Biomass

Bernard R. Parresol

Volume 1, pp 196–198

in

Encyclopedia of Environmetrics
(ISBN 0471 899976)

Edited by

Abdel H. El-Shaarawi and Walter W. Piegorsch

© John Wiley & Sons, Ltd, Chichester, 2002

Biomass

Biomass, the contraction for biological mass, is the amount of living material provided by a given area or volume of the earth's surface, whether terrestrial or aquatic. Biomass is important for commercial uses (e.g. fuel and fiber) and for national development planning, as well as for scientific studies of ecosystem productivity, energy and nutrient flows, and for assessing the contribution of changes in forestlands (especially tropical) to the global carbon cycle.

Ecology and the Environment

Biomass in an **ecosystem** is the mass or weight of living tissue, which is commonly subdivided into five fundamental trophic levels forming the basic food chain:

1. producers, which are green photosynthesizing plants
2. herbivores, which eat producers
3. predators, which eat herbivores
4. top predators, which eat predators
5. decomposers, which break down dead tissue of all five groups [5].

In terrestrial ecosystems, the biomass distribution resembles a pyramid, where mass progressively decreases from producer to top predator. Aquatic systems that appear green or blue-green exhibit the biomass pyramid, but some clear waters have a dipyramid-shaped biomass distribution, i.e. narrow at the bottom and top, and wide in the middle. Biomass reflects the distribution of both energy and materials in the community.

Plant biomass absorbs carbon dioxide during growth and emits it during combustion; therefore, it recycles atmospheric carbon. If we replant harvested biomass, carbon dioxide is returned to the cycle of new growth so there is no net gain in atmospheric carbon to add to the greenhouse effect. The burning of fossil fuels takes 'old' biomass and converts it into 'new' carbon dioxide that contributes to the greenhouse effect and depletes a nonrenewable resource. Because of low sulfur content, biomass can be cofired with coal in existing power plants to achieve compliance with laws such as the US Clean Air Act Amendments. Large-scale 'biomass burning', i.e. deliberately set fires to clear land, is a significant source of carbon dioxide and particles in our atmosphere [8].

Bioenergy

Bioenergy is fuel energy that can be derived directly or indirectly from biological sources. Organic matter that is used as a source of biomass energy includes trees, corn, rice hulls, peanut shells, sugar cane, grass clippings, leaves, manure, and municipal solid waste. Biomass energy from wood, crop residues (known as bagasse), and dung remains the primary source of energy in developing regions. For example, there are innumerable woodstoves being used to produce heat for buildings or for cooking in such regions. The total annual world production of plant biomass is estimated at 2740 Quads (1 Quad = 10^{16} British thermal units (BTUs)), which is eight times the total annual world consumption of energy (340 Quads) [1]. Therefore, biomass represents a very large renewable energy resource. Through short rotation forestry, advances in harvesting and processing techniques, and more efficient stoves and boilers, biomass can supply a large portion of the world's energy. Economic benefits, especially for rural communities, are expected as biomass power technologies [2] and energy crops are commercialized and create new jobs (*see* **Economics, environmental**).

Estimation

Detailed information on biomass resources is collected typically through inventory techniques. Amount of biomass is exceedingly hard to quantify from an aerial perspective [14]. However, modern technologies such as the Laser Vegetation Imaging Sensor [12] hold promise as new remote sensing tools for analyzing forested areas and other vegetation types in a three-dimensional format. For example, the new sensor estimates vegetation height and the amount of leaves and branches in a vertical column. (Above-ground biomass of trees and vegetation such as arborescent cacti, e.g. saguaro, is closely related to their height.)

The most common procedure for estimating biomass is through the use of regression methods. Individual organisms are chosen through an appropriate selection procedure and the weights or mass are

determined and related by regression to one or more dimensions of the organism. An innovative approach for predicting plant biomass uses projected area of the plant (as measured by computer-based image analysis) as an explanatory variable. Studies have shown that projected crown area alone can explain more than 97% of the variation in tree seedling or sapling mass [10].

The process of collecting data and developing biomass relationships falls under the subject of *allometry*, the measure and study of growth or size of a part in relation to an entire organism. West et al. [15] provide a general theory of allometric scaling laws based on fractal networks of branching tubes and Broad [3] gives a theory of multivariate allometry. Normally, biomass data exhibit heteroscedasticity, i.e. the error variance is not constant over all observations. In such instances, weighted regression analysis is used to achieve appropriate parameter estimates.

The process of physically collecting biomass data can be very labor intensive. Direct measurement may be too expensive and time consuming for larger organisms such as trees. The only practical alternative is subsampling (*see* **Sampling, environmental**). Valentine et al. [13] and Gregoire et al. [6] describe two procedures, **randomized branch sampling** and **importance sampling**, for selecting sample paths to obtain unbiased estimates of the biomass content of a tree.

Most biomass inventories consist of two principal phases. In the first phase, a relatively large sample of organisms is selected and measured for characteristics of interest. The organisms are usually in clusters defined in terms of fixed area sample plots. These organisms are not measured for biomass. In the second phase, a relatively small sample of organisms is selected and measured for biomass and for the same characteristics as the first phase sample. The second phase sample is used to develop the biomass regression function(s). The function(s) is (are) then applied to the first phase sample to calculate inventory estimates of average biomass per unit area. When previously constructed biomass regressions are available, the second phase sample is not necessary. Note, however, that this procedure makes the critical assumption that the population for which the regression function was calculated and the population currently being inventoried are comparable. An approach proposed by Cunia [4] can be used to combine the error from the first phase sample plots with the error from the second phase sample. This approach requires that the estimators be of the form

$$\hat{w} = b_1 z_1 + b_2 z_2 + \cdots + b_m z_m = \mathbf{b}'\mathbf{z} \qquad (1)$$

where $\mathbf{b}$ is the coefficient vector from the biomass regression function and $\mathbf{z}$ is a vector of statistics calculated from the data of the sample plots. The variance of $\hat{w}$ is calculated as

$$S_{\hat{w}\hat{w}} = \mathbf{b}'\mathbf{S}_{\mathbf{zz}}\mathbf{b} + \mathbf{z}'\mathbf{S}_{\mathbf{bb}}\mathbf{z} \qquad (2)$$

where $\mathbf{S}_{\mathbf{zz}}$ and $\mathbf{S}_{\mathbf{bb}}$ are the covariance matrices of $\mathbf{z}$ and $\mathbf{b}$. The first term of $S_{\hat{w}\hat{w}}$ is the variance component associated with the error of the sample plots and the second term is the variance component associated with the biomass regression.

Further details on and a review of biomass assessment can be found in Parresol [11], while Kemp et al. [7] cover the important, allied issues of aquatic microbial biomass.

Resources

The Biomass Resource Information Clearinghouse (BRIC) is a clearing house for international biomass information. BRIC can be found on the Internet at `http://rredc.nrel.gov/biomass`. BIOPAK [9] is a menu-driven package of computer programs that calculates the biomass, area, or volume of plant components. It has application in ecosystem studies for calculating biomass allocation, productivity, and leaf area; in wildlife and entomological studies for calculating browse (foliage + small twigs), fruit, and inflorescence mass; and fire management for calculating fuels of live plants by size class. To obtain information and to download BIOPAK see the Internet site `http://www.fsl.orst.edu/lter/data/software/biopak.htm`.

References

[1] BRIC (2000). What is biomass? *Biomass Resource Information Clearinghouse*, National Renewable Energy Laboratory, Golden.

[2] Bridgwater, A.V. & Boocock, D.G.B., eds (1997). *Developments in Thermochemical Biomass Conversion*, 2 Vols. Chapman & Hall, London.

[3] Broad, L.R. (1998). Allometry and growth, *Forest Science* **44**, 458–464.

[4] Cunia, T. (1987). Error of forest inventory estimates: its main components, in *Estimating Tree Biomass*

Regressions and Their Error, Proceedings of the Workshop on Tree Biomass Regression Functions and Their Contribution to the Error of Forest Inventory Estimates, Wharton, E.H. & Cunia T., comps. *General Technical Report NE-GTR-117*. US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, pp. 1–13.

[5] Forman, R.T.T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*, Cambridge University Press, Cambridge.

[6] Gregoire, T.G., Valentine, H.T. & Furnival, G.M. (1995). Sampling methods to estimate foliage and other characteristics of individual trees, *Ecology* **76**, 1181–1194.

[7] Kemp, P.F., Sherr, B.F., Sherr, E.B. & Cole, J.J., eds (1993). *Handbook of Methods in Aquatic Microbial Ecology*, Lewis, Boca Raton.

[8] Levine, J.S., ed. (1996). *Biomass Burning and Global Change*, 2 Vols, MIT Press, Cambridge.

[9] Means, J.E., Hansen, H.A., Koerper, G.J., Alaback, P.B. & Klopsch, M.W. (1994). Software for computing plant biomass – BIOPAK users guide. *General Technical Report PNW-GTR-340*. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland.

[10] Norgren, O., Elfving, B. & Olsson, O. (1995). Non-destructive biomass estimation of tree seedlings using image analysis, *Scandinavian Journal of Forest Research* **10**, 347–352.

[11] Parresol, B.R. (1999). Assessing tree and stand biomass: a review with examples and critical comparisons, *Forest Science* **45**, 573–593.

[12] Society of American Foresters (1999). Measuring forests in 3-d: new sensor helps measure carbon storage, *The Forestry Source* **4**, March.

[13] Valentine, H.T., Tritton, L.M. & Furnival, G.M. (1984). Subsampling trees for biomass, volume, or mineral content, *Forest Science* **30**, 673–681.

[14] Waring, R.H. & Running, S.W. (1998). *Forest Ecosystems: Analysis at Multiple Scales*, 2nd Edition, Academic Press, San Diego.

[15] West, G.B., Brown, J.H. & Enquist, B.J. (1997). A general model for the origin of allometric scaling laws in biology, *Science* **276**, 122–126.

(*See also* **Ecological study design**; **Forest carbon cycling**; **Forest inventory**)

BERNARD R. PARRESOL