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Field Manual for Mode of Death Census

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1 Introduction

We are interested in understanding how trees die for two reasons. Firstly, the mode of tree death indicates underlying casual factors that contribute to the death (Putz et al. 1983, Arriaga 2000, Cherubini et al. 2002). Secondly, the way in which trees die also affects the ensuing forest dynamics, including the mortality, regeneration and growth in the ecosystem, and potentially its floristic composition and diversity (Franklin et al. 1987, Phillips et al. 1994, Arriaga 2000). The modes of death of an individual tree can be categorised most simply as died standing, uprooted, or snapped off.

Trees which **'die standing'** generally leave small gaps, and once it is sufficiently rotten the trunk of the individual will gradually disintegrate and fall scattered around the tree (Gale and Hall 2001). Such canopy gaps may favour regeneration of shade-tolerant species or may recover by expansion of adjacent crowns (Whitmore 1978, Krasny and Whitmore 1992). An '**uprooted'** tree is subjected to lateral forces on the trunk (e.g. other tree falls or hurricane disturbance) that exceed root-soil holding strength but do not break the stem (Putz et al. 1983). This may disturb the soil layers and cause inversion of soil horizons, which in turn alters the micro-environment and tends towards selection of the pioneer seeds in the soil bank as germinants (Putz 1983). With some lateral forces on the bole of a living tree that are not strong enough to dislodge and break the bottom roots, the living tree may die '**snapped off'** due to its loose density or unbalanced structure (Putz et al. 1983, Everham III 1996). In this kind of situation, the remaining upright trunk may occasionally allow the broken tree to re-sprout; the fallen canopy of a snapped tree, compared to the whole trunk and canopy of an uprooted tree, has a smaller impact on the forest; moreover, the pioneer seedlings might less frequently regenerate in the tree crown gaps of snapped trees than those caused by uprooted trees due to the lack of soil-disturbance (Putz 1983, Putz et al. 1983, Arriaga 2000).

Some causes of tree mortality might be obvious, such as wind blow-down of a tree, or wildfire burn, many causes are ambiguous and complex (Franklin et al. 1987). Gale and Barfod (1999) suggest that different modes of death are caused by dissimilar factors: 'died standing' trees are mostly influenced by biotic agents, snapped trees are caused partly by physical and partly by biotic agents, whereas uprooted trees are mostly caused by extrinsic physical agents.

A tree can 'die standing' as a result of intrinsic senescence (Whitmore 1978), extrinsic biotic agents, such as shading by competition of overhead canopy or lianas (Putz 1984) and attack by pathogens (Arriaga 2000, Cherubini et al. 2002), or extrinsic abiotic physiological disturbance, such as lightning (Magusson et al. 1996), drought, and flooding (Swaine et al. 1987). However, the factors causing trees to uproot may be similar to those of snapped trees. These include intrinsic species specific traits (e.g., wood density (Putz et al. 1983)), root anchorage (Putz et al. 1983, Gale and Barfod 1999), tree architecture (Putz et al. 1983), extrinsic treefall events (Lieberman et al. 1985), and abiotic disturbance, such as catastrophic wind (Everham III 1996, Arriaga 2000). Overall, wood properties could be the most important intrinsic factors influencing relative probabilities of uprooting versus snapping (Putz et al. 1983). One study also proposed that the patterns of mode of tree death are related with slope position: along the topography gradient from valleys to the ridge tops, trees tend to die standing than die uprooted (Gale and Hall 2001).

The dimensions of the causes of mortality modes comprise factors intrinsic to the tree itself, extrinsic biotic factors, and extrinsic abiotic factors. Since different modes of death affect the subsequent forest dynamics, it is important to determine the dominant mode of death in an area and to identify the factors that control the mortality patterns in a forest.

2 Study objectives

The objectives of the modes of death study are to better understand the mortality pattern and the relationships between environment and mortality processes in Amazonia region. This 'RAINFOR Field Manual for Mode of Death Census', based on the study of Venezuela field-trip in 2004, is intended as the basis for a standard method for future surveys.

The questions of the mortality mode research are:

(1) What is the dominant mode of death among Amazonia region?

(2) What are the magnitude and frequency patterns of multiple treefalls?

(3) Do the proportions of each mortality mode vary with the tree size class?

(4) How is the proportion of the mode of tree death related to environmental conditions?

3 Study methods

A. Plot set up:

The modes of tree death census plots are based on the RAINFOR (Red Amazónica de Inventarios Forestales; Amazon Forest Inventory Network) census plots.

B. Environmental data:

The environmental data includes:

(1) GPS (Global Positioning System): use a 12- channel handheld receiving set (Garmin GPS12, Olanthe, KS, USA) to locate the position of study plot in the map.

(2) Slope: every 20 m measure slope angle (± 5˚) by sighting between two vertical 1.3 m tall objects with a clinometer.

(3) Slope position: valleys, mid-slopes, upper slopes, plateau, or ridges.

(4) Elevation (m): from the reading of GPS.

(5) Soil sampling

   a. Major soil class, with samples taken for laboratory analysis (*cf.* RAINFOR soil sampling protocols)

   b. Drainage category on a 1 to 10 scale

   c. Depth

(6) Disturbance history

   a. Type

   b. Frequency

   c. Magnitude

C. Tree mortality mode:

(1) **Criteria:**

a. Mortality mode: Every tree with DBH $\geq$ 10 cm which is/was rooted in the sample area.

(2) **Record** (refer to Table 1)**:**

a. Number of quadrat

b. Tag number of dead tree

c. Species: if this can be recognized

d. Diameter of the dead tree: the diameter at 1.3 m height in the previous census data.

e. Mortality mode

i. **Standing:** Trees that died standing and subsequently collapsed are recognized by their crown debris often scattered in all directions around the tree stump. The broken edges of the debris are characterised by smooth edges and lack prominent splinters. Neighbouring vegetation damage appears to be more recent than the apparent age of the bole. They also tend to have softer boles that have often fragmented into smooth-ended segments upon falling. The total height of the dead tree is also recorded. Previous field notes may indicate a tree approaching negative carbon balance (e.g., 'old', 'senescing', or 'swamped by lianas').

ii. **Snapped:** trees have their crown branches attached to the far-end of the fallen bole and with visible broken trunk. The breakage sections of their boles are characterised by splinters. Neighbouring vegetation damage appears to be simultaneous with the snapping event. Estimate the height of the stump. Be careful of trees which were broken at 0 m, which is different from an uprooted tree, and make a note of this.

iii. **Uprooted:** trees are with upturned root plates and also take some soil with the plates.

iv. **Vanished:** if there are no pieces of wood in the previous recorded location and the nearby area, the individual is treated as vanished.

v. **Question mark '?':** if the tree is too decomposed to identify the mode of death with a reasonable degree of confidence.

Note 1: If the individual is in the state of 'rotten' (i.e., 2.5 or greater on the 1 to 3 visual scale for categorising the degree of decomposition in dead wood, see note 'g' below), then any interpretation of the mode of the tree death would be unreliable without additional evidence. Therefore, individuals in the decomposition degree of 2.5 and 3 may be removed from the data set. This is often the case when the census interval is long.

Note 2: If the actual situation of the dead individual is snapped but with strong hints that the individual first died standing and then broke, we treat the mode of the dead individual as 'standing → snapped' (coded as 1-3).

Notes 3: The mode of death of recently died trees can still be uncertain, for example, trees locate by a stream side can first 'die standing' then subsequently falls down by loss of the root anchor.

f. Direction of fall: use a compass to measure the direction from the base to the crown top of an uprooted tree, or of the snapped tree to the branch end.

g. Estimate the degree of wood decay:

1 Intact. There is more than 75 % of the wood intact and/or hard, and sometimes with fine twigs still attached. This could be a recently fallen bole.

1.5 Slightly damaged. The surface of the bark is with some damage, or could be a piece of wood where the bark had weathered but the heartwood is still hard.

2 Damaged and in bad condition. The log has experienced some decay, and between the decomposition degree of 1.5 and 2.5.

2.5 Somewhat rotten. Part of the wood is friable.

3 Rotten. There is more than 75 % of the wood soft and rotten, a machete blade enters easily, and the wood collapses when stepped on.

h. With/ without buttress root. If with buttress root, then measure the height and ground width of the buttress root.

i. Multiple treefall events:

i. The killer tree ("killed others", KO), the largest tree that lies on top of another tree or decomposed debris.

ii. Other tree killed ("others killed", OK), fallen trees are physically below another fallen tree. Need to note the tag number of the killer tree.

iii. How many trees died in a treefall event? Calculate the magnitude of the treefall event, for all trees ≥10cm dbh, including trees from outside the plot.

Note 1: Remember to distinguish between trees killed that were rooted inside and those rooted outside the sample area, to be able to derive accurate per-unit-area rate estimates.

Note 2: It is supposed that in general the trees in a multiple treefall event should be in a similar degree of decomposition. Sometimes we cannot find a target tree but know it to have been located close to another tree which is now on the ground; in these cases we tend to treat the target tree as 'vanished'. Although the wood density and the stem diameter could be two of the effects contributing to differential degree of decay, if the candidate 'killer tree' appears to have fallen recently (in decomposition degree of 1 or 1.5) and the possible 'killed tree' is completely 'vanished', we tend to treat the vanished individuals as dying in a separated event instead of being killed by the recently fallen trunk.

Note 3: If a tree is died standing but is then crushed by other falling tree, then only note it as crushed by the other (with the number of the crushed others tree); don't consider this as a multiple treefall event.

j. Signs of previous damage: Lianas/ heart rot/ termite/ insect/ fire …….

k. If it is a dead trunk but with re-sprout diameter ≤ 10 cm, then take a note of 'with re-sprout'.

Table 1 Field work sheet of mortality mode

Census of Mortality Mode: Place __________ Plot name ___________ Recorder __________ Census date _____/____/____ (d/m/y)

Quadrat	Sub-quadrat	No.	Species	Diameter (cm)	Mode of death[a]	Height (m)	Height of snap (m)	Direction of fall	Degree of decay [b]	w/ buttress height (m) [c]	Multiple treefall [d]	Notes[e]

a

1	dead, standing
2	dead, uprooted
3	dead, snapped
V	vanished

b

1	died recently
1.5	slightly damaged
2	damaged and in bad condition
2.5	somewhat rotten
3	rotten

c

YB	With buttress root
YS	With stilt root
N	Without buttress and stilt root

*Note the height of the root

d

Solo	Solo
KO	dead, killed other tree
OK	dead, other tree killed; note tag no. of KO tree.

* Note how many trees die in an event

e

D	diseased
I	with insect infection
L	by liana
P	Previous physical damage
S	by strangler

* Record the dead trees which are **rooted inside** the plot

4 Some suggested data analyses, depending on the questions motivating the research:

(1) Analyse the basic mortality information.

a. Annual mortality rate (m)

$\boldsymbol{N_1 = N_0 (1-m)^t}$

$\boldsymbol{m = 1 - (N_1/N_0)^{1/t}}$

N_0 and N_1 are population counts at the beginning and at the end of the measurement interval (t) (Sheil *et al.* 1995)

b. Exponential mortality coefficient (λ)

$\boldsymbol{\lambda = \log_e (N_0/N_1)/t}$

N_0 and N_1 are population counts at the beginning and at the end of the measurement interval (t) (Sheil *et al.* 1995)

(2) Analyse the mode of tree death data.

a. The proportion of different modes (standing, uprooted, broken, vanish and others) of tree death.

b. The number of events of multiple-tree-fall and the frequency distribution of how many trees die in one event.

c. The orientation of the fallen trees. Is there a predominant direction?

d. The proportion of modes of tree death in different size classes (Kolmogorov-Smirnov two sample test (refer to (Putz et al. 1983)). The diameter classes used in this research are:

Class 1: 10 cm ≤ X < 20 cm; Class 2: 20 cm ≤ X < 40 cm; Class 3: 40 cm ≤ X

(3) Use **Mantel test, ANOVA or William's corrected G-test** to test the relationship (correlation) between tree death mode, tree properties and along the environmental factors gradients: DBH class, height class, wood density, slope, slope position, elevation, soil category, soil drainage, soil depth, and disturbance frequency (used by Gale and Barfod 1999).

5 Inventory equipment checklist

Category	Items	Notes
Plot set up		
	String	To mark the borders of the plot
	Permanent markers	To mark coordinates on the strings
Environmental data		
	Clinometer	To measure the slope
	Compass	To measure the direction of the fallen log
	GPS	To locate the position of the plot
	Soil sampling equipment	
	Machete	
Tree mortality mode		
	Pens	
	Clipboard	
	Recording sheets: Mode of death	≈ 25 sheets per hectare (10 samples per sheet)
	Recording sheets: Dead wood	
	2 m diameter measuring tape × 2	To measure diameter
	30 m measuring tape	Help to measure the edge of the plot
	Binoculars	
	Notebooks	

6 References

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