Analysis of Pooled FIA and Remote Sensing Data for Fiber Supply Assessment at the Warnell School of Forest Resources at the University of Georgia—Other Studies and Effective Information Dissemination

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Abstract.—We provide here a short description of the origin, current work, and future outlook of the Fiber Supply Assessment program at the D.B. Warnell School of Forest Resources, University of Georgia, whose work includes various analyses of FIA data. Since 1997, the program has intended to assist the implementation of the new Southern Annual Forest Inventory System through related data analyses. Currently its projects include basic problems in theory of equations and parameter estimation and various analyses of ground inventories and remote sensing and GIS data. We describe some of these projects and associated software, hardware, and information dissemination problems and solutions.

The Fiber Supply Assessment program (FSA) at the Daniel B. Warnell School of Forest Resources was initiated by Dean Arnett Mace, Jr. in 1997. The establishment of this program coincided with the beginning of the implementation of the Southern Annual Forest Inventory Analysis System (SAFIS) and was intended to provide the school's input into solving the various problems of timely and accurate fiber supply assessment in Georgia.

Parties interested in creation of this program included members of the forest product industry, and others. Their expectations were directed toward finding new relationships and revealing information in the new annual measurement data produced by SAFIS. The new design of the continuous annual inventory was attracting many questions about statistical accuracy, the possibility of monitoring growth, and differences between current and former periodic estimates.

Notwithstanding the above, in the beginning the FSA could not focus on the annual data analysis due to the unavailability of such data. Furthermore, there was also little pragmatic value in work on new estimators because it seemed rather futile to begin changing the barely conceived statistical design, which was so new that it was not even quite implemented yet. Thus, at the outset the FSA focused initially on theoretical studies of inventory projection equations. Subsequent efforts concentrated on building collaborative studies with other programs and exploring funding opportunities related to the general mandate of the program. Presently the program is collaborating with forest biometrics, the quantitative forest management and wood quality programs, the center for forest business, forest finance, forest economics, and a number of forest product industry partners.

Research of the Fiber Supply Assessment Program

Inventory projection equations: Forest inventory updates and projections frequently rely on a special type of equation known as a self-referencing function (Northway 1985). Such equations are applied to model such stand characteristics as basal area, volume, and different height measures. They contain two types of parameters: the global model parameters, and the initial condition parameters, which are snapshot observations of the modeled phenomena usually available through inventory measurements. These equations are used to model various characteristics that depend on unobservable variables (e.g., site productivity). Examples of the modeled characteristics in forestry

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are height (e.g., Bailey and Clutter 1974), diameter (e.g., Clutter *et al*. 1983), basal area (e.g., Pienaar and Shiver 1986), volume (e.g., Coile and Schumacher 1964), trees per unit area (e.g., Bailey *et al.* 1985), and biomass and carbon sequestration (e.g., Cieszewski *et al.* 1996). The self-referencing functions, or the inventory projection equations, are usually calibrated on pooled longitudinal and cross-sectional data and can be expressed by either dynamic or static equations.

The FSA focuses almost exclusively on the dynamic equations, also known as dynamic site equations, which are relatively scarce in forestry literature. Out of a few hundred publications on self-referencing models, only a couple of dozen use dynamic equations (Cieszewski 2001). Similarly, in spite of an abundance of literature on parameterization of explicit static equations (i.e., $Y=f(t)$), there is little literature available on derivation of these implicit dynamic equations $Y=f(t, Y)$). Our program made major contributions in this area by founding the generalization of the algebraic difference approach (Cieszewski and Bailey 2000), providing internationally examples of its applications (e.g., Cieszewski *et al.* 1999; Cieszewski, in press; Cieszewski and Nigh 2002; Cieszewski and Zasada 2002), and presenting new methods of dynamic equation derivation (e.g., Cieszewski 2001).

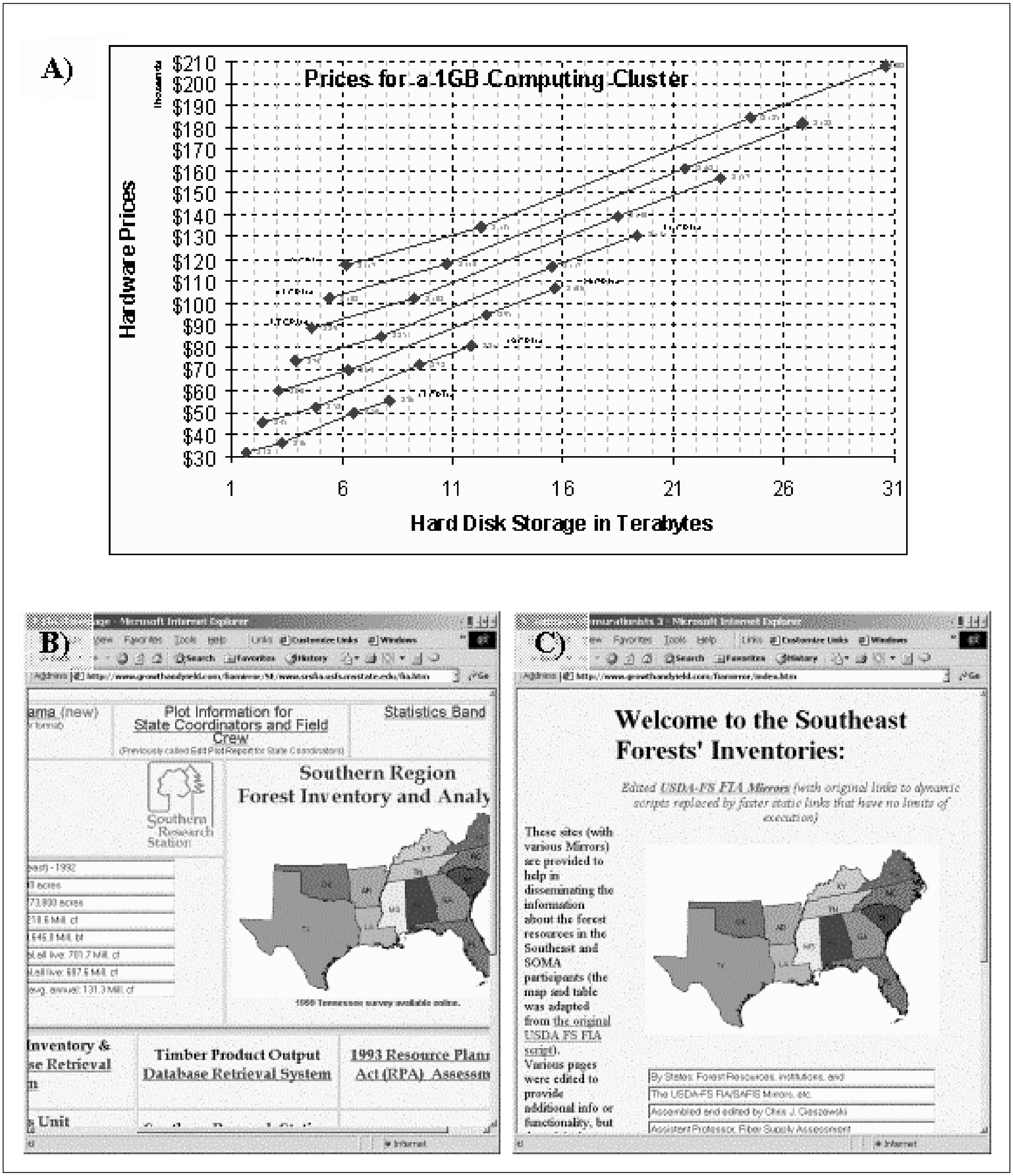
Long-term sustainability analysis: In 2000 collaboration between the Wood Quality, Forest Biometrics, and the FSA began a major research effort on long-term sustainability analysis of fiber supply in Georgia. The Dean of the School supported this effort with an initial investment of $40,000 for software and hardware necessary for initiation of spatially explicit estate simulation analysis. At the beginning of 2001 this effort created a new postdoc position and led to extensive research and analyses of various Georgia forest resource data. Subsequently, long-term research was made possible through TIP3 funding of a 3-year project with the postdoc position and graduate students. The main data for the analysis came from the FIA 1997 and 2000 surveys. Supplementary information came from various GIS and remote sensing sources including the Landsat TM 7 imagery. A preliminary approach to the analysis was described first in Cieszewski *et al.* (2001). Subsequent stages and technical details can be found in Cieszewski *et al.* (2002) and Zasada *et al.* (2002). Part of the long-term sustainability analysis project concentrates on studying impacts of intensive management practices on future wood production in Georgia. Assumptions and results for the intensive plantation management practices are described in Zasada *et al.* (2003a).

The sustainability project involves many simulations and massive numerical outputs. Reviewing the results is a considerable challenge even for the team members and much more so for the clients and public. The initial results consisted of over 1,000 graphs, maps, and tables that were organized for public access on the Web at http://www.growthandyield.com/sustain/ in a navigational tree framework with expandable/collapsible branches (fig. 1A). This presentation is fairly effective but as the number of images and text files grew it became apparent that invoking images by mouse click is not an effective way of viewing thousands of images. To solve this problem and enable more effective browsing through the massive outputs, we designed a new Web construct based on dynamic image tables (e.g., fig. 1B and 1C) being displayed automatically when a mouse cursor browses over navigation tables (on a click the display image table becomes the navigation table and a new display image table is browsed as the mouse-over display as on figure 1C). The later results from this project are being published at http://www.growthandyield.com/movesustain/ in a dynamic navigation framework optimized for fast and efficient browsing of large numbers of tables and images; however, the users need to be patient at loading time when large numbers of images are preloaded to speed up subsequent response time.

Assessment of stream and road buffers: In 2002 the USDA Forest Service agreed to sponsor a study on assessment of protective buffers such as the stream management zones and road beautifying buffers. It has been a major contribution to the research in the FSA. The technical aspects and preliminary results of this project are described in detail in Zasada *et al.* (2003b) in the proceedings of the joint meeting of the 4th Annual FIA Symposium and 2002 Southern Mensurationists conference. Lowe *et al.* (2003) describe the technical details associated with the GIS analysis of spatial distribution of stream and road buffers and assumptions behind the spatial distribution of the FIA and industrial ground measurement data used in this and the long-term sustainability analysis.

Landscape level inventory visualization: Initial efforts towards effective presentations of the results of inventory projections in the long-term sustainability analysis included research in computer-generated landscape images for inventory

Figure 1.—*Information dissemination on the spatially explicit analysis: A) Phase 1 static presentation; B) Phase 2 dynamic presentation; C) Dynamic map display for various inventory projections; D) Phase 2 of landscape visualization; E) Example of a Phase 2 computer generated image of forecasted inventory.*



visualization. It was a seed project intended to attract explicit funding for such research, results of which could be used in public relations and various analysis of aesthetical, recreational, and visual implications of different forest management practices. Examples of the results of this research have been published on the Web at http://www.growthandyield.com/landscape/ in the form of two tables (e.g., fig. 1D) of image thumbnails. These Web pages include short descriptions of an initial and an advanced phase of the project with a number of examples illustrating how the quality of the images changed at different phases of the project. The quality of the final phase images (e.g., fig. 1E) is by far not the best possible, but the project was suspended due to lack of funding.

Biomass and carbon analysis: We have derived in this study an estimate of carbon and biomass pools in Georgia forests based on the USDA Forest Service Forest Inventory Analysis data of the 1997 survey. The results include tables with estimates and a map of the biomass density and pools at a subcounty level of resolution, which is based on spatially explicit simulations of the potential cover type polygons implied by the FIA data with approximate plot locations. Our results include estimates of the biomass pools in the belowground roots, aboveground tree, and foliage. This study estimates biomass density and pools at a tree level using diameters and heights. The results are then propagated to the plot level using the USDA Forest Service tree expansion factors, and then transformed to plot-dependent polygons using the plot expansion factors. The plot-dependent polygons were spatially simulated using a simplified assumption of homogeneity of conditions surrounding each plot to the extent of the area defined by this plot's expansion factor. Despite the simplified assumption, the derived map provides an excellent visual representation of the distribution of forest biomass densities and pools in the State with distinctive patterns observed in various areas of urban development, federally owned forests, primary commercial forestland, and other land use areas. Coniferous forests with the highest total biomass density are located mostly in three regions: northern Georgia (Appalachian Highlands), the southern part of the Piedmont, and the eastern part of the Coastal Plain. Deciduous and mixed forests with the highest biomass density are concentrated first of all in the northern part of the State—especially in the Blue Ridge physiographic province, and in the western part of the East-gulf Coastal Plain. Counties with the highest biomass density were located primarily in the northern part of the State while counties with the lowest density tended to be on the coast. A journal manuscript describing this study is under review.

Hypermap Web Pages: To facilitate online Internet access to the inventory estimates for various types of geographical divisions in Georgia, we have developed several types of hypermap systems (fig. 2), which are interactive, user-friendly, and rich in abundant information on Georgia forest inventories. The first generation of the hypermaps is available at http://www.growthandyield.com/LiveMaps/clickmaps.htm and requires the user to click on a selection of a display on a first-level selection navigation table. Changing the display of the maps from static to dynamic with different maps displayed as the user moves the mouse over different navigation selections was a major improvement, which can be accessed at http://www.growthandyield.com/LiveMaps/movemaps.htm (fig. 2A). In both these map systems, once the first-level selection is executed, the maps dynamically display a small table with summary statistics for different subunits of the State (fig. 2B). The newest system of the hypermaps is the most comprehensive and dynamic. Mouse-over movement over the first level navigation table dynamically displays tables with various maps that are available for the different divisions of Georgia and can be accessed at http://www.growthandyield.com/movemaps/ (fig. 2C). When one of the map-tables is selected, it becomes a navigation table displaying enlarged map images dynamically as it is browsed over (fig. 2D). When one of the maps is selected, it becomes a navigation table/map displaying dynamically summary graphs for each subunit of the State (fig. 2E). Finally, when the subunit of the State is selected in any of the systems, the user is taken to a page with extensive inventory summary tables (fig. 2F).

Other associated projects and solutions: Among the most important projects associated with the FSA is the geostatistical analysis study described in these proceedings. The objective of this project was to evaluate the applicability of the Landsat TM imagery for analyzing the textural information of pine forest images. Other associated projects have mostly been the results of seeking the best solutions in work organization and the most productive work environment. The bibliography

Figure 2.—*Hypermap Web pages with inventory estimates for different divisions of Georgia: A) Navigation table with dynamic maps; B) Navigation hypermap with a dynamic table; C) Navigation table with dynamic would-be navigation map-table; D) Navigation map-table with dynamic hypermap; E) Navigation hypermap with dynamic graphs.*

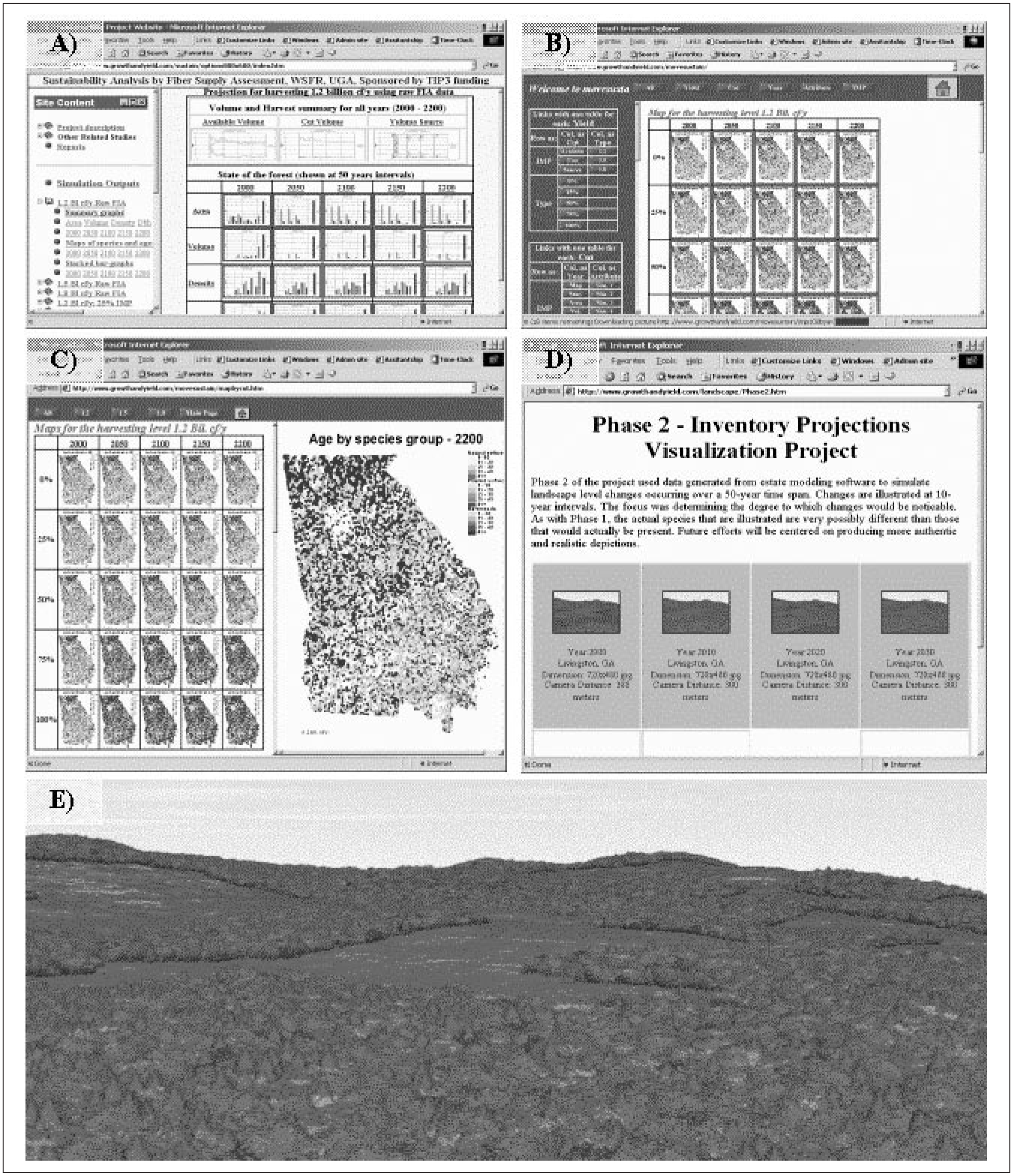


Figure 3.—*Other studies and administrative/management Web sites associated with the Fiber Supply Assessment program: A) Online literature database; B) Fiber supply assessment online publication retrieval system; C) Comparison of the first panel FIA annual inventory estimates to the last periodic inventory estimates; D) Comparison of the first and second panel FIA annual inventory estimates to the last periodic inventory estimates.*

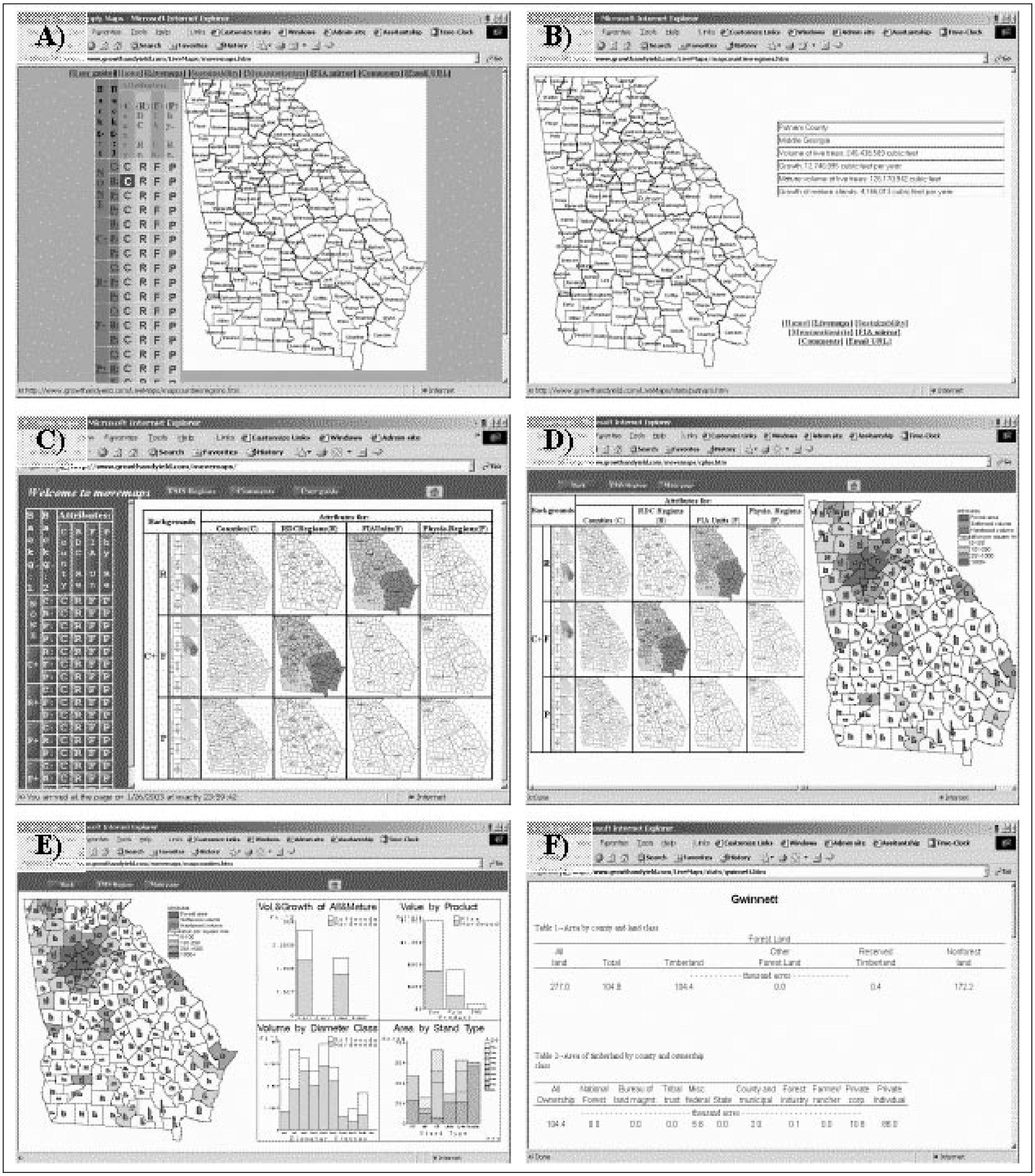
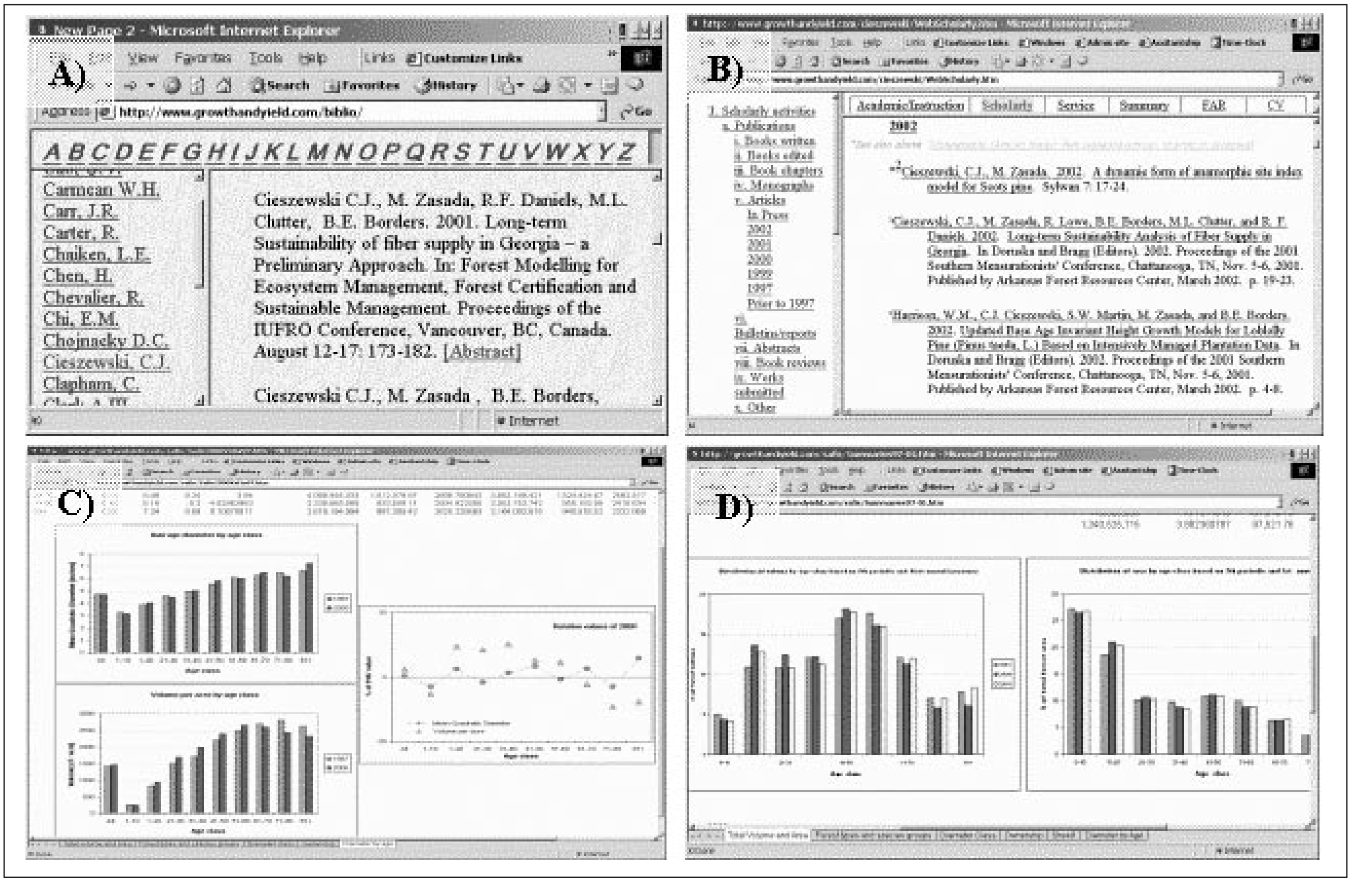


Figure 4.—*Optimized hardware/software solutions: A) Cost of a computing cluster built with inexpensive generic hardware. The lines on the graph mark expandability of the hard disk storage from 1 to 5 Hard Disks per CPU. Note that the 5th HD is priced as an external FireWire disk that is portable and can be used with laptops. B) Mirror of the USDA Forest Service database site, having the same appearance as the original site. C) As in B) but with different skin.*



project was initiated to streamline literature reviews and database management with online access at http://www.growthandyield.com/biblio/ (fig. 3A). The system contains full texts of all the articles researched in the program (available only for internal use due to copyright laws). All publications produced in the FSA can be retrieved online using a self-maintained user-database at http://www.growthandyield.com/cieszewski/WebScholarly.htm (fig. 3B), or through the information dissemination page at http://www.growthandyield.com/chris/. Finally, the FSA timely comparisons of recent FIA inventory estimates are available online at http://www.growthandyield.com/safis/ in the form of Excel-generated HTML spreadsheets with various associated graphs (e.g., fig. 3C). The spreadsheets contain more extensive comparisons between inventories than those commonly published by the USDA Forest Service or the Georgia Forestry Commission. The main analysis for the comparisons between the inventory estimates is conducted in SAS and then published on the Web using Excel only for presentation of the results.

FSA Innovative Hardware and Software Solutions

Hardware solutions: Analysis of satellite imagery in conjunction with various inventory and GIS data requires massive computing and storage capabilities (needs at the time of writing this piece exceeded 5 Terabytes and were expected to double before June 2003). The most productive and cost efficient solution was based on building a high-speed computing cluster (fig.

4A). We built a 1-Gb project-specific sub-networked computing cluster designated for extensive data processing and forest inventory simulations. The cluster enables the FSA program to perform many new strenuous computational tasks such as long-term, spatially explicit simulations of forest resource availability in Georgia or complex GIS analyses. The project allows for a computer simulation series that previously required months to complete to now be done in less than a week per each subdivision. Moreover, the high-speed sub-network provides opportunities for high-efficiency data storage because transfer rates between different CPUs are comparable to the access rates on native drives. Even with an administrative overhead, the effective time of copying data between different CPUs is much faster than going through the school network. The project-specific sub-network benefits the school at large by freeing up a large amount of resources since all traffic commonly generated by projects is removed from the school lines.

Software "programming optimization": Because many of the FSA studies use the FIA data and its Web pages, it is critical that the relevant online access be in good working order and available at all times. For this reason, we make mirrors of various sites and copy entire structures of their directories onto our computers so that we can use them for offline browsing even when they, or the network, are down. At the same time some Web sites cannot be used offline because of the way they are programmed, and we need then to either reprogram the sites or to refrain from making their mirrors. Such decisions depend on how reliable is the original provider of the subject site and on how much work is required for the reprogramming. The USDA Forest Service Database Retrieval System is a good example of a site that needs reprogramming for offline browsing. First, the provider was frequently inaccessible and even when accessed was painfully slow. The problem is that the program is too advanced. It computes tables in real time generating many temporary files, which quickly reach a critical number—crashing the server. We optimized the program by replacing the dynamic table generating programs with preprocessed static HTML tables. The improved mirror of this database can be accessed at either of the two locations: http://www.growthandyield.com/fiamirror/SE/www.srsfia.usfs.msstate.edu/fia.htm (fig. 4B) and/or http://www.growthandyield.com/fiamirror/ (fig. 4C).

Summary and Conclusions

The FSA has developed many diverse research studies intended to satisfy current funding requirements or to attract different funding sources. Future directions of research will depend chiefly on funding opportunities. In hardware solutions we will follow the computing cluster strategy as the cheapest solution to large computing and storage needs, which can be built even with moderate equipment.

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