LBA-ECO ND-04 Secondary Forest Recovery, Structure, and LAI, Central Amazonia, Brazil

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Revision date: February 22, 2012

Summary:

This data set reports measurements of the canopy and structure of secondary forests regenerating from abandoned pastures. These secondary forests are located in the state of Amazonas, Brazil, along the road BR-174 north of the city of Manaus within three fazendas (cattle ranches) now in various stages of grazing, pasture abandonment, or pasture reclamation: Fazenda Rodao (km 46), Embrapa-District of SUFRAMA (DAS) pasture research site (km 53), and Fazenda Dimona (km 72). Ten secondary forest study sites were selected within the three fazendas where post-pasture forest recovery ranged from 0 to 14 years since abandonment.

From 2000-2001 estimates of leaf area index (LAI) and canopy cover were derived from hemispherical canopy digital photographs, and estimates of aboveground biomass and basal area were derived utilizing allometric equations from diameter at breast height (DBH) measurements. Estimates were classified by growth-form and diameter class. See Feldpausch et al. (2005) for more information. There are four comma-delimited data files with this data set and one companion file with information regarding the allometric equations relating diameter at breast height (for dbh > 5 cm) to dry weight for biomass calculations.

Data Citation:

Cite this data set as follows:

Feldpausch, T.R., E.C.M. Fernandes, M.A. Rondon, S.J. Riha, and E. Wandelli. 2012. LBA-ECO ND-04 Secondary Forest Recovery, Structure, and LAI, Central Amazonia, Brazil. Data set. Available on-line [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/ORNLDAAC/1068

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This data set was archived in February of 2012. Users who download the data between February 2012 and January 2017 must comply with the LBA Data and Publication Policy.

Data users should use the Investigator contact information in this document to communicate with the data provider. Alternatively, the LBA website [http://lba.inpa.gov.br/lba/] in Brazil will have current contact information.

Data users should use the Data Set Citation and other applicable references provided in this document to acknowledge use of the data.

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1. Data Set Overview:

Project: LBA (Large-Scale Biosphere-Atmosphere Experiment in the Amazon)

Activity: LBA-ECO

LBA Science Component: Nutrient Dynamics

Team ID: ND-04 (Fernandes / Wandelli)

The investigators were Fernandes, Erick C.M.; Wandelli, Elisa Vieira; Ackerman, Ilse Lieve; Duxbury, John; Feldpausch, Ted R.; Ferreira, Frank Correa; Gallardo-Ordinola, Jorge Luis Enrique; Garcia, Silas; Hines, Kristen; Kuczak, Christienne N.; Lehmann, Johannes; Luizao, Flavio de Jesus; Luizao, Regina Celi Costa; Milgroom, Jessica; Queiroz, Juliete Maria Tome de; Riha, Susan J.; Schwendener, Carol Melanie; Silva, Guilherme Castilho da; Silva, Rubenildo Lima da; Cabrera, Lucerina Trujillo and Welch, Steven A. You may contact Feldpausch, Ted R. (trf2@cornell.edu).

LBA Data Set Inventory ID: ND04_Secondary_Forest_Recovery

The area of secondary forest (SF) regenerating from pastures is increasing in the Amazon Basin; however, the return of forest and canopy structure following abandonment is not well understood. We studied the development of leaf area index (LAI), canopy cover, aboveground biomass, stem density, diameter at breast height (DBH), and basal area (BA) by growth-form and diameter class for ten SFs regenerating from abandoned pastures.

Related Data Set:

- LBA-ECO ND-04 Secondary Forest Carbon and Nutrient Stocks, Central Amazonia, Brazil

2. Data Characteristics:

There are four comma-delimited data files with this data set and one companion file with information regarding the allometric equations relating diameter at breast height (for dbh > 5 cm) to dry weight for biomass calculations.

File #1: ND04_Secondary_Forest_LAI_2000-01.csv
File #2: ND04_Secondary_Forest_DBH.csv
File #3: ND04_Secondary_Forest_Structure_Means.csv
File #4: ND04_Secondary_Forest_Plot_Information.csv

Companion file:
File #5: ND04_Secondary_Forest_Allometric_Equations.txt

Fazenda names/sampling location information:

Fazenda name code	Fazenda name	Description
DAS	Embrapa	Amazonia Ocidental Agricultural District of SUFRAMA (DAS) pasture research site, BR-174 Km 53-54 (North of Manaus)
Rodao	Fazenda Rodao	BR-174 Km 46 (North of Manaus)
Dimona	Fazenda Dimona	ZF-3 Km 72 (North of Manaus)

File #1: ND04_Secondary_Forest_LAI_2000-01.csv

Column	Heading	Units/format	Description
1	Sample_date	yyyymmdd	Sampling date (yyyymmdd)
2	Sample_month	mm	Month in which sampling was done: March, June, September, December
3	Sample_year	yyyy	Year in which sampling was done
4	Location_ID		Sampling location ID code, consisting of fazenda name code + forest site number within each fazenda (See companion file: ND04_Secondary_Forest_Plot_Information.csv)
5	Stand_age		Secondary forest age at the onset of the study (years since pasture abandonment) in ranges: 0 to 2, 2 to 4, 4 to 6, 6 to 8, 12 to 14
6	Plot_ID		Plot identification number: each forest had four plots varying in area between 100 and 400 m2
7	Rep_no		Identification of replicate samples within each plot for each LAI measurement
8	Height	cm	Sampling height in centimeters (cm). Measuring LAI at two heights allows computation of the scrub layer by subtraction of LAI at 5 from 150

9	Treatment		Fertilizer treatment: - Control: no additions - P: P added at a rate of 50 kg/ha as TSP - P+Ca: P (50 kg/ha)+Ca (2 t/ha) - P+Ca+G: P(50 kg/ha)+Ca (2 metric t/ ha)+Gypsum (CaSO4) (1 metric t/ha)
10	LAI_1	m2 m-2	Estimated Leaf Area index (LAI) in meter squared of leaf area per meter squared of ground area calculated using the CI-110 Digital Plant Canopy Analyzer [C-110: CID, Inc., Vancouver Washington]
11	Mean_leaf angle	degrees	Mean leaf angle in degrees
12	Trans_coef	%	Transmission coefficient; a factor that describes the regional clarity of the atmosphere with respect to instantaneous transmission of direct radiation
13	Threshold		Threshold set within the CI-110 software used to differentiate between leaf margins and sky
14	Canopy_opennes	%	Canopy openness based on the GLA software reported in percent (%) [GLA: Gap Light Analyzer 2.0 software (Frazer et al., 1999)]
15	LAI_GLA_4	m2 m-2	Estimated Leaf Area Index (LAI) in meter squared of leaf area per meter squared of ground area calculated using the GLA software for the 4th ring [GLA: Gap Light Analyzer 2.0 software (Frazer et al., 1999)]
16	LAI_GLA_5	m2 m-2	Estimated Leaf Area Index (LAI) in meter squared of leaf area per meter squared of ground area calculated using the GLA software for the 5th ring [GLA: Gap Light Analyzer 2.0 software (Frazer et al., 1999)]
Missing data represented by -9999, data not collected are represented by -4444			

Example data records:

```
Sample_date,Sample_month,Sample_year,Location_ID,Stand_age,Plot_ID,Rep_no,Height,Treatment,
LAI_1,Mean_leaf angle,Trans_coef,Threshold,Canopy_openness ,LAI_GLA_4,LAI_GLA_5
20000912,September,2000,DAS-1,0 to 2,9,1,150,P,
-9999,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,9,2,150,P,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,9,3,150,P,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,9,4,150,P,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,9,5,150,P,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,8,1,150,Control,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,8,2,150,Control,
0,0,-4444,-4444,0,0,0
20000912,September,2000,DAS-1,0 to 2,8,3,150,Control,
0,0,-4444,-4444,0,0,0
```

File #2: ND04_Secondary_Forest_DBH.csv

Column	Heading	Units/format	Description
1	Location_ID		Sampling location ID code, consisting of fazenda name code + forest site number within each fazenda (See companion file: ND04_Secondary_Forest_Plot_Information.csv)
2	Stand_age		Secondary forest age at the onset of the study (years since pasture abandonment) in ranges: 0 to 2, 2 to 4, 4 to 6, 6 to 8, 12 to 14
3	Plot_ID		Plot identification number: there are 4 plots per forest with the exception of DAS-1 which has 12 plots
4	Subplot_ID		Subplot identification number: there are 3 subplots per plot
5	Subplot_area	m2	Subplot area in meters squared (m2)
6	Plant_ID		Plant identification number
7	Scientific_name		Scientific name of the plant where identified in the format Genus species or "Not determined"
8	Common_name		Local name of plant where identified or "Not determined"
9	Growth_form		Plant growth form: tree, shrub or liana
10	DBH	mm	Diameter at breast height: measured in millimeters (mm) at 1.3 meters above the surface of the soil
11	Field_notes		Comments from the field notebooks
Missing data indicated by -9999			

Example data records:

```
Location_ID,Stand_age,Plot_ID,Subplot_ID,Subplot_area,Plant_ID,Scientific_name,Common_name,Growth_form,DBH ,Field_notes
DAS-1,0 to 2,1,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,2,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,3,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,4,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,5,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,6,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
DAS-1,0 to 2,7,-9999,-9999,-9999,Not determined,Not determined,-9999,-9999,No stems
greater than or equal to 1 cm DBH
```

File #3: ND04_Secondary_Forest_Structure_Means.csv

Column	Heading	Units/format	Description
1	Location_ID		Sampling location ID code, consisting of fazenda name code + forest site number within each fazrnda (See companion file: ND04_Secondary_Forest_Plot_Information.csv)
2	Stand_age		Secondary forest age at the onset of the study (years since pasture abandonment) in ranges: 0 to 2, 2 to 4, 4 to 6, 6 to 8, 12 to 14
3	Vegetation_group		Type of vegetation: tree, shrub, liana, or total which indicates that all 3 categories are represented
4	Biomass_TABG	mg ha-1	Total aboveground biomass calculated using allometric equations for the trees, lianas, and shrubs reported as mg ha-1 (See below for contents of companion file (File #5): ND04_Secondary_Forest_Allometric_Equations.txt). See accompanying documentation for equations.
5	DBH_mean	cm	Mean diameter at breast height in centimeters (cm) for each forest. Diameter was measured at 1.3 meters above the ground or above prop roots where they occurred
6	Stem_density_mean	stems ha-1	Mean number of stems per hectare (stems ha-1) for each forest
7	Basal_area_mean	m2 ha-1	Mean basal area calculated from measured dbh and scaled from the sum of all area inventoried to m2 per hectare for each forest, reported as m2 ha-1
Missing data are represented by -9999			

Example data records:

```
Location_ID,Stand_age,Vegetation_group,Biomass_TABG,DBH_mean,Stem_density_mean,Basal_area_mean
DAS-1,0 to 2 ,tree,0,0,0,0
DAS-1,0 to 2 ,shrub,0,0,0,0
DAS-1,0 to 2 ,liana,0,0,0,0
DAS-1,0 to 2 ,total,0,-9999,0,0
Rodao-1,0 to 2 ,tree,0,0,0,0
Rodao-1,0 to 2 ,shrub,0,0,0,0
Rodao-1,0 to 2 ,liana,0,0,0,0
Rodao-1,0 to 2 ,total,0,-9999,0,0
Rodao-4,2 to 4,tree,0.08,0.86,75,0
Rodao-4,2 to 4,shrub,0.18,0.73,300,0.1
Rodao-4,2 to 4,liana,0,0,0,0
Rodao-4,2 to 4,total,0.25,-9999,375,0.1
DAS-2,4 to 6,tree,22.27,3.05,6375,7
DAS-2,4 to 6,shrub,1.1,1.81,1875,0.5
```

File #4: ND04_Secondary_Forest_Plot_Information.csv

Column	Heading	Units/format	Description
1	State		Study location state: Amazonia
2	Region		Study location region: Manaus

3	Km_marker		Study location kilometer marker along the highway BR-174 running north from Manaus to Venezuela, or ZF-3, a feeder road to BF-174
4	Fazenda_name		Fazenda name (See Fazenda Name / Description above)
5	Location_ID		Sampling location ID code, consisting of fazenda name code + forest site number within the fazenda
6	Stand_age		Secondary forest age at onset of study, i.e. years after pasture abandonment: 0 to 2, 2 to 4, 4 to 6, 6 to 8, 12 to 14
7	N_Plots		Number of plots in forest
8	Plot_dimensions	m	Plot dimensions as width of plot in meters X depth of plot in meters (m)
9	N_subplots		Number of sub-plots in the plot
10	Subplot_dimensions	m	Sub-plot dimensions as: width of sub-plot in meters X depth of sub-plot in meters (m)
11	Plot_area	m^2	Total area sampled per plot in meters squared (m^2)
12	Forest_area	m^2	Total area sampled per forest in meters squared (m^2)

Example data records:

State,Region,Km_marker,Fazenda_name,Location_ID,Stand_age,N_plots,Plot_dimensions,N_subplots,Subplot_dimensions,
Plot_area,Forest_area
Amazonas,Manaus,km 54,Embrapa DAS Experiment,DAS-1,0 to 2,12,10x10,1,10x10,
100,1200
Amazonas,Manaus,km 54,Embrapa DAS Experiment,DAS-2,4 to 6,4,15x15,3,4x5,
60,240
Amazonas,Manaus,km 54,Embrapa DAS Experiment,DAS-3,12 to 14,4,20x20,3,5x7,
105,420
Amazonas,Manaus,km 72,Fazenda Dimona - ZF3 ,Dimona-1,6 to 8,4,15x15,3,4x5,
60,240
Amazonas,Manaus,km 72,Fazenda Dimona - ZF3 ,Dimona-2,12 to 14,4,20x20,3,5x7,
105,420
Amazonas,Manaus,km 72,Fazenda Dimona - ZF3 ,Dimona-3,6 to 8,4,15x15,3,4x5,
60,240
Amazonas,Manaus,km 46,Fazenda Rodao,Rodao-1,0 to 2,4,15x15,1,15x15,
225,900
Amazonas,Manaus,km 46,Fazenda Rodao,Rodao-2,6 to 8,4,15x15,3,4x5,
60,240
Amazonas,Manaus,km 46,Fazenda Rodao,Rodao-3,4 to 6,4,15x15,3,4x5,
60,240
Amazonas,Manaus,km 46,Fazenda Rodao,Rodao-4,2 to 4,4,10x10,1,10x10,
100,400

File #5: ND04_Secondary_Forest_Allometric_Equations.txt

Allometric equations relating diameter at breast height (for dbh > 5 cm) to dry weight of dominant secondary forest species in central Amazonia, Brasil. Based on Nelson et al. 1999.

Family	Scientific_name	Allometric equation	R2
Cecropiaceae	Cecropia sp.	ln (DW)= -2.5118 +2.4257*ln (dbh)	0.98
Celastraceae	Goupia glabra	ln (DW)= -1.7972 +2.4206*ln (dbh)	0.99
Clusiaceae	Vismia japurensis	ln (DW)= -1.7829 +2.3651*ln (dbh)	0.99
Clusiaceae	Vismia cayennensis	ln (DW)= -2.3706 +2.5392*ln (dbh)	0.99
Flacourtiaceae	Laetia procera	ln (DW)= -2.224 +2.5105*ln (dbh)	0.99
Melastomateceae	Bellucia sp.	ln (DW)= -1.8158 +2.370*ln (dbh)	0.99
Mixed species		ln (DW)= -1.9968 +2.4128*ln (dbh)	0.98

Allometric equation relating basal area (in cm2) to dry weight for lianas. Based on Putz 1983. Log (DW)= 0.12+ 0.91*log(BA) R2= 0.82

Citations:

Nelson, B.W., R. Mesquita, J.L.G. Pereira, S.G.A. d. Souza, G.T. Batista and L.B. Couto. 1999. Allometric regressions for improved estimate of secondary forest biomass in the central Amazon. Forest Ecology and Management 117: 149-167.

Putz, F.E. 1983. Liana biomass and leaf area of a 'terre firme' forest in the Rio Negro Basin, Venezuela. Biotropica 15: 185-189.

Site boundaries: (All latitude and longitude given in decimal degrees)

Site (Region)	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude	Geodetic Datum
Amazonas (Manaus) - EMBRAPA CPAA pasture research station (Amazonas (Manaus))	-60.03	-60.03	-2.518	-2.518	World Geodetic System, 1984 (WGS-84)
Amazonas (Manaus) - Fazenda Dimona (Amazonas (Manaus))	-59	-59	-2	-2	World Geodetic System, 1984 (WGS-84)
Amazonas (Manaus) - Fazenda Rodao (Amazonas (Manaus))	-60.02365	-60.02365	-2.57156	-2.57156	World Geodetic System, 1984 (WGS-84)

Time period:

- The data set covers the period 2000/09/12 to 2001/09/01
- Temporal Resolution: Vegetation samples were collected in one campaign completed between late June and early July 2001. Nutrient concentrations were scaled up using DBH and biomass measurements from an earlier campaign done in December 2000/January 2001. LAI data were collected every 3 months between Sept 2000 and Sept 2001

Platform/Sensor/Parameters measured include:

- FIELD INVESTIGATION / ALGORITHM / FOREST MANAGEMENT
- FIELD INVESTIGATION / ANALYSIS / ABOVEGROUND BIOMASS
- FIELD INVESTIGATION / ANALYSIS / NUTRIENTS
- FIELD INVESTIGATION / ANALYSIS / REFORESTATION
- FIELD INVESTIGATION / ANALYSIS / LEAF CHARACTERISTICS

3. Data Application and Derivation:

Using individual tree and shrub DBH measurements we calculated dry biomass by life-form and diameter class using two sets of allometric equations developed in the region (for stems greater than 5 cm diameter, from Nelson et al. (1999); for smaller stems, from Mesquita unpublished data). We calculated mean basal area for all stems by calculating basal area for the individual based on DBH and summing the values per plot. Using allometric equations developed in Amazonian terra firme sites, we calculated basal area of individual vines and converted basal area to dry biomass (Putz, 1983).

These data allow the calculation of rate the recovery of secondary forests as well as the structure of the recovering forest in terms of stem size and density.

4. Quality Assessment:

Since we only measured DBH for stems greater than or equal to 1 cm diameter, our estimates underestimate total aboveground biomass and stem density.

5. Data Acquisition Materials and Methods:

Study sites:
The study sites were located in the state of Amazonas, Brazil along the road BR-174 north of the city of Manaus. The terrain is undulating with an elevation of 50-150 m.a.s.l. The plateau soil is classified as dystrophic, isohyperthermic, clayey kaolinitic Hapludoxes with approximately 80 to 95% clay. Regional climate is tropical humid and the mean temperature is 26.7 degrees C. Mean annual rainfall in Manaus is 2.2 meters with March and April the wettest months.

Ten secondary forests were selected within three fazendas (cattle ranches) now in various stages of grazing, pasture abandonment or pasture reclamation: Fazenda Rodao (km 46), Embrapa-District of SUFRAMA (DAS) pasture research site (km 53), and Fazenda Dimona (km 72). Defining “abandoned” was problematic since there may have been an infrequent rotation of temporary contract grazing of a few cattle. The abandonment date was then indefinite since cattle may periodically graze the area until all palatable forage is replaced by woody successional vegetation. To address this issue, the data are provided as age classes, rather than purport to define a fixed abandonment date (Feldpausch et al., 2005). The regenerating forests within each fazenda represented individual pastures that were abandoned from 0–2 to 12–14 yr. Within the selected forest (time since pasture abandonment 0-14 years), located on plateau Oxisols, we established 4 plots of 100 m2 to 400 m2 area. Within each plot 3 subplots ranging in size from 35 to 100 m2 were established. A total of 0.56 ha of area was included in this study across the 10 forests.

LAI measurements:

Leaf area index was measured in all sub-plots beginning in September 2000 and repeated every three months for a year. The LAI measurements were taken with a portable, electronic handheld hemispheric (fish-eye) lens (CI-110: CID, Inc., Vancouver Washington) with the plane of the lens set parallel to the ground. LAI was measured at 5 and 150 cm above the ground, which resulted in 12 LAI images per forest per height (total of 240 images). The two heights allow for the distinction of understory (leaf area below 150 cm height)and overstory leaf area. All photographs were taken using the incident light characteristic of morning and evening twilight hours.

Leaf area index was calculated from the digital photos using the CI-110 software (version 3.0.1.1) on a high-resolution LCD monitor. We reduced the field of view from 180 degrees to 150 degrees to reduce the misclassification of stems as leaves. After setting an image specific threshold to differentiate between leaf margins and sky, the software uses gap fraction analysis to calculate LAI for each image (Norman and Campbell 1989).

Canopy cover, a measure of the percentage of leaf cover obscuring the open sky as viewed from the ground, was calculated from the same digital photos using the Gap Light Analyzer 2.0 software (Frazer et al. 1999). Additional LAI estimates were made from the GLA software based on reductions in the hemispheric view from GLA ring 4 and ring 5.
Canopy cover was calculated using the canopy gap diffuse data, the fraction of pixels in each sky region that are open (white) on the fisheye photograph, weighted by hemispherical area.

Forest structure and biomass measurements:
Diameters of all stems (trees, shrubs and vines) with diameters at breast height (1.3 m above ground for all live trees with diameters greater than or equal to 1 cm or above prop roots where they occurred) were measured in each sub-plot in late December 2000/early January 2001. Using individual tree and shrub DBH measurements we calculated dry biomass by life-form and diameter class using two sets of allometric equations developed in the region (for stems greater than 5 cm diameter, from Nelson et al. (1999); for smaller stems, from Mesquita unpublished data). We calculated mean basal area for all stems by calculating basal area for the individual based on DBH and summing the values per plot. Using allometric equations developed in Amazonian terra firme sites, we calculated basal area of individual vines and converted basal area to dry biomass (Putz, 1983).

6. Data Access:

This data is available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Data Archive Center:

Contact for Data Center Access Information:
E-mail: uso@daac.ornl.gov
Telephone: +1 (865) 241-3952

7. References:

Feldpausch, Ted R., Susan J. Riha, Erick C. M. Fernandes, Elisa V. Wandelli, 2005: Development of Forest Structure and Leaf Area in Secondary Forests Regenerating on Abandoned Pastures in Central Amazônia. Earth Interact., 9(6):1-22. doi: http://dx.doi.org/10.1175/EI140.1

Frazer, G.W., C.D. Canham and K.P. Lertzman. 1999. Gap Light Analyzer (GLA): Imaging software to extract canopy structure and gap light transmission indices from true-color fisheye photographs: User's manual and program documentation (version 2.0). Simon Fraser University, Burnaby, BC, Canada and the Institute of Ecosystem Studies, Millbrook, NY 36 pp.

Nelson, B.W., R. Mesquita, J.L.G. Pereira, S.G.A. d. Souza, G.T. Batista and L.B. Couto. 1999. Allometric regressions for improved estimate of secondary forest biomass in the central Amazon. Forest Ecology and Management 117: 149-167.

Norman, J.M. and G.S.Campbell. 1989. Canopy structure. Pages 301-325 in Plant Physiological Ecology: Field Methods and Instrumentation. J.E.R.W. Pearcy, H.A. Mooney and P.W. Rundel editors.

Putz, F.E. 1983. Liana biomass and leaf area of a 'terre firme' forest in the Rio Negro Basin, Venezuela. Biotropica 15: 185-189.

Related Publications

- Feldpausch, T.R., M.A. Rondon, E.C.M. Fernandes, S.J. Riha, and E. Wandelli. 2004. Carbon and nutrient accumulation in secondary forests regenerating on pastures in central Amazonia. Ecological Applications 14(4):S164.
- dos Santos, U.M., J.F.D. Goncalves, and T.R. Feldpausch. 2006. Growth, leaf nutrient concentration and photosynthetic nutrient use efficiency in tropical tree species planted in degraded areas in central Amazonia. Forest Ecology and Management 226(1-3):299-309.
- Silva, C. E. M. d. 2005. Eficiencia no uso dos nutrientes por especies pioneiras apos correcao da acidez do solo e adubacao fosfatada sobre area degradada na Amazonia central - M.S. Thesis. Instituto Nacional de Pesquisas da Amazonia, Manaus, Brazil.
- Silva, C. E. M. d., J. F. d. C. Goncalves, T. R. Feldpausch, F. J. Luizao, R. R. d. Morais, and G. O. Ribeiro. 2006. Eficiencia no uso dos nutrientes por especies pioneiras crescidas em pastagens degradadas na Amazonia central (Nutrient use efficiency for pioneer species grown on abandoned pastures in central Amazonia). Acta Amazonica 36:503-512.
- Feldpausch, T.R. 2002. Carbon and nutrient accumulation, forest structure, and leaf area in secondary forests regenerating from degraded pastures in Central Amazonia, Brazil. Thesis, Cornell University.