used in the tree census on the plot. The location of piece endpoints can be in either plot coordinates, absolute coordinates (Universal Transverse Mercator; UTM), or both (the field data definitions in Table 3 are sized to accommodate UTM values). Maintained in the LOG table.

8) Length - The length of deadwood is imputed from the surveyed location of the endpoints (Fig. 3), or can be measured in the field. Maintained in the LOG table.

9) Large end diameter - diameter should be measured using the same measurement methods as used for DBH. Maintained in the LOG table.

10) Small end diameter - diameter should be measured using the same measurement methods as used for DBH. If the leader is present, diameter is recorded as “0.0”. Any other diameter indicates some breakage of the piece. Maintained in the LOG table.

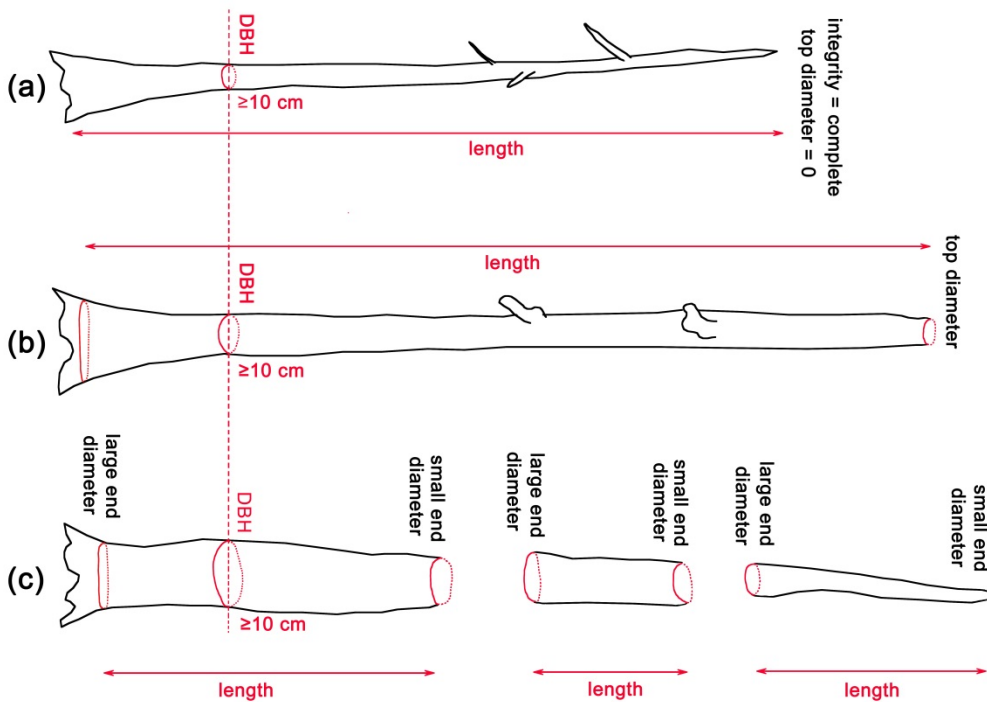


Fig. 4. Required measurements of logs for volume estimates of a complete log (a), incomplete log (b) and a log fragmented in pieces (c).

12) Log Decay Classes - There are five degrees of decomposition distinguished for standing and down deadwood, illustrated separately for coniferous and broadleaved tree species (Fig. 2). Decay class is recorded in the LOG table.

- 1- Freshly fallen tree (usually windthrow or a basal rot); texture – wood intact; branches of 2nd order are attached; fully barked (usually $\geq 80\%$ of stem surface); species is still recognizable;
- 2- Texture – wood intact to partly hard or soft; branches of first order are partly attached; partly barked; the species can usually still be identified;
- 3- Texture – wood hard but in large pieces; the wood is not compact any more along the entire stem length with the core or outer mantle subjected to rot. The genus can often be recognized, but species identification is difficult;
- 4- Texture – wood chunks small, soft, and blocky; the wood is not compact and the cross-section is either elliptical or circular;
- 5- The wood is at a stage of advanced rot; texture – wood chunks soft and powdery; deadwood no longer has a cylindrical shape; the species cannot be identified any more, a kick into a stem results in stem breakage, there are often just “little graves” with the patchy vegetation.

13) Ground contact (GC): can be an important determinant of decomposition rates. Therefore, one data parameter maintained for every piece of wood is its contact with the ground (Fig. 5), detailing whether the log is either supported (main stem supported in the air = ‘Air’) or on the ground (‘Ground’). When it is reasonable to specify parts with different Ground contact it is possible to divide one piece into two pieces although they are not spatially interrupted. However, they are treated as two independent pieces and described separately in all attributes. Maintained in the LOG table.

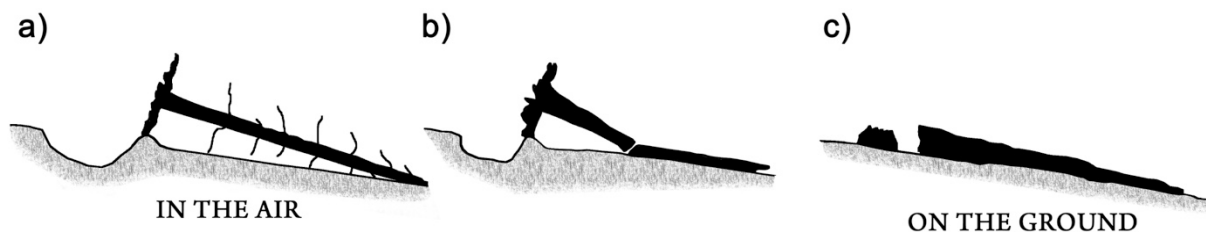


Fig. 5. Ground contact of logs. When wood is initially on the ground, it is often supported by some combination of the roots, branches, or other logs (a). When wood has been down for some time, or when a bole fragments upon falling, pieces are often completely on the ground (c). When a bole is partially on the ground and partially supported (b), it should be recorded as two individual pieces, so that each piece can have the appropriate ground contact code.

14) Piece quadrats – this field is semi-colon separated list of quadrats where the piece is found. Although the quadrats, where the piece is present, can be derived from the geospatial data (Fig. 3), for quadrat level analyses, this tabular data field is useful for searches. Maintained in the LOG table.

15) Piece volume – this is the volume of the piece (in units of m^3) calculated as a

BOX 7: The last records. There are two possible farewells for censused trees - reaching the status of ‘Dead not tracked’ or ‘Consumed’. The status ‘Dead not tracked’ is used for small dead trees with DBH <10 cm. The status ‘Consumed’ is assigned when a stem has completely decomposed (or burned) and no traceable pieces remain in the plot. The status is recorded at the stem level (in the Tree table), which signifies that the stem has unambiguously completed its lifecycle as woody entity. Various research permit conditions may require the removal of tags of the stems that have been ‘Consumed’ and from the down logs with the status ‘Dead not tracked’.

frustum of a cone or by allometric equations (see Box 6).

Table 3. Attributes of the LOG table. For sites collecting data with automated mapping equipment, this table constitutes all the required data. For sites collecting data using compass and tape with reference to existing mapped entities, the fields from Table 3a should be added. FK = SQL foreign key linked to the appropriate table.

Field Name	Attribute	Type, Code, Dimension	Note
TREE_TAG	Tree tag No.	VARCHAR	FK Tree table
STEM_TAG	Stem tag No.	VARCHAR	FK Tree table
PIECE_ID	Piece identifier	CHAR(1)	
PIECE_LE_X	Piece position	DECIMAL(8,2)	Coordinates
PIECE_LE_Y	Piece position	DECIMAL(9,2)	Coordinates
PIECE_LE_Z	Piece position	DECIMAL(6,2)	Coordinates
PIECE_SE_X	Piece position	DECIMAL(8,2)	Coordinates
PIECE_SE_Y	Piece position	DECIMAL(9,2)	Coordinates
PIECE_SE_Z	Piece position	DECIMAL(6,2)	Coordinates
PIECE_LENGTH	Length	DECIMAL(3,1)	Not null
PIECE_LE_DIAM	Large end diameter	DECIMAL(5,2)	Not null
PIECE_SE_DIAM	Small end diameter	DECIMAL(5,2)	Not null
INTEG	Integrity	ENUM('C','F')	Not null
LDC	Log decay class	DECIMAL(1)	FK LDC table
GC	Ground contact	ENUM('Ground','Air')	Not null
PIECE_QUAD	Piece quadrats	VARCHAR(25)	Not null
PIECE_VOL	Piece volume	DECIMAL(5,2)	Null
COMMENT	Field comments	VARCHAR	

Table 3a. Additional attributes of the LOG table for sites locating logs by using compass and tape to reference new logs to existing mapped entities. The reference field can either be the STEM_TAG of the original tree (the usual case), another STEM_TAG, a grid reference point, or the small end of a larger piece of wood from the same STEM_TAG.

Field Name	Attribute	Type, Code, Dimension	Note
REFERENCE	An entity with a known location	VARCHAR	
REF_TO_LE_DISTANCE	The distance from the reference point to the piece large end	DECIMAL(5,2)	
REF_TO_LE_AZIMUTH	The azimuth from the reference to the piece large end	INTEGER	0 to 359
LENGTH	The length of the log	DECIMAL(5,2)	
LOG_AZM	The azimuth of the log from LE to SE	INTEGER	0 to 359

Table 4. Attributes of the LDC (Log Decay Class) table. Optional field may include translations of DEFINITION into local languages (DEFINITION2, DEFINITION3, etc.).

Field Name	Attribute	Type, Code, Dimension	Note
CODE	Log decay class codes (1, 2, 3, 4, 5)	INTEGER	
DEFINITION	Text of definitions	VARCHAR(400)	From section 12.

Table 5. Attributes of the STATUS table. FK = SQL foreign key linked to the table references.

Field Name	Attribute	Type, Code, Dimension	Note
TREE_TAG	Tree tag No.	VARCHAR	FK Tree table
STEM_TAG	Stem tag No.	VARCHAR	FK Tree table
ADV_STATUS	Advanced Status	ENUM('Intact', 'StemSnap', 'NotTracked', 'Snag', 'Stump', 'Hole', 'WTPit', 'BLS', 'Consumed')	