

Forest Measurement and Biometrics in Forest Management: Status and Future Needs of the Pacific Northwest USA

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Forest measurement and biometrics (FMB) programs have been at the heart of forestry education in North America since its beginnings at the Biltmore Forest School more than 100 years ago. Over the intervening period, the field of forestry has changed in critical ways. There are many forest management and policy issues that, at first glance, do not appear to involve FMB but which, on further examination, are found to be closely linked. In this regard, FMB has both an “inside” and “outside.” The outside part faces interactions with its clients and front-line sciences (e.g., forest ecology, silviculture, etc.) which bring new data-analytic ideas to FMB. The clients and professionals in these allied sciences need solutions to pressing quantitative questions. The inside face relates to the need to extend the structure of statistical inference, integrate emerging technologies, and adapt mathematical and statistical precepts to FMB needs. In this essay, we provide a brief overview of the current diversity of FMB applications using examples from business, policy analysis, and ecosystem and landscape analysis; offer our views on the most critical challenges facing FMB researchers and practitioners in the 21st Century; and outline ways how FMB professionals and academic forestry programs might cooperate to meet these challenges. We assert that FMB needs to be responsive to contemporary resource management challenges and address the many land management challenges in the Pacific Northwest and around the world.

Keywords: forest measurement and biometrics, decision-support, landscape level analysis, quantifying timber and nontimber resources

Forest measurement and biometrics (FMB) programs have been at the heart of forestry education in North America since its beginnings at the Biltmore Forest School more than 100 years ago. Over the intervening period, the field of forestry has changed in critical ways. It has evolved to embrace a much broader view of the goals for forest management: more types of forest outputs are important, not just timber. In addition, it has become increasingly quantitative in its approaches to research and management. Rising forest values increase the demand for accuracy and precision in quantitative approaches for management prescriptions and projected outcomes, necessitating quantitative approaches. Both trends have magnified the importance of FMB as tools of forestry science. Forest measurement focuses on collecting, summarizing, and analyzing information at tree, stand, and forest levels. Forest biometrics ap-

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plies mathematics and statistics to efficiently analyze and quantify past, present, and future attributes at all three levels. FMB offers valuable information for decisionmaking because it provides quantitative measures of current resources, means to compare differences between alternative experimental resource treatments, and methods to project future outcomes of management practices.

This essay provides a brief overview of the current diversity of FMB applications using examples from business, policy analysis, and ecosystems studies. The second section gives our views on the most critical challenges facing FMB researchers and practitioners based on resource decisionmaking needs. A third section offers comments on how we think FMB professionals and academic forestry programs might cooperate in meeting these challenges.

Some State-of-the-Art Applications of FMB in Forestry

To illustrate the sophistication and complexity of current FMB applications in modern forestry practice, we consider three examples: large-scale inventory and monitoring issues in corporate forestry, public policy analysis, and ecosystem and landscape analysis.

Corporate—Large-Scale Inventory and Monitoring Issues. Corporate forestland owners do business in an intensely competitive environment. Demands for profitability and adherence to standards and regulations require timely, accurate, and precise information about the entire forest resource under management. Recent trends in the growth of timber investment management options (TIMOs) and real estate investment trust (REIT), with needs to monitor and verify progress on relatively short-duration investment plans, have accentuated these needs. This information must be collected and analyzed in an increasingly efficient manner. Emerging technologies such as Light Detection and Ranging (LiDAR) offer unprecedented opportunities to reshape the delivery of this information. The importance of FMB in embracing these new technologies and providing the business-critical data required to remain competitive has never been greater. Corporations need to respond by encouraging graduate-level training in FMB, cosponsoring research into FMB methods and technologies, and collaborating with solution

providers to develop comprehensive planning tools.

The rapid emergence of quantitative tools for forest inventory, management, and planning (e.g., geographic information systems [GIS]) has created a knowledge gap between the technologies and their cost-effective application for large-scale inventory and monitoring. Corporations are in a unique position to provide insights on information needs to use these technologies successfully. Cosponsoring research to provide this information not only advances the field and trains new scientists, but also yields results that directly affect a company's profitability.

Solution providers (companies that develop and market hardware and software technologies) often take the lead in integrating new tools and techniques to meet challenges faced in large-scale inventory and monitoring. Collaboration with these providers can give FMB scientists access to their findings and resources. Such access is critical to sustained, relevant research into today's inventory and monitoring problems. As an example, Stand Management, Hardwood, Genetics Cooperatives, as well as consulting firms, users group, and private growth modelers have integrated forest growth models, developed by both university and federal researchers, into their planning tools. Gathering information on the obstacles overcome in the integration process, model performance under comprehensive use, and discovery of missing model features is invaluable in formulating new research strategies targeting identifiable needs.

Public Policy Analysis—Restoration Thinning and Fire Hazard Reduction. Growing public concern for fire losses at the wildland–urban interface has spawned federal legislation (Healthy Forests Restoration Act of 2003) and an array of proposals for the use of mechanical thinning and other practices to reduce fuel hazards and increase vigor and growth of public forestlands in all regions. Analysis of these options for policy decisions entails extensive application of FMB tools: periodic inventory plots, estimation of the volumes of material to be removed, projection of growth and yield under various treatment regimes, and prediction of fire behavior characteristics across a landscape based on stand components. Tradeoffs between different treatment approaches need to be analyzed, especially at the landscape scale. Three examples illustrate these applications.

Hummel and Calkins (2005) recently examined the seemingly competing goals of fire hazard reduction treatments and maintenance of late-seral stage structure on a forest reserve near Mount Adams in the state of Washington. Based on growth projections, they concluded that more aggressive thinning would offer the greatest reduction in fire hazard across the landscape while ensuring that the current level of late-seral stage structure would be maintained. In a second instance, Adams and Latta (2005) examined the regional timber harvest and price impacts of restoration thinning programs applied broadly to national forestlands in eastern Oregon. Using plot-level models, they project harvest, growth, and inventory on private lands in the region and illustrate how these measures would vary under different forms of restoration thinning programs on public lands. Abt and Prestemon (2006) describe a roughly similar approach at a west-wide scale.

Ecosystem and Landscape Analysis. Historically, foresters have focused on managing individual stands. This orientation arose partly because the stand was the traditional operational unit of forest management but also because of the difficulty of projecting multiple resource values at the landscape level. Modern FMB methods, models, and statistical tools have greatly reduced these limitations, allowing for simultaneous analysis of many resource values at the landscape level. This has enabled application of high-capacity optimization methods (e.g., heuristic schemes such as tabu search, simulated annealing, and genetic algorithms) to solve multivariate landscape optimization problems that were intractable 20 years ago (e.g., Bettinger et al. [1997, 1999]). Ongoing cooperative work between Oregon State University and the Oregon Department of Forestry provides an example of the utilization of multiple aspects of FMB in problem formulation and analysis: forest inventory of stands, spatial overlays of the road and stream network on the stand location map in three dimensions (GIS), projection of forest growth by treatment alternative for each stand over time, spatial quantification of wildlife habitat structure, and quantification of constraints imposed by the Oregon Forest Practices Act and by federal regulations (Oregon Department of Forestry 2001). Using these inputs, an optimization process efficiently searches for the best mix of management alternatives over the landscape that maximizes present net

worth, while meeting necessary habitat and riparian protection constraints over time.

A second example of FMB applications in landscape management planning is the Cissel et al. (1999) study of the Blue River watershed in the Cascade Range in Oregon. Cissel's team examined landscape-level alternatives to the federally mandated Northwest Forest Plan (NWFP). Like the previous example, this management area also had goals of future landscape structures that provide desired plant and wildlife habitat, watershed protection, and timber production, all in a socially acceptable manner. Rather than fragmenting both the management and the landscape by imposing the default NWFP stream buffer widths and corridors throughout the entire riparian system, Cissel's team formed contiguous landscape blocks of 20–150 ha (based on landform and disturbance risk) as the basic management units. When contrasted with the stand-level prescriptions of the NWFP after 200-year projections, the landscape approach resulted in a strikingly different and considerably less fragmented landscape, especially with respect to aquatic reserves and timber harvest. Furthermore, long-term goals were met. Such a study would have been impossible without two key elements: (1) a comprehensive basic resource inventory and (2) FMB models of vegetation and other resource responses to management that recognize interactions across resources and across spatial scales from stand to landscape.

Critical FMB Challenges

Forest resource management in all parts of the world is faced with a myriad of increasingly complex decision problems. Many fields of science contribute methods and data that aid in examining these decisions. In the short term, information can be assimilated qualitatively, but qualitative and quantitative estimates and projections are clearly desirable and defensible in the long term because of their replicability. This recognition offers FMB professionals both a challenge to continue developing tools useful in the analysis of large and highly integrated systems and an opportunity to grow as a partner with other disciplines in the land-management decision areas. In our view, some of the most significant challenges facing FMB professionals in the 21st Century include the following:

- Improving stochastic modeling and validation at a range of spatial scales.

- Quantifying nontimber resources and environmental impacts, including wildlife, aquatic resources, biodiversity, landslide, and various hazards.

- Developing flexible and comprehensive methods that are user-friendly.

- Providing tailored products for specific uses.

- Geospatial analysis.

Improving Stochastic Modeling and Validation at a Range of Spatial Scales.

Deterministic analysis can not portray the variability of outcomes that is a fundamental characteristic of natural systems and critical for most emerging forest policy issues (e.g., carbon accounting, quantifying fire risk, or even determining if a silvicultural treatment is significantly different from the control). Experiments on small and large scales combined with short and long time periods are needed to mimic temporal and spatial variability and answer large-scale inference problems. FMB has a role in quantifying and incorporating variability and error distributions to expand the scope of inference, elucidating the analysis, and validating results (or projections) to meet these challenges.

Quantifying Nontimber Resources and Environmental Impacts. Increasingly, FMB plays a significant role in providing critical information to forest resource management and policy decisionmaking by quantifying characteristics of nontimber resources such as wildlife habitat and the distribution and frequency of threatened species. Although some of these attributes have been classified as qualitative rather than quantitative, future long-term decisions based on quantitative estimates and projections are clearly desirable and necessary. Moreover, spatial analysis of habitat capability generally dictates the use of quantitative methods. Two examples illustrate this point:

1. Forest resource planning processes in the western United States have been placing an increasing emphasis on wildlife and fish habitat goals. With this in mind, Bettinger et al. (1999) developed a method that incorporates a Habitat Effectiveness Index for Roosevelt elk into the objective function of a mathematical forest planning model. The main contribution of this approach is the ability to measure and evaluate the tradeoffs between achieving a certain level of a complex wildlife goal and commodity production goals.

2. Basic forest measurement techniques such as line intersect sampling have proven to be valuable for many types of habitat analysis and monitoring. Line intersect sampling has been a favored method for analyzing both population levels (e.g., marbled murrelet) and habitat biodiversity (e.g., for waterfowl).

Additionally, FMB methods provide approaches to quantify habitat suitability for many endangered species. In the Pacific Northwest (PNW), this pertains to primary factors that can affect endangered species: breeding, feeding, and cover. FMB offers methods that consider these factors in quantifying habitat quality.

Developing Flexible and Comprehensive Methods. Integration of advanced technology and conventional mensurational techniques is critical in meeting contemporary requirements for monitoring, evaluation, reporting, verification, certification, and carbon accounting. This integration needs to include spatial and temporal information to describe and interpret vegetation layers, succession, and trends such as climate change.

In thinking about sustainable resource management over the long term, there is a need to integrate various scales of physiological processes, stand- and landscape-level dynamics, and policy and socioeconomic issues. To achieve desired goals and to meet reporting requirements, advances in updating and maintaining inventory information at varying temporal and spatial scales are required. This includes data acquisition and analysis procedures. Recent years also have brought masses of new resource observations through media such as LiDAR (e.g., Reutebuch et al. [2005]) and satellite imagery and the need to seamlessly link these data via GIS at multiple scales. Data also need to be consistent and nearly complete. This requires the strengths of FMB methodology such as forest inventory, remote sensing, GIS, and imputation methods to fill in missing values.

Because of increasing activities in land transactions (merger and acquisitions, land transfer, and trades), the need for accurate information on site quality and long-term valuation is increasing. There is a new sense of urgency caused by rapid ownership changes (e.g., conversion of integrated industrial forestland to TIMOs and REITs), changing market conditions and investment strategies, and monitoring and reporting needs.

Providing Tailored Products for Specific Uses. FMB will play a vital role in providing quantitative estimates of output for newly developing nontraditional forest products such as woody biomass and carbon. Previously a European endeavor, woody biomass plantations now have been established in many areas of the PNW using fast-growing species and hybrids. Despite their growing popularity, there are few suitable biomass volume and weight equations for use by producers and industries. Numerous researchers have argued that there are many uncertainties that exist in large-scale biomass estimation such as measurable tree characteristics, variation in stand densities, species composition, past management practices, and genetic variation. Further development of accurate generalized biomass equations will require extensive data analysis of biomass for species and varieties from many different regions of the United States.

Questions abound in current forest management debates related to wildland fire risk-reduction treatments and opportunities to use wood removals to recover cost of treatments (Adams and Latta 2005). The plethora of small-diameter material eligible for thinning compounds the problem (Calkin and Gebert 2006). FMB methods (forest inventory and growth modeling) are needed to provide input to such regional management problems.

One tool currently under development is the use of hybrid models to merge traditional stand growth projection with process models to meet industry needs for wood quality assessment and biomass estimation. Mechanistic crown models that grow (and keep track of) individual branches throughout the crown have the potential to provide detailed information on knot size and location along the stem, which is related directly to wood quality and lumber grade. Other recent developments are the uses of acoustic velocity (Briggs 2005 and Carter et al. 2005) and stress wave (Wang et al. 2001) methods to nondestructively test wood products and standing trees for stiffness, strength, and elasticity. For these and other developments, FMB methods are essential to solving such multidisciplinary problems, which in this case involves tree physiology, tree growth modeling, and wood quality and use.

Geospatial Analysis. Although the use of GIS technology represents a considerable reduction in the historical limitations of projecting multiple resource values at the landscape level, geospatial information sys-

tems (focusing on spatial statistics) are an area that has previously been either overlooked or effectively untapped with regard to widespread landscape analysis. For example, several chapters of a recently released research synthesis in PNW have identified this problem (e.g., Marcot and Molina [2006]). One very useful application of spatial statistics is spatial interpolation. These are methods by which landscape and topographical data can be estimated in areas where no relevant data has been collected by using nearby data from samples (usually taken at stand level). This is different from standard statistical interpolation in that it takes into account different landscape level variables such as topography, distance, and changes in elevation across the landscape and can use these variables as covariates to create accurate interpolated data. The machinery for this type of geospatial analysis has been in place for some time. However, many forestry professionals lack the statistical knowledge and the GIS background needed to make geospatial analyses of this type commonplace.

This represents an opportunity for FMB to provide assistance and education with regard to geospatial analysis. The primary benefit of this is that when using geospatial analyses, site-based sample data can be used to create a much broader inference than would otherwise be possible. The most common alternative to this would be to collect more samples or, in a forest landscape setting, to sample more intensively, which can be time-consuming and very costly. In addition to its inferential benefits, geospatial analysis can be a useful tool in initially designing a forest sample to fit the desired scope of inference for a particular forest landscape. The accuracy and precision of spatial interpolation, e.g., is highly dependent on the information that is available from which to build the geospatial analysis. Identifying the preferred methods of spatial analysis beforehand can greatly aid in developing a sampling design for the landscape in question that will maximize the precision of the landscape-level inference.

FMB Practice, Research, and Education

Collaborative User-Researcher Projects.

The needs of industry for talented individuals are not very different from those of public research organizations such as the USDA Forest Service Research (FSR) Stations. Both need a

steady influx of highly qualified FMB experts that can creatively tackle the management challenges of the future. FSR likewise uses collaboration across a wide variety of partners to meet specific research goals. Regarding support of graduate students, FSR commonly uses Joint Venture Agreements to fund specific research projects through universities. The goal is not the direct education of a candidate or the completion of a degree; rather, a sound education is obtained as a matter of course while completing the joint research project in cooperation with the major professor and the sponsoring FSR scientists. The goal is new knowledge that fills a specific knowledge gap, and all parties benefit.

Linking FMB and Decision Sciences.

Although FMB traditionally has been a less visible component of forest management and planning, it is directly linked to the decision sciences such as policy, economics, and planning. In economic decisions, e.g., FMB plays an integral part in providing the most accurate information possible for forest attributes in the current inventory and in future projections. FMB is also playing an increasingly important role in providing new ways to quantify qualitative information so that it can be more effectively drawn into the decision process.

FMB can be even more closely linked to business decisionmaking. The vitality of forestry businesses is dependent on the accuracy of quantitative information pertaining to direct action taken by the company. Many forestry businesses have in-house biometricians who analyze data that are vital to the success or failure of proposed ventures. This is a case in which the consequences of the performance of an FMB specialist can be directly felt by both the specialist and the employer.

FMB Programs at Higher Education

Institutions. Although the face of forestry has changed dramatically through the years, FMB is as important as ever. Despite the many subdisciplines in forestry (e.g., silviculture, ecology, genetics, tree physiology, and wood technology), there are numerous common threads of methods or data that allow FMB to link, contribute, learn, and broaden the opportunities in a multidisciplinary manner. In doing so, FMB contributes to both undergraduate and graduate teaching and broadens the scope of both research questions and multidisciplinary analyses.

The need for FMB programs at higher learning institutions stems jointly from the development of innovations in forest re-

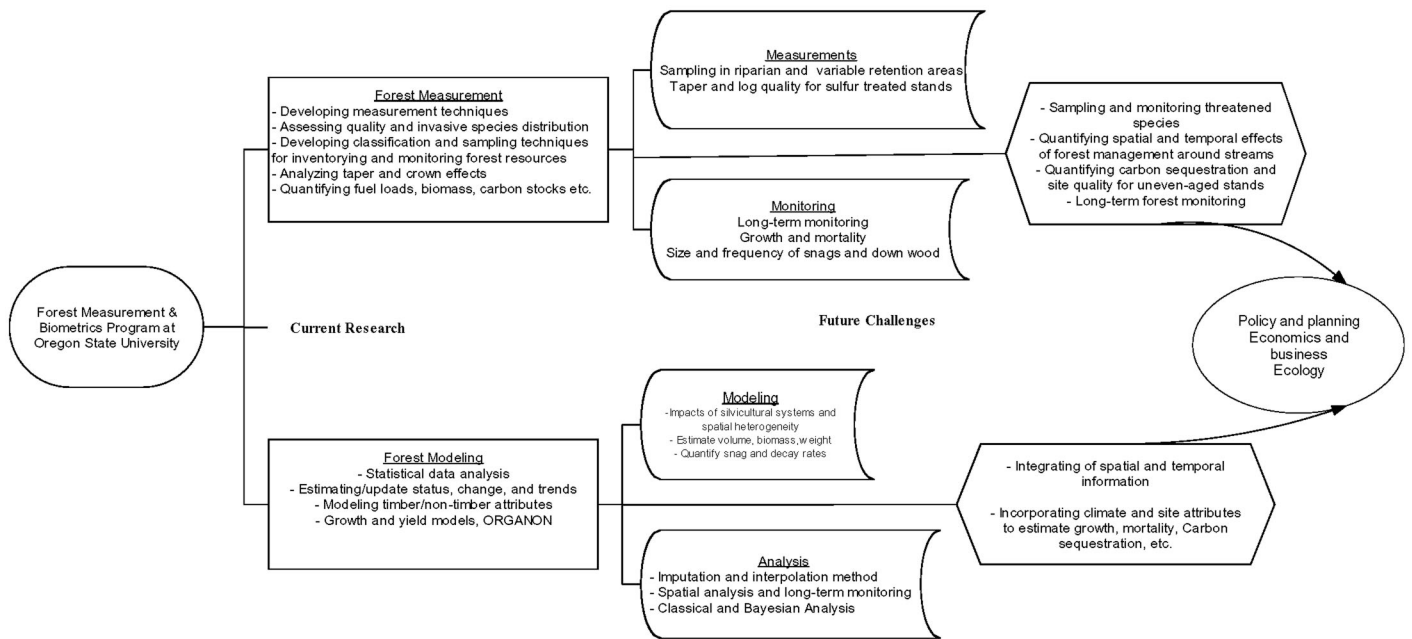


Figure 1. FMB program at Oregon State University.

source management and the ongoing evolution of existing strategies in forest management and decisionmaking. One pertinent issue is the decrease of trained professionals at the federal, state, and private levels. As the “baby boom” generation continues to retire, many agencies are experiencing a sharp decrease of staff trained and experienced in FMB. This represents not only a lack of personnel to work on existing research, but also a shortage of new research ideas during a time when the need for improved methods of forest analysis is greatest. Therefore, there is need for better integration (perhaps automation) of spatial and temporal information.

The 2002 National Capacity in Forest Research (National Research Council 2002) reported stability in numbers of advanced degree awards in forest science in recent years. Unfortunately, forest mensuration was second only to urban forestry in having the fewest students enrolled. Sustained support for the development of students in the quantitative fields of mensuration and biometrics can play an important role in bolstering undergraduate and graduate numbers and future employees. Internships, sponsored graduate research programs, and participation in university–industry research cooperatives are time-tested avenues to support graduate student development. Directing these efforts toward FMB study areas is an effective method to build FMB capacity.

One of the primary sources of FMB education in the PNW is the College of Forestry at Oregon State University. Currently, in the Forest Resources Department, FMB programs are organized into two major categories: forest measurement and forest modeling (Figure 1). The forest management program focuses on familiarizing students with forest measurement techniques and equipment, while providing a background in forest inventory analysis, log grading, and general analyses for forest composition. Students that specialize in forest management begin their education in forest measurement as undergraduates with an intense mensuration course designed to provide them with the knowledge of measurement techniques and equipment that they would need to work for a resource management agency or a private company or a nonprofit organization. The forest modeling program focuses on more advanced statistical analyses of inventory data and modeling of various forest attributes such as tree size, tree vigor, and competitive status. Both programs are being expanded to include measurement and analytical methods for many nontimber resources such as wildlife habitat, composition of endangered species, recreation, and soil characteristics (e.g., site quality).

To manage forest resources in perpetuity, forest professionals need high-quality, up-to-date forest inventories that provide information at varying scales. One particular

area that the FMB program at Oregon State is striving to address is spatial analysis and long-term monitoring (Figure 1). These analyses are being tailored to include monitoring of both timber and nontimber resources.

Summary and Conclusions

There are many forest management and policy problems that, at first glance, do not appear to involve FMB but which, on further examination, are found to be closely linked. In this regard, FMB has both an “inside” and an “outside.” The outside part faces interactions with its clients (such as natural resource specialists) and front-line sciences (e.g., forest ecology, silviculture, and more), which bring new data-analytic ideas to FMB. The clients and professionals in these allied sciences need solutions to pressing statistical/quantitative questions. The inside face relates to the need to extend the structure of statistical inference, integrate emerging technologies, and adapt mathematical and statistical precepts to FMB needs (e.g., mixed-effects modeling). We strongly suspect that FMB will soon see a burst of new theories and methodologies, that this surge will feature a combination of both traditional frequentist reasoning and modern Bayesian methods (e.g., hybrid Gibbs samplers), and that it will focus jointly on timber and nontimber resources in multidisciplinary analyses. We believe

that the FMB of this generation will participate in a new age of statistical (quantitative) innovation that might rival the golden age of Fisher, Neyman, Bitterlich, Grosenbaugh, Furnival, Stage, and others.

FMB has provided tools to enhance and extend quantitative thinking in other sub-disciplines of forestry, such as silviculture, ecology, wood technology, and economics. FMB is essential to efficiently quantifying and analyzing variation and managing the resultant uncertainty. We assert that FMB needs to be responsive to contemporary resource management challenges and address the many land-management challenges in the Pacific Northwest United States and around the world.

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