



## ECOINFORMATICS: REPORT

# ForestPlots.net: a web application and research tool to manage and analyse tropical forest plot data

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### Keywords

Carbon dynamics; Climate change; Data management; Ecoinformatics; Long-term plots; Tropical forest; Vegetation database.

### Abbreviations

C = carbon; POM = Point of measurement; RAINFOR = The Amazon Forest Inventory Network; AfriTRON = African Tropical Rainforest Observation Network

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### Abstract

Tropical forests are biologically diverse ecosystems that play important roles in the carbon cycle and maintenance of global biodiversity. Understanding how tropical forests respond to environmental changes is important, as changes in carbon storage can modulate the rate and magnitude of climate change. Applying an ecoinformatics approach for managing long-term forest inventory plot data, where individual trees are tracked over time, facilitates regional and cross-continental forest research to evaluate changes in taxonomic composition, growth, recruitment and mortality rates, and carbon and biomass stocks. We developed ForestPlots.net as a secure, online inventory data repository and to facilitate data management of long-term tropical forest plots to promote scientific collaborations among independent researchers. The key novel features of the database are: (a) a design that efficiently deals with time-series data; (b) data management tools to assess potential errors; and (c) a query library to generate outputs (e.g. biomass and carbon stock changes over time).

### Introduction

The development of vegetation databases facilitates research by allowing users to standardize and compile data according to their research interests. Vegetation databases, as listed in the Global Index of Vegetation Plot Databases (GIVD; Dengler et al. this issue), are usually developed for a particular type of vegetation and/or a particular region. The large majority of the databases listed in GIVD are databases for individual European countries. The small number of databases for tropical regions is counter to their ecological importance as tropical forests play a major role in the Earth system (Denman et al. 2007).

### Aims of the ForestPlots.net Web Application

The ForestPlots.net web application was designed primarily as a repository for long-term intact tropical forest inventory plots, where trees within an area are individually identified,

measured and tracked through time. It supports the continent-wide forest monitoring networks in South America (The Amazon Forest Inventory Network, RAINFOR; Malhi et al. 2002) and Africa (African Tropical Rainforest Observation Network, AfriTRON, Lewis et al. 2009), as well as ecological, plot-based research in South-east Asia and Australia. The aims of the web application are (i) to enable network participants to access and manage their data online in a secure environment, (ii) to integrate and standardize forest plot data, and (iii) to promote data sharing across the scientific community and to provide access to publicly available forest inventory data.

The features and capabilities of ForestPlots.net expand on those of its predecessor, the RAINFOR database (Peacock et al. 2007), by allowing individual researchers to (i) securely access and manage their data online and, upon request, share their data with other researchers, (ii) download fieldsheets to re-census plots and upload new

plot re-censuses, (iii) run routine error-checking procedures, and (iv) run standardized queries across their plots.

ForestPlots.net data providers and general users agree to adhere to the 'Ethical Code, Data Sharing & Publication Policy for ForestPlots.net Database Users' (Appendix S1). In addition, ForestPlots.net allows users to access publicly available data. Currently, there are more than 170 field campaign censuses from a similar number of plots from Africa and South America that can be viewed and downloaded by the public, following registration.

### Data Management of Long-Term Plot Data

The web application was developed to explicitly track temporal changes in stem growth, mortality and live tree biomass carbon. The database was implemented using Microsoft SQL-Server 2005 and is managed using a multi-lingual user interface (English, Spanish, Portuguese and French). Most of the plot data contained in the database come from plots that, after establishment, are re-sampled periodically. Our approach consists of repeatedly measuring individual tree diameter at breast height (DBH) in a given area. We measure diameter and point of measurement and record the status (live or dead) and, where appropriate, mode of death of individual trees. The database currently holds information on more than 600 plots and 400 000 trees.

To facilitate plot data management we developed an 'upload wizard' for uploading information from new plots and re-censused plots. The aim of the upload wizard is to systematically support the data standardization process, thus ensuring that all data are subjected to the same verification and validation procedures. The first step of the upload process involves providing geographical information, plot, forest type and sampling strategy. Once the plot metadata are entered and the data file is uploaded, the taxonomic information for all the trees measured is checked against a species master list. This species master list has been compiled from names from the TROPICOS (<http://www.tropicos.org>) list for South America (valid names, includes synonyms), accepted names (valid names, adjudicated synonymy) from the African Flowering Plants Database (<http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php>) and accepted names from the Queensland Herbarium ([http://www.derm.qld.gov.au/wildlife-ecosystems/plants/queensland\\_herbarium/index.html](http://www.derm.qld.gov.au/wildlife-ecosystems/plants/queensland_herbarium/index.html)). Family names of all genera for all three sources have been checked against the Angiosperm Phylogeny Group II flowering plants classification (The Angiosperm Phylogeny Group 2003). The next phase of the database will include checking our species list against 'the plant list' (<http://www.theplantlist.org>) to produce a master list of accepted names. With each new census upload, any

changes in tree species determinations are detected and updated. Finally, the checking and verification process ensures that the file format, units for tree diameters and point of measurement, and alive and dead status coding are valid and complete. The forest sampling and coding methodologies are explained in detail on [http://www.geog.leeds.ac.uk/projects/rainfor/pages/manuals\\_eng.html](http://www.geog.leeds.ac.uk/projects/rainfor/pages/manuals_eng.html). Once a plot census is saved, the user can decide whether the plot metadata or diameter measurements and species data should be shared with other users.

In addition, fieldsheet files, formatted for use in the field, can be generated for any plot that is in the database, again to enforce data standardization. Once the data are collected, the use of fieldsheet files accelerates the data entry and upload process. The upload wizard has proved to be a useful tool when dealing with large numbers of plot files. Users can check their data for possible errors using an error-checking wizard to highlight the researchers' data to be re-checked for possible problems. The error-checking wizard first checks the number of stems between censuses for consistency and displays a count of 'missing' or 'extra trees' in each census. 'Missing trees' may be due to not entering the field data from a particular tree at a particular census, or the accidental deletion of a diameter measurement of a particular tree at a particular census. The most common cause of 'missing trees' is where mortality coding is missed when a tree dies. 'Extra trees' occur when a tree previously coded as dead is then coded as alive in a later census (which may be a mistake, or due to a tree having been missed or classified as dead in a previous census).

After the stem count consistency check, the error-check wizard finds trees with extreme diameter changes between censuses. The default values are 40 mm yr<sup>-1</sup> and 5 mm yr<sup>-1</sup> for increase and decrease in diameter, respectively; however, these values can be changed depending on the knowledge the user has about a particular plot (e.g. increasing the maximum diameter growth for trees in plots growing on very fertile soils). Once uploaded, the raw data are marked as 'read only' to maintain data integrity. However, if the researcher wants to alter, for example, an extreme growth rate due to a data entry error (e.g. a tree growing from 100 to 1100 mm, instead of 100 to 110 mm) the web interface allows the user to make and document the necessary corrections, which are kept alongside the originally uploaded data. If further investigation and new field measurements warrant that a different error correction procedure is preferred, the diameter can still be subsequently interpolated or extrapolated as described in Baker et al. (2004) and Lewis et al. (2009).

A source of potential bias in the analysis and interpretation of long-term plot data is the treatment of stems where the point of measurement (POM) must be moved

due to the development, or expected future development, of a buttress or stem deformity. These changes to the POM often need to be made in the field, as continuing to measure diameter at the same height despite trees developing buttresses and deformities ('buttress creep') causes inflation of stem diameter growth measurements and later inflated stem diameter trees that die, which in turn inflates basal area and biomass stock and flux (growth and mortality) estimates. A diameter standardization algorithm is applied using the measurements at the new and old POMs (Appendix S2), which helps to identify and handle these necessary changes.

### Data Analysis

ForestPlots.net incorporates a query library to produce outputs of plot biomass, basal area, stem dynamics, productivity and wood density, and provides researchers with instant information on the status of their plots. A recently compiled global wood density database (Chave et al. 2009; Zanne et al. 2009) is included within this application because it is a key tree functional trait and is included in allometric equations that relate stem diameter values to tree biomass. The database has proved a useful tool for our understanding of the role of Amazonian and African tropical forests in global carbon cycle dynamics, and their response to diverse environmental changes affecting tropical forests (Malhi & Phillips 2004). Recent publications using long-term plot data have shown a globally important pan-tropical increase in carbon storage in forests of ca.  $1.3 \text{ Pg C yr}^{-1}$  (Lewis et al. 2009) (but that this carbon 'sink' is vulnerable to change as a consequence of climate change; Phillips et al. 2009).

### Future Directions

The development of ForestPlots.net has proved a useful aid in research investigating recent changes in the growth, recruitment, mortality and carbon balance of tropical forests over large areas. However, for more sophisticated analyses that produce a clearer picture of the susceptibility of tropical forests to climate change it is necessary to couple plot data with environmental data sets. Therefore, future developments will likely include a direct link between ForestPlots.net and climate databases.

In addition, given the high tree species diversity and lack of ecological knowledge about many species, it is difficult to make statistically robust and ecologically meaningful inferences about changes. One method of dealing with these limitations is to utilize functional traits to assess species responses. We plan to include important functional traits such as tree height and leaf physical and chemical characteristics in the near future.

ForestPlots.net has been a critical tool for scientific researchers, resulting in new understanding of the role of tropical forests within the Earth System (e.g. Lewis et al. 2009; Phillips et al. 2009). Beyond this, the database also has applied uses, such as monitoring carbon via a fusion of inventory and remote sensing data, which is a critical component of the UN 'Reduced Emissions from Deforestation and forest Degradation' (REDD+) scheme to pay developing countries to reduce carbon emissions from deforestation. From both basic and applied scientific perspectives, the early phase of our database ForestPlots.net has been a success, and we anticipate further development to improve both our understanding and wise management of the world's most biodiverse habitat.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Figure S1.** Tree with POM change. DBH1 = diameter as measured in the field in a particular census; DBH2 = diameter standardized to old POM; DBH3 = diameter standardized to new POM.

**Figure S2.** Weighted mean changes in above-ground carbon using different protocols for trees with POM change. Raw = original data; Initial POM = diameters standardized to original POM; Final POM = diameters standardized to new POM; Mean POM = mean of standardization to initial and final POM; Ignore = trees with POM are excluded from the calculations; Zero growth = the diameter of trees with POM change remains constant after first measurement; Mean Growth = diameter of trees with POM change is calculated using mean growth rate by size class; All Mean = mean of all the previous methodologies.

**Appendix S1.** Ethical Code, Data Sharing & Publication Policy for ForestPlots.net Database Users.

**Appendix S2.** Managing Point of Measurement (POM) changes.

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