colonized in the future. However, forests may die back in warmer regions.

See also: **Ecology**: Human Influences on Tropical Forest Wildlife. **Environment**: Carbon Cycle; Environmental Impacts. **Genetics and Genetic Resources**: Genetic Aspects of Air Pollution and Climate Change. **Mensuration**: Tree-Ring Analysis. **Soil Development and Properties**: Nutrient Cycling. **Tree Physiology**: A Whole Tree Perspective; Forests, Tree Physiology and Climate.

Further Reading

Houghton JT, Ding Y, Griggs DJ, *et al.* (eds) (2001) *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Jarvis PG (1998) *European Forests and Global Change: The Likely Impacts of CO_2 and Temperature*. Cambridge, UK: Cambridge University Press.

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, and White KS (eds) (2001) *Climate Change 2001: impacts, adaptation and vulnerability contribution of working group II to the third assessment report of the intergovernmental panel on climate change*. Cambridge UK: Cambridge University Press.

Saxe H, Cannell MGR, Johnsen Ø, Ryan MG, and Vourlitis G (2001) Tree and forest functioning in response to global warming. *New Phytologist* 149: 369–400.

EXPERIMENTAL METHODS AND ANALYSIS

Contents

Biometric Research

R E McRoberts, US Department of Agriculture Forest Service, St Paul, MN, USA

Published by Elsevier Ltd., 2004

Introduction

Any discussion of research in a scientific field is subject to caveats because research must of necessity be less definitive than a discussion of the field's established operational practices. First, enumerations of current research topics will be dated and subject to the perspective of the enumerator. Second, the foci of research change quickly and are subject to funding and societal priorities, perceptions of issues that demand immediate attention, and technical and technological advances. Finally, research, by definition, indicates that final solutions have not been achieved and that results may only be reported as preliminary or as works in progress. Thus, this assessment of biometric research in forest inventory should be considered a static summary in a rapidly changing discipline.

Given these caveats, current biometric research in forest inventory is focused in three major areas: forest sustainability, data delivery, and spatial estimation. With respect to forest sustainability, regional, national, and international public constituencies seek assessments of the effects on forest resources of forest management practices and environmental changes. Their demands have spawned international working groups and assessment procedures such as the Ministerial Conference on the Protection of Forests in Europe and the Montreal Process for assessing forest sustainability. Further, they have influenced national inventory programs to broaden the scope of data collection to include observation of attributes such as soil, lichens, pollutant-sensitive plant species, and down woody material. With respect to data delivery, inventory clients demand timely and precise estimates of forest attributes, summarizations, and estimates for their own areas of interest, and access to field data for their own analyses and to augment noninventory data. Finally, with respect to spatial estimation, the traditional emphasis of forest inventory has been the production of large-scale estimates of forest attributes such as area, volume, and species distribution and temporal changes in these attributes with the objective of answering the question, 'How much?' Increasingly, however, forest inventory clients are also asking the question, 'Where?' Answering the latter question requires spatial extensions of inventory plot information across the landscape. Thus, this article focuses on three biometric research topics: forest sustainability, data delivery, and spatial estimation. A vision for forest inventory that simultaneously addresses all three topics is also outlined.

Forest Sustainability

Frameworks for Sustainability Assessments

The 1992 Rio Earth Summit produced a statement of forest principles and conventions on biodiversity, climate change, and desertification. It further called upon all nations to manage development in a manner that sustains natural resources. Definitions of forest sustainability generally incorporate three components: (1) a process based on the integration of environmental, economic, and social principles; (2) satisfaction of present environmental, economic, and social needs; and (3) maintenance of forest resources to assure that the needs of future generations are not compromised. In 1993, Canada convened a seminar in Montreal on the topic of sustainable management of boreal and temperate forests. The seminar was sponsored by the Conference on Security and Cooperation in Europe and focused on defining criteria and indicators that can be used to measure progress toward sustainable development of forests. Criteria are categories of conditions or processes by which forest management may be assessed with respect to sustainability, while indicators are measurable aspects of the criteria. Following the Montreal seminar, the European countries opted to work under the framework of the Ministerial Conference on the Protection of Forests in Europe. North and South American, Asian, and Pacific Rim countries initiated a similar effort formally known as the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. Informally known as the Montreal Process, this effort focused on the development and implementation of a set of internationally accepted criteria and indicators. The criteria for both the European and Montreal Process groups are identical, and the indicators for the four criteria that can be directly addressed via forest inventory observations are very similar (**Table 1**).

Traditionally, national forest inventories have emphasized the collection and analysis of individual tree attributes such as species, age, diameter, height, mortality, removal, and regeneration and collective tree attributes such as forest cover type, proportion crown cover, and plantation versus naturally regenerated. Although national inventories collected some nontree information before the early 1990s, the 1992 Rio Earth Summit provided the impetus for the development of sampling designs and estimation procedures for entire suites of information related to the health and sustainability of forest resources. Today, national forest inventories are the primary sources of information for regional, national, and international forest sustainability assessments and reporting requirements.

Designs and Analyses

The collection and analysis of data related to the forest sustainability criteria and indicators present a

Table 1 Categories of European and Montreal Process indicators for forest sustainability criteria

Criterion	*Categories of indicators*	
	Ministerial Conference on the Protection of Forests in Europe	*Montreal Process*
Conservation of biological diversity	Forest area	Forest area
	Tree species composition	Ecosystem diversity
	Landscape pattern	Fragmentation
	Threatened species	Species diversity
	Genetic resources	Genetic diversity
	Regeneration	
Maintenance of productive capacity of forest ecosystems	Roundwood and nonwood production	Area and growing stock available for timber production
	Balance between increment growth and fellings	Removal of timber and nontimber products relative to sustainable levels
	Value of marketed services	Area and growing stock of native and exotic species
	Forest under management plans	
	Air pollutants	Air pollutants
Maintenance of forest ecosystem health and vitality	Defoliation and forest damage	Pests, pathogens, exotic species, damage
	Protective area: soil erosion, water preservation, infrastructure, natural resources	Land managed for protective functions
		Soil erosion, organic matter, compaction, and accumulation of toxic substances
		Water bodies with significant deviation from historic properties

myriad of biometric research challenges. For example, the Forest Inventory and Analysis (FIA) program of the US Forest Service has augmented its sampling efforts to include the collection of information on tree crown condition, tree damage, ozone injury to vegetation, lichen diversity as a biomonitor of pollutant exposure, understory vegetation diversity, soil chemistry and erosion, and down woody material. These variables are sufficiently different that distinct sampling designs are usually necessary, as are separate approaches to estimation. For example, down woody material information is collected from line transects, soil information is collected from soil cores, while tree crown condition, tree damage, and ozone injury to vegetation are visually estimated. The additional biometric challenge is to develop methodology for using this raw inventory data to assess more complex phenomena such as carbon sequestration and forest wildfire risk.

Also, because the greatest proportion of the total cost of measuring an inventory plot is the travel to and from the plot location, the sampling designs for the additional variables must be integrated with sampling designs for the traditional variables, either on the same plots or in close proximity to them. In addition, because of the substantial additional cost of obtaining observations for these variables, the number of plots with the additional observations per unit area is substantially less than for traditional inventory plots; for the FIA program of the US Forest Service, the ratio is approximately 1:16. Thus, in order to relieve analysts and users from having to choose between only moderately precise regional estimates or imprecise estimates for smaller areas, biometric research must focus on developing methods for increasing the precision of estimates of the current status and change in these variables. Finally, sustainability analyses often depend on detection of spatially disparate pest-, pathogen-, or human-induced phenomena and may require risk-based sampling designs and designs constructed to detect rare events. Although inventory plots may be inadequate for detecting such rare phenomena, they are excellent for identifying areas with high probabilities of detecting these events.

In summary, the collection and analyses of data for evaluating forest management practices with respect to sustainability are increasing in priority. Observations of at least some variables necessary for these analyses will require special sampling designs which must be integrated to the greatest extent possible with traditional inventory sampling designs. Biometric research to develop procedures for estimating the current status and change in these variables at meaningful geographic scales for relevant temporal intervals is crucial.

Data Delivery

Internet Access

Because national forest inventories are typically funded by national governments, there are valid arguments for maximizing the utility of inventory data by making it publicly accessible. Internet access is becoming the medium of choice for distributing inventory data to the public, although a variety of constraints may be necessary depending on form of the data to which access is provided. Internet access to tabular summarizations for the same estimation units as is provided in published inventory reports has become routine with few constraints. However, internet access to tabular summarizations for user-defined estimation units requires real-time computations and is more complex. An approach using map-based estimation is discussed in the section on spatial analysis below. Another approach is to select the plots located in the user's estimation unit and then calculate estimates in the same manner as does the inventory program. If inventory programs calculate estimates on the assumption of simply random sampling, this approach is fairly trivial. However, because of budgetary constraints, inventory programs frequently cannot observe enough plots to satisfy precision requirements for many variables under an assumption of simple random sampling unless ancillary data are used to augment the estimation processes. Many programs rely on stratified estimation and use remotely sensed data, particularly classified satellite imagery, as the means of stratifying estimation units. Inventory data users requesting tabular summarizations for their own estimation units often wish to increase the precision of their estimates by using the same stratifications developed by the inventory programs. However, land cover classifications based on even medium-resolution satellite imagery (e.g., 30×30 m Landsat thematic mapper imagery) require storage of and access to such large amounts of data that real-time estimation may be severely retarded. One solution is to provide users with summarizations of stratifications for geographic units of predetermined size and configuration. Two approaches are then possible. Either the boundaries of the user's estimation unit are forced to conform to the boundaries of the stratification summary units or the user's estimation unit is used with the stratification summaries for units that do not conform to the user's estimation unit. In the first case, an approximated user's estimation unit is used with the actual stratifications, and in the second case, the actual user's estimation unit is used with an approximated stratification. The research challenge is to select the size of the stratification summarization unit that minimizes the effects of the compromises. This problem may, of course, disappear as storage space and real-time processing speed increase, although it may also be exacerbated as classifications of finer-resolution satellite imagery are used for stratification.

Plot Integrity and Data Privacy

Inventory users often request access to raw inventory data rather than tabular summarizations, frequently for purposes of combining it with noninventory data such as satellite imagery for their own analyses. For example, researchers seek inventory observations for use as training or validation data for classifying satellite imagery or for map validation. For these applications, the exact coordinates of plot locations are usually necessary, either to associate field observations with satellite image pixels or to compare them with map predictions. Although inventory programs release plot information to the public, they generally resist releasing actual plot locations. First, release of plot locations may entice users to visit plot locations to obtain additional information which could result in artificial disturbance of the ecology of the sites and, in turn, induce bias in the inventory estimates. Second, forest inventory programs rely on the goodwill of private forest landowners for permission to observe plots on their land. Landowners generally do not welcome unwarranted or frequent intrusions and often only permit visits by inventory crews contingent on assurances that the plot locations and proprietary information will not be released.

Accommodating users' desires for the greatest utility and distribution of inventory data while simultaneously protecting the ecological integrity of inventory plot locations, preventing unwarranted intrusions on private land, and protecting the proprietary nature of information obtained from plots on private lands have emerged as crucial issues. Two measures have been considered: creating uncertainty in plot locations and creating uncertainty in the ownership of plots on private land. Creating uncertainty in plot locations discourages users from attempting to visit the plots, thus protecting them from artificial disturbance and protecting the landowner from unwarranted intrusions. This measure entails releasing to the public coordinates for plots that are known only to fall within a circle of area A centered at the actual plot location. Creating uncertainty in the ownership of plots on private land protects private landowners from unwarranted disclosure of proprietary information. This measure entails swapping observations between plots on private land. Plots on private land are first grouped into similarity pools with respect to criteria that are stable over time and retain as much utility of the data after swapping as possible, and then information for a proportion of plots within similarity pools is exchanged. Potential criteria for forming similarity pools include spatial location, site characteristics, and perhaps broad forest cover types. When creating uncertainty in plot locations, the area, A, of the circle containing the actual plot location is revealed to the public, although the center of the circle is not revealed. When creating uncertainty in plot ownership, the similarity criteria may be revealed to the public, but neither the swapping proportion nor the plots with swapped observations are revealed.

Although creating uncertainty in the locations and ownerships of plots satisfies the plot integrity, privacy, and nondisclosure requirements, there remain biometric research challenges. Knowing that inventory programs do not release the actual coordinates of plot locations, users often submit maps or satellite image classifications and request that the inventory program validate these spatial products by providing the map or classification categories for locations corresponding to inventory plots. If aggregated summaries of the results for large numbers of plots suffice, then no plot integrity or disclosure requirements are violated. However, if results for individual plots are required, then challenges arise. If the circle of area A is not wholly contained within a single map or classification category, then revealing the map category for an individual plot reduces the uncertainty in the plot location to an area of size less than A.

Users also request that inventory programs assist in satellite image classification efforts by appending the spectral values of satellite image pixels associated with actual plot locations to the inventory data for the plot. Technically, this does not require that actual plot locations be revealed to the user. However, even for medium-resolution satellite imagery, combinations of spectral values are sufficiently unique that the total area of pixels with the same spectral values as the pixel containing the actual plot location is often less than A. In addition, with two or more dates of Landsat thematic mapper imagery for the same scene (i.e., 12–14 spectral bands of data), it is not uncommon for the combination of spectral values for a single pixel to be unique, in which case revealing the spectral values for a pixel associated with a plot also reveals the plot location to within the 30×30 m resolution of the imagery.

The biometric research challenge is to assure compliance with plot integrity, privacy, and nondisclosure requirements while minimizing the area, A, of the circle containing the actual plot location, selecting similarity criteria that retain maximum utility of the swapped data, and minimizing the swapping proportion. Global selections for these parameters are unlikely. First, for areas in which ownership is fragmented into parcels of area less than *A*, creating uncertainty in plot locations may also create sufficient uncertainty in plot ownership. In this case, swapping is unnecessary and would serve only to degrade further the utility of the inventory data. Second, the criteria for establishing similarity pools will differ by region. For example, in mountainous areas, elevation may be an important similarity measure because of its high correlation with species composition, whereas in other regions elevation may be of little use.

In summary, timely delivery of inventory data and data summaries in a variety of formats for a variety of users for a variety of purposes has become mandatory. The biometric research challenge is to do so in the most timely and user-friendly manner that preserves the utility of the data while simultaneously accommodating integrity, privacy, and disclosure requirements.

Spatial Analyses

Traditionally, forest inventory has relied on sample-based estimation methods and has emphasized plot configurations and sample designs that produce efficient and precise estimates of tree-based forest attributes for large areas. Increasingly, however, inventory clients request resource estimates for small areas and estimates of the spatial distribution of the resource. Thus, two related research topics have emerged. First, maps of forest attributes that fill the spatial gaps between plot locations are required, and second, procedures for precisely estimating attributes for small areas are necessary. The challenges associated with both topics require innovative approaches for combining inventory plot data with ancillary data, particularly satellite imagery.

Maps

Mapping forest attributes observed on inventory plots inevitably requires a data source that can function as a bridge between arbitrary mapping units and mapping units containing inventory plots. Satellite imagery is emerging as the bridging data source of preference, although approaches to constructing the bridge depend on the image pixel size relative to the size of inventory plots. When the image pixel size is much greater than the plot size, then the approach is to associate the spectral values of groups of pixels containing inventory plots with aggregated information for groups of inventory plots. When the image pixel size is comparable to the plot size, then plots may be associated in one-to-one relationships with pixels and a variety of classification techniques, including maximum likelihood, regression, and nearest neighbors techniques, may be used. The cost of imagery with pixel sizes orders of magnitude smaller than plot size is generally beyond the budget constraints of national inventory programs, so use of this imagery is not discussed further.

Map-based estimation Maps of forest attributes could simultaneously resolve data access and estimation issues. Estimation using maps requires the uncertainty of predictions for individual mapping units, but these quantities may usually be estimated in conjunction with mapping operation. If the satellite image pixel size is of the same order of magnitude as the inventory plot size, then models of the relationship between plot-level aggregations of inventory observations and spectral values of pixels may be formulated, and inventory plot attributes may be predicted for each image pixel using the spectral values as predictors. When using regression to estimate the parameters of a model with statistical expectation described by a function $f(\mathbf{X};\beta)$, where $\mathbf{X}$ is a vector of image spectral values and β is a vector of parameters to be estimated, the variance of a prediction for an individual pixel is approximated by:

$$\mathrm{Var}(\hat{Y}_i) = \left[\frac{\partial f}{\partial \beta}(X_i)\right]' V^{-1} \left[\frac{\partial f}{\partial \beta}(X_i)\right] + \sigma_\varepsilon^2$$

where σ_ε^2 is the variability of observations around model predictions, and V^{-1} is the covariance matrix of the model parameters where the components of V are given by:

$$v_{ij} = \sum_{k=1}^{n} \left[\frac{\partial f}{\partial \beta_i}(X_k)\right] \left[\frac{\partial f}{\partial \beta_j}(X_k)\right]$$

and where k indexes observations. Thus, the estimate, $\hat{Y}_{\mathrm{tot}}$, for the total of an attribute (e.g., volume, forest area, biomass) for a user estimation unit and the variance of the estimate, $\mathrm{Var}(\hat{Y}_{\mathrm{tot}})$, are provided by:

$$\hat{Y}_{\mathrm{tot}} = \sum_{i=1}^{N} \hat{Y}_i$$

and:

$$\begin{aligned}\mathrm{Var}(\hat{Y}_{\mathrm{tot}}) &= \mathrm{Var}\left(\sum_{i=1}^{N} \hat{Y}_i\right) \\ &= \left\{\sum_{i=1}^{N}\sum_{j=1}^{N}\left[\frac{\partial f}{\partial \beta}(X_i)\right] V^{-1} \left[\frac{\partial f}{\partial \beta}(X_j)\right]'\right\} \\ &\quad + \left[\sum_{i=1}^{N}\sum_{j=1}^{N}\mathrm{Cov}(\varepsilon_i, \varepsilon_j)\right]\end{aligned}$$

where i now indexes image pixels, of which N is the total number. A crucial issue is whether the estimate of $\mathrm{Var}(\hat{Y}_{\text{tot}})$ is larger when obtained from the map or when obtained directly from the plot observations using estimations based on simple random sampling or stratified estimation. The trade-off will be between the small number, n, of plot observations, assumed to be with little or no measurement error, and the large number, N, of mapping unit predictions, each with nonzero prediction uncertainty. If the variance estimate obtained from the map is as small or smaller, then user requests for estimates may be satisfied directly from the map, do not require direct access to plot data, and alleviate concerns about ownership because predictions for individual pixels do not disclose proprietary information. In addition, if the predictions for individual pixels are unbiased, then estimates may be obtained for small areas in which there may be no plots or there may not be enough plots per stratum for stratified estimation.

The spatial challenge to biometric researchers is to construct maps depicting the distribution of forest resources that not only answer the user question, 'Where?' but that also facilitate unbiased and precise estimation for both large and small areas. Research on mapping and map-based estimation of forest attributes is also of considerable interest to environmental scientists wishing to relate the status and change in forest resources to climatic, soil, and other environmental spatial data and to forest industry planners wishing to plan roads and select mill locations.

A Vision for Forestry Inventory Estimation

A visionary objective of an inventory program is to associate a tree list, or an aggregation of several tree lists, with each mapping unit. The map will be constructed by imputing to each mapping unit the entire suite of observations from inventory plots associated with similar mapping units. Inventory estimates will be derived from the map rather than from plot observations using sample-based methods, because the former method produces more precise estimates. Further, appropriate correlations among map-based predictions of forest attributes are preserved because entire suites of observations are imputed simultaneously. As with the model-based approach to estimation discussed in the section on spatial analyses, realization of the vision dispenses with many plot integrity, privacy, and disclosure issues.

Realization of the vision requires two crucial components: an adequate data source for bridging the gap between arbitrary mapping units and mapping units containing inventory plots, and an analytical tool that uses the bridging data to impute simultaneously to mapping units all attributes observed on inventory plots. Although a variety of spatial products including soil, climatic, and digital elevation maps may support and enhance the bridging function, the key data source will likely be satellite imagery and will further likely include imagery from active sensors that penetrate the forest canopy. Among the candidate analytical tools, the nonparametric k-nearest neighbors (k-NN) imputation technique popularized by the Finnish National Forest Inventory merits serious consideration.

The *k*-Nearest Neighbors (*k*-NN) Approach

With the k-NN approach, for an arbitrary mapping unit, u_i, the set of mapping units, $\{u_j\}$, associated with inventory plots is ordered with respect to the distance, d_{ij}, between u_i and each u_j. Distances are calculated using variables, X, common to all mapping units. A variety of distance measures, including unweighted and weighted Euclidean distance and Mahalonobis distance, are possible. For example, the weighted Euclidean distance, d_{ij}, between u_i and u_j is calculated as:

$$d_{ij} = \sqrt{\sum_{m=1}^{M} v_m (X_{mi} - X_{mj})^2}$$

where m indexes the variables, X, used to calculate distance, M is the number of variables, and v_m is the relative weight assigned to each variable. The value of the attribute imputed to mapping u_i is calculated as:

$$\hat{Y}_i = \frac{1}{k\left(\sum_{j=1}^{k} w_{ij}\right)} \sum_{j=1}^{k} w_{ij} Y_{ij}$$

where k is the number of nearest neighbors selected, the summations are over the k neighbors closest to u_i with respect to the distance measure, and w_{ij} is the weight assigned to each nearest neighbor in the estimation process. Common selections for w_{ij} include $w_{ij} = 1$, $w_{ij} = d_{ij}^{-1}$, and $w_{ij} = d_{ij}^{-2}$. Calibration of the k-NN approach requires selections for the distance measure, the variables used to calculate distance, variable and nearest-neighbor weighting schemes, and k. Calibration selections are often based on minimizing a criterion such as mean square residual or maximizing a criterion such as proportion correctly classified using a leaving-one-out cross-validation approach.

Several research challenges are associated with operationally implementing the k-NN technique. First, not all aspects of k-NN estimation are intuitive.

Selection of variables for calculating distances between mapping units that are unrelated to the attribute to be estimated may have a detrimental effect on the calibration criterion. Also, selection of a value of k that is too small may result in values of residual mean square that are greater than if the overall mean had been used as the imputation for each mapping unit. Second, implementing the k-NN technique requires all mapping units $\{u_j\}$ containing inventory plots to be ordered with respect to distance separately for each mapping unit for which an imputation is to be calculated. If $\{u_j\}$ is a large set, then the ordering process may require large amounts of time. In addition, calibration may be a trial-and-error process requiring testing all combinations of values of k, distance variables, and weighting schemes to identify the particular combination that optimizes the calibration criterion. Third, defensible approaches to estimation of uncertainty have not been fully developed.

The future of forest inventory, today as it has been in the past, is to deliver more timely, more precise, more comprehensive inventory data and estimates to more users in more formats with less cost. The near-term solution is to provide internet access to spatial products that simultaneously depict entire suites of forest attributes across landscapes and that permit unbiased and precise estimation of those attributes for both large and small user-defined areas of interest. Although certainly nontrivial, imputing tree lists to individual mapping units would not only lead to realization of this vision but would also greatly facilitate compliance with plot integrity, privacy, and disclosure requirements.

Summary

The biometric research challenges in forest inventory are many, vary by program, and change over time. Research challenges were discussed in three topic areas: forest sustainability, data delivery, and spatial estimation. In the area of forest sustainability, the challenges are to integrate sampling designs for variables providing information on the health of the forest with traditional inventory sampling designs and to develop estimation methods that permit precise estimates for temporal trends in the variables using data from a sparse spatial array of plots. In the area of data delivery, the challenge is to provide users access to the greatest amount of data in a form with the greatest utility while satisfying plot integrity, privacy, and disclosure requirements. In the area of spatial estimation, the challenge is to construct maps of forest attributes that depict their spatial distribution and that permit precise estimation for small areas. The challenges are interdependent and will continue for the foreseeable future, although the approaches to addressing them will undoubtedly change.

See also: **Biodiversity**: Biodiversity in Forests. **Experimental Methods and Analysis**: Statistical Methods (Mathematics and Computers). **Inventory**: Modeling; Multipurpose Resource Inventories. **Landscape and Planning**: Spatial Information. **Mensuration**: Forest Measurements. **Resource Assessment**: Forest Change; GIS and Remote Sensing; Non-timber Forest Resources and Products.

Further Reading

Anonymous (1997) *Canada's Report on the Montreal Process: Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests.* Ottawa, Canada: Montreal Process Liaison Office.

Csoka P (1997) *Interim Report on the Implementation of Resolution H3 of the Helsinki Ministerial Conference on the Protection of Forests in Europe: Results of the Second Inquiry.* New York: United Nations.

Franklin SE (2001) *Remote Sensing for Sustainable Forest Management*. New York: Lewis.

Iles K (2003) *A Sample of Inventory Topics – A Practical Discussion for Resource Samplers on Forest Inventory Techniques*. Nanaimo, Canada: Kim Iles.

McRoberts RE, Nelson MD, and Wendt DG (2002) Stratified estimation of forest area using satellite imagery, inventory data, and the k-nearest neighbors technique. *Remote Sensing of Environment* 82: 457–468.

Tomppo E (1991) Satellite imagery-based national forest inventory of Finland. *International Archives of Photogrammetry and Remote Sensing* 17: 2333–2351.

Design, Performance and Evaluation of Experiments

V LeMay, University of British Columbia, Vancouver, BC, Canada
A Robinson, University of Idaho, Moscow, ID, USA

Introduction

Experimental design is similar to sampling and inventory design in that information about forest variables is gathered and analyzed. However, experiments presuppose intervention through applying a treatment (an action or absence of an action) to a unit, called the experimental unit. The goal is to obtain results that indicate cause and effect.

For each experimental unit, measures of the variables of interest (i.e., response or dependent