United States
Department
of Agriculture

Forest Service

Rocky Mountain
Research Station

Proceedings
RMRS-P-54
September 2008

Third Forest Vegetation Simulator Conference

Fort Collins, Colorado
February 13–15, 2007

Havis, Robert N.; Crookston, Nicholas L., comps. 2008. **Third Forest Vegetation Simulator Conference**; 2007 February 13–15; Fort Collins, CO. Proceedings RMRS-P-54. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 234 p.

Abstract

The Forest Vegetation Simulator (FVS) is a suite of computer modeling tools for predicting the long-term effects of alternative forest management actions. FVS was developed in the early 1980s and is used throughout the United Sates and British Columbia. The Third FVS conference, held February 13–15, 2007, in Fort Collins Colorado, contains 20 papers. They describe the use of FVS on the stand and landscape scale, and to analyze fuels management in the presence of insects and fire. Several papers compare FVS predictions of the effects of insects and disease to field measurements. FVS is continually evolving and improving in technology and capability to meet the needs of its ever increasing user community. Papers describe new methods for data acquisition and preparation for input to FVS, new economic analysis capabilities within FVS, new methods for simulating forest regeneration, new developments in calculating growth and mortality, and future plans for incorporating the effects of climate change in model simulations.

Keywords: forest management, forest planning, growth and yield, vegetation dynamics, habitat modeling, carbon inventory, prognosis model, landscape dynamics, fire, fuels, climate change, economics, forest health

The Compilers

Robert N. Havis is a Systems Analyst with the USDA Forest Service, Forest Management Service Center (FMSC) in Fort Collins, CO. A Civil and Environmental Engineer by training, Dr. Havis has developed natural resource simulation tools, including models for mine waste management, agricultural water quality, eutrophic lake management, stream bed load transport and gravel quality, and contaminant dispersion around dredging operations. He has been involved in software development and support for the FVS base model and extensions since 1998. The FMSC is the technology transfer center for the FVS model system. It distributes software to the public, provides user training and hotline support, and develops new geographic variants and enhancements to the base model system.

Nicholas L. Crookston is an Operations Research Analyst with the USDA Forest Service, Rocky Mountain Research Station in Moscow, ID. He has spent his career working on the base FVS system and its extensions. His first contribution to FVS, in the late 1970s, involved creating the first extension—one that represented mountain pine beetle population dynamics in lodgepole pine. Work on the development of the Douglas-fir tussock moth and western spruce budworm extensions followed. These extensions formed a template on which all FVS extensions have been based. Mr. Crookston conceived and built the Event Monitor and, in a collaborative effort with Al Stage, built the Parallel Processing Extension to FVS. His recent efforts have been in building the Suppose user interface, managing the development of the Fire and Fuels Extension and leading the effort to develop a climate-driven version of FVS.

Acknowledgments

Funding for this publication was provided by the Forests and Woodlands Ecosystems Research Program of the Rocky Mountain Research Station (RMRS), the Forest Health Technology Enterprise Team, and the Forest Management Service Center, all part of the USDA Forest Service. The compilers are particularly grateful to Dennis Ferguson, RMRS; Loa Collins, Publications RMRS; and Sheryl Romero, ITX. The conference organizing committee included Robert Havis (chairperson), Judy Adams, Dave Cawrse, Nicholas Crookston, Gary Dixon, Chad Keyser, Stephanie Rebain, Erin Smith-Mateja, and Don Vandendriesche.

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Third Forest Vegetation Simulator Conference

Fort Collins, CO
February 13–15, 2007

Compilers:
Robert N. Havis
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Citations to Previous Conference Proceedings

Teck, Richard; Moeur, Melinda; Adams, Judy, comps. 1997. Proceedings: Forest Vegetation Simulator conference; 1997 February 3–7; Fort Collins, CO. Gen. Tech. Rep. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 222 p.

Crookston, Nicholas L.; Havis, Robert N., comps. 2002. Second Forest Vegetation Simulator Conference; February 12–14, 2002; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 208 p. Online: http://www.fs.fed.us/rm/pubs/rmrs_p025.html

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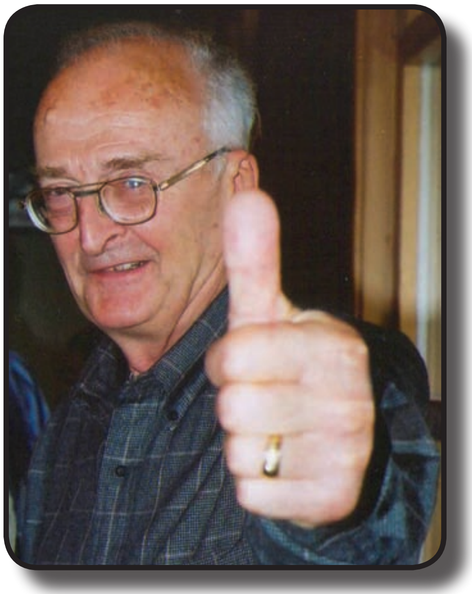
Albert R. Stage



Al Stage showing how to use your thumb as an angle guage in variable plot sampling (photo by Kim Iles).

Dedication

These proceedings are dedicated to Al Stage, Emeritus Scientist who passed away July 12, 2008. Al was one of the giants in forest biometrics research and forest growth dynamics modeling in the world. His broad breadth of knowledge, analytical skills, creativity and curiosity, and his sheer love of science, made him a consummate forest scientist. It is noteworthy that his most productive year measured in refereed journal papers was 2007, many years after becoming an Emeritus Scientist. He had more work to do and many more papers planned than his lifetime permitted.

Al was best known for the creation of the Prognosis Model for Stand Development, first published in 1973. This model is the core of what is currently known as the Forest Vegetation Simulator (FVS), the most widely used forest growth model in the world. Al's vision, his quiet but persuasive prodding, and his firm grasp of biophysical, mathematical, and statistical concepts are at the foundation of FVS. Many who had the pleasure of working closely with him stand in awe of his achievements; the fervor and pace with which Al attacked forestry research was exhausting!

Contents

Improving Longleaf Pine Mortality Predictions in the Southern Variant of the Forest Vegetation Simulator

R. Justin DeRose[1]
John D. Shaw[2]
Giorgio Vacchiano[3]
James N. Long[1]

Abstract—The Southern Variant of the Forest Vegetation Simulator (FVS-SN) is made up of individual submodels that predict tree growth, recruitment and mortality. Forest managers on Ft. Bragg, North Carolina, discovered biologically unrealistic longleaf pine (*Pinus palustris*) size-density predictions at large diameters when using FVS-SN to project red-cockaded woodpecker (Picoides borealis) habitat. Inventory data from Ft. Bragg indicated the mortality submodel was responsible for the over-predictions. Three approaches to remedy longleaf pine mortality predictions in FVS-SN were explored: (1) using stand density modifier keywords, (2) using a tree size cap to influence mortality rates but not growth, and (3) iteratively invoking a mortality rate based on empirical data. Results showed the third approach was the only viable alternative. Details of this approach are described so that an FVS-SN user can effectively constrain predicted longleaf pine size-density combinations at realistic levels. Although the approach was successful, it required advanced knowledge of size-density relationships for longleaf pine. It also demands an advanced understanding of FVS-SN from the user. We suggest over-prediction of size-density relations at large diameters will be evident in any growth and yield model using similar mortality logic. Therefore our results provide a general framework for improving the accuracy of mortality predictions in FVS.

Introduction

Forest growth and yield models such as the Southern Variant of the Forest Vegetation Simulator (FVS-SN) (Donnelly and others 2001) typically consist of component submodels that describe tree growth, recruitment (sprouting), establishment (seeding), and mortality. The extent to which submodel predictions realistically portray natural and managed stand dynamics should be routinely evaluated. Recently, as part of a larger study, FVS-SN was found to over-predict growth and yield in mature longleaf pine (*Pinus palustris* Mill.) stands on the Ft. Bragg military installation in North Carolina (Shaw and others 2006). Realistic predictions of stand dynamics for longleaf pine forests are a necessary component of habitat recovery efforts currently underway for the endangered red-cockaded woodpecker (*Picoides borealis*) (Blythe and others 2001). FVS-SN simulations of pure longleaf pine stands by forest managers revealed unrealistic size—density combinations for large (greater than 10 inches) diameter stands on Ft. Bragg (Pat Wefel, personal communication). Over-prediction of size-density relationships is likely due to erroneous mortality rates, which implicates the mortality submodel. In this study, we used a density management diagram (DMD) for longleaf pine (Shaw and Long 2007) to explore the deficiencies of the FVS-SN mortality model and developed possible approaches for its correction.

Currently, two types of mortality occur in FVS-SN: (1) background and (2) density-related. **Background mortality** is estimated when stands are below 55 percent of forest type-dictated maximum stand density index (SDIMax). For this mortality type it is assumed there is no density-dependent mortality and an annual compound interest formula is used to calculate mortality. Furthermore, disturbance agents such as insects, fire, and pathogens are assumed to be exclusive of background mortality (Dixon 2002). **Density-related mortality** is estimated when stands are above 55 percent SDIMax and below 85 percent SDIMax, (SDIMax mortality), presumably as a result of competition and self-thinning. Ninety percent of SDIMax is considered an upper limit to stand density and if the current inventory SDI exceeds 90 percent, then SDI is reset so that current SDI is 85 percent of the maximum. If SDI is between 85 percent and 90 percent, it is reduced to 85 percent SDIMax. Stand dynamics throughout the simulation are determined by the relationship between current inventory SDI and SDIMax (Dixon 2002). Background mortality stops once SDIMax mortality begins.

In: Havis, Robert N.; Crookston, Nicholas L., comps. 2008. Third Forest Vegetation Simulator Conference; 2007 February 13–15; Fort Collins, CO. Proceedings RMRS-P-54. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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The DMD, developed using range-wide empirical data from both managed and unmanaged longleaf pine stands, is a conceptual model useful for evaluating stand dynamics (Shaw and Long 2007). The 'mature stand boundary' (MSB) displayed on the DMD represents an empirical ceiling to possible size - density combinations for natural and managed stands of longleaf pine (Shaw and Long 2007). FVS-SN mortality logic tends to maintain stands within 55 percent and 85 percent of SDIMax after they reach the 55 percent threshold (Dixon 2002). In contrast, the MSB indicates size-density combinations cannot be maintained within this range of densities. The non-linear MSB (in log-log space) suggests mortality actually proceeds at a constant rate relative to SDIMax mortality, indicating less efficient use of growing space by larger diameter (Dq) stands. The biological mechanisms for less efficient occupancy of growing space by larger trees are not well known but, a number have been postulated. First, it is possible that as trees increase in size mortality proceeds but with an increasing chance of density-independent mortality (in other words, lightning or pathogens). Second, Zeide (1985) suggested 'self-tolerance,' or the intra-specific ability to coexist, might decrease with increasing density where 'self-tolerance' is not necessarily related to shade tolerance. Similarly, Assmann (1970) observed 'crown disengagement' in even-aged forest stands which has been attributed to increased height growth resulting in physical crown interaction, removing leaf area and subsequently reducing growth (Long and Smith 1992). The over-prediction of size-density relationships could result in unrealistic management scenarios and, regardless of the mechanisms, more realistic estimates of longleaf pine mortality are needed.

To assess FVS-SN mortality predictions, we used stand data to examine the effect the mortality submodel has on predicting size-density combinations. We then explored three potential approaches to modifying and improving mortality rates: (1) using stand density modifier keywords, (2) using a tree size cap which affects mortality but not growth, and (3) iteratively invoking a mortality rate based on empirical data (in other words the MSB). We evaluated our results graphically against the MSB on the DMD (Shaw and Long 2007) because it represents the most detailed quantification of the 'ceiling' to size-density combinations for longleaf pine. Conceptually, we aimed to maintain stand dynamics below the empirical MSB threshold.

Methods

Data for this study came from the Ft. Bragg military installation in North Carolina. An intensive forest inventory was designed to collect information necessary for FVS-SN submodel testing and calibration. Details of the study design, data collection, and model calibration have been described (Shaw and others 2006). For the purposes of this study relatively pure longleaf pine stands (greater than 70 percent total basal area, table 1) were chosen from the Ft. Bragg forest inventory database (table 1) and run using the current southern variant file (revision date: 7-31-07, downloaded from http://www.fs.fed.us/fmsc/fvs/software/varfiles.php) in Suppose 2.0, the graphical user interface

Table 1—Stand number, number of plots per stand, percentage basal area in longleaf pine, trees per acre (TPA), mean stand diameter (QMD), stand density index (SDI), and site index (SI) for the sample stands.

Stand number	Number of plots	Percent longleaf pine	TPA	QMD(in)	SDI	SI (ft)
1032	15	86	89	10.2	92	62
2157	15	100	215	7.2	127	69
3089	10	70	226	8.1	161	67
4012	20	78	75	11.0	87	65
5046	5	96	340	7.0	194	91
5088	9	95	138	10.3	145	70
6014	15	82	178	6.0	78	65
7064	10	85	269	6.7	140	87
8045	10	99	173	8.8	141	66
8090	10	75	142	8.4	108	55
9051	10	89	195	8.5	149	59
10001	15	71	454	5.6	178	65

of FVS. The default cycle length of five years was used. Three approaches to simulate empirically observed size-density patterns were explored:

1. Stand density modifier keywords (SDIMax / BAMax) were used to emulate the MSB. The default SDIMax (390) in FVS-SN was reset to 350 as an example and simulations from each stand were graphically examined on the DMD.
2. The TreeSzCp keyword was used to adjust mortality to 10 percent for longleaf pine above 10 inches DBH and this size cap was set to effect mortality predictions only (Van Dyck 2005). An SDIMax of 390 (FVS-SN default) was used for this analysis.
3. We used the FixMort keyword in the Event Monitor to invoke approximately 2 percent annual mortality (Palik and Pederson 1996) when the stand approached the MSB (MSB-modified mortality). The Event Monitor program logic was:

```
1. IF
2. BADBH GT (18.68-20.63*Exp(-13.25*(BTPA)**(-0.503)))+2
3. THEN
4. FixMort  0  Parms(All, 1-(1-0.021751)**(CENDYEAR-YEAR), 0., 999., 0, 0)
5. ENDIF
```

This effectively iterated a mortality rate of approximately 10 percent (line 4) per cycle when the beginning cycle Dq was greater than the fitted MSB equation (line 2). We then re-ran FVS-SN with relatively pure longleaf pine stands (table 1) and compared the original with the modified output.

Size-density trajectories were inspected on the longleaf pine DMD to compare the differences in projected size-density relationships for each approach and assess how well they corresponded to the MSB. For illustration only three of the 12 sample stands were randomly chosen (3089, 4012, and 10001) to display in the figures.

Results

Unrealistic combinations of size and density were predicted in simulations of longleaf pine (fig. 1) using the default FVS-SN, which suggested inadequate mortality predictions. The southern variant projected size-density combinations above the MSB approximately 80 to 100 years into each simulation. The predicted linear nature (in log-log space) of the trajectory for each stand, presumably a result of SDIMax mortality logic, approached and surpassed the MSB. This resulted in over-predictions of stand growth and yield.

The SDIMax (or BAMax = SDI x 0.5454154) keyword approach, which lowered the maximum stand density, changed simulation output based on our arbitrarily chosen SDIMax of 350. However, over-predictions were still apparent, albeit at lower relative densities (fig. 2). If a larger SDIMax had been chosen it is likely larger over-predictions would have occurred. Regardless of the chosen SDIMax, FVS-SN size-density combinations will eventually cross the MSB due to their linear (in log-log space) nature. The SDIMax for longleaf pine across its geographic range has been quantified; therefore, there is little ecological rationale for modification of SDIMax in FVS-SN.

The TreeSzCp keyword approach appeared to increase mortality rates compared to the default model (fig. 3). Although we set the keyword to affect mortality only and not diameter growth, as there is no evidence to support diameter increment reduction of large DBH longleaf pine on Ft. Bragg (mean ± std. dev. for five-yr diameter growth of trees greater than 20 inches = 0.553 inches ± 0.195, n = 272), the mortality rate was not sufficient to maintain size-density combinations below the MSB.

The FixMort keyword modification resulted in size-density combinations consistent with the MSB. The greater mortality rate (approximately 10 percent per cycle) thus appeared to most closely mimic the MSB. Although mortality was greater in the MSB-modified trajectory than in the baseline simulation, mean stand diameters were similar during both simulations (figure 4).

Discussion

Density-independent mortality, or annual background mortality, is likely underestimated in FVS-SN. Palik and Pederson (1996) reported 1.9 percent annual background mortality for longleaf pine in mature, second-growth stands of longleaf pine. We calculated a range of background mortality of 0.19–0.2 percent, for 4 and 20 inch dbh

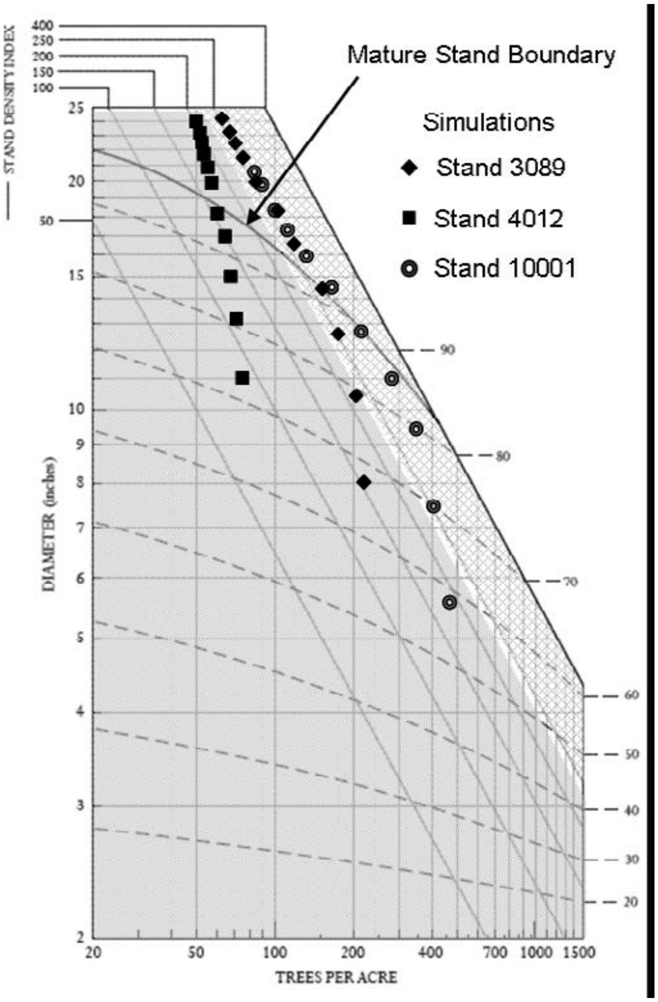

Figure 1—Trajectories of three of the sample stands (table 1), projected with the default southern variant and plotted on the density management diagram, showing size—density combinations well above the mature stand boundary. Symbols are plotted every 20 years for clarity. Grey area shows where background mortality occurs, hatched area indicates density-dependent mortality.

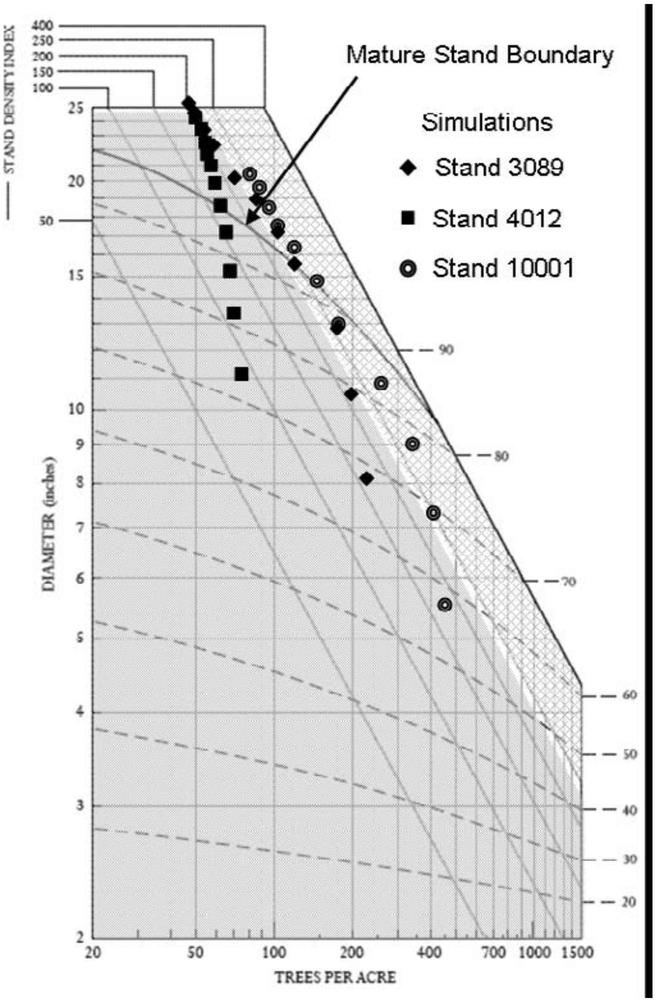

Figure 2—Trajectories of three of the sample stands (table 1) plotted on the density management diagram showing the effect of adjusting the SDIMax keyword from 390 to 350 on mortality predictions. Symbols are plotted every 20 years for clarity. Grey area shows where background mortality occurs, hatched area indicates density-dependent mortality.

trees respectively using the default values in FVS-SN (Dixon 2002; Donnelly 2001). The assumption that density-dependent mortality begins at 55 percent of SDIMax is consistent with the literature (Drew and Flewelling 1979; Long 1985) and likely accurately describes the 'zone of imminent competition mortality'. It is probably unrealistic however, that background mortality no longer operates after density-dependent mortality (SDIMax) is invoked as is currently done in FVS-SN. Background mortality emulates natural mortality agents that are operating concurrently as stands increase in relative density (for example lightning). Therefore both density-independent and dependent factors should be simultaneously considered when SDIMax exceeds 55 percent. The SDIMax ceiling of 85 percent (Dixon 2002) appeared effective for predicting self-thinning (for example stand 10001) (fig. 1). However, maintenance of a stand greater than 55 percent but less than 85 percent SDI, when Dq is large, appears to be the major problem with FVS-SN mortality logic (fig. 1). Therefore, an SDI-based approach to mortality seems adequate as long as consideration for an increasing rate of mortality is given at larger diameters.

The TreeSzCp keyword approach failed to maintain realistic size-density combinations (fig. 3). We increased mortality for longleaf pine 10 inches dbh and greater but this was not sufficient to limit size-density combinations below the MSB. There is no evidence to suggest that large diameter longleaf pine would die faster than a background mortality rate of approximately 1.9 percent (Palik and Perderson 1996). In fact, our five-yr diameter

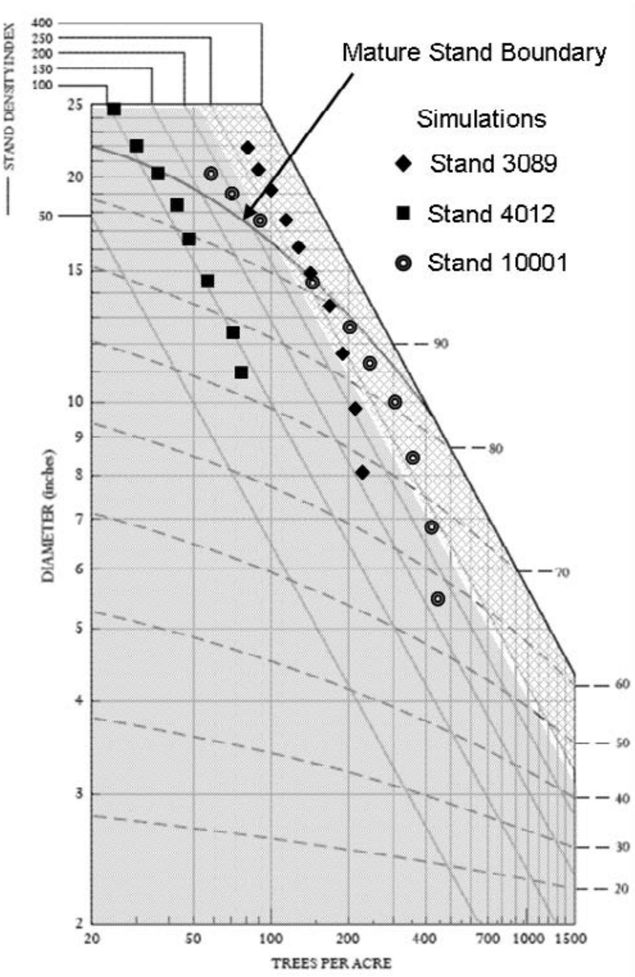

Figure 3—Trajectories of three of the sample stands (table 1) plotted on the density management diagram showing the effect of using the TreeSzCp keyword on mortality predictions. Symbols are plotted every 20 years for clarity. Grey area shows where background mortality occurs, hatched area indicates density-dependent mortality.

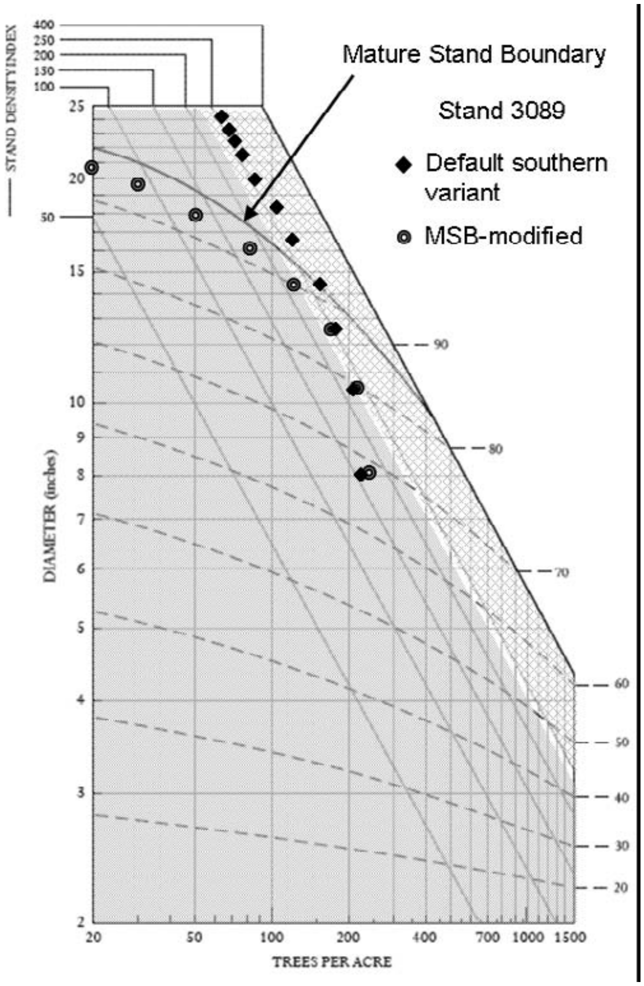

Figure 4—Longleaf pine stand 3089 projected for 200 years using the default southern variant and the FixMort mortality logic showing a divergence in mortality rates. Symbols are plotted every 20 years for clarity. Grey area shows where background mortality occurs, hatched area indicates density-dependent mortality.

growth measurements suggested larger trees (greater than 20 inches dbh) are vigorous and adding substantial increment. The TreeSzCp approach also resulted in size-density combinations for some stands that fell near 25 percent of SDI (fig. 3) where vacant growing space might promote undesirable understory species, specifically turkey oak (*Quercus laevis* Walt.) on Ft. Bragg, in the absence of fire. Understory fire was a ubiquitous force in natural longleaf pine forests (Van Lear and others 2005) and is maintained through prescribed burning on Ft. Bragg. Modeling stands with size—density combinations below the 25 percent threshold, a conventional threshold for predicting the availability of growing space for understory trees (Long 1985), might realistically incorporate regenerating understory species. However, in this study it was not necessary to include regeneration in model simulations because we were focused on mortality of the mature overstory. Palik and Pederson (1996) suggested mortality rates in longleaf pine proceed so slowly that openings for longleaf pine regeneration develop very slowly without hurricanes, which corroborates our decision to ignore regeneration in this study.

By invoking a higher mortality rate (approximately 10 percent per cycle) in large diameter longleaf pine stands, realistic size-density combinations were achieved. As indicated in the FixMort keyword coding logic, maintaining size-density combinations below the MSB requires redefining the mortality rate such that density is reduced at a much greater rate as trees increase in Dq. Our MSB-predicted mortality rate was approximately double that of default FVS-SN. It is realistic to expect the predicted size-density combinations to fall below the MSB, which describes the ceiling and not average, size-density relationships. Further sophistication of projected size-density relationships is possible by fine-tuning our Event Monitor logic by increasing or decreasing the intercept (+2 in our example); however, this is not recommended unless based on detailed stand-level information. Such an adjustment would change projected size-density combinations relative to the MSB.

Although our FixMort approach created realistic projections of size-density combinations by bridging density-dependent and independent mortality, it is computationally difficult and likely not easily implemented by the many FVS users who may not, for example, be comfortable using the Event Monitor. Furthermore it requires the existence of an established MSB relationship for the species of interest. If fitted MSB relationships were known for enough commercial tree species, their incorporation into FVS would greatly facilitate more accurate size-density projections. Mimicking the MSB required FVS-SN to eliminate trees well above the rate of mortality currently predicted in large Dq stands (approximately 10 inches) using SDIMax. Incorporating mortality mediated by the MSB in place of SDIMax in FVS-SN would require relaxing the current assumption that as stands increase in Dq basal area stays constant. Realistically, basal area and SDI should be allowed to decrease as Dq increases.

Increasingly in forest management, the creation and maintenance of large, mature trees is a priority. For example, on Ft. Bragg maintaining large diameter longleaf pines at low densities is a primary forest management goal as this is a critical component of red-cockaded woodpecker nesting and foraging habitat (U.S. Fish and Wildlife Service 2003). Management for a few large diameter trees focuses stand dynamics modeling on unconventional areas of size-density combinations (in other words, low densities). This highlights the importance of effective simulation of forest stand dynamics.

Conclusions

Density-dependent (SDIMax) mortality was responsible for the over-prediction of size-density combinations in mature stand simulations. We found the longleaf pine DMD useful as a graphical tool to display and evaluate mortality predictions. We suggest that any growth and yield model incorporating the same mortality logic as FVS-SN will also produce unrealistic combinations of size and density for mature stands. Our alternative, based on the longleaf pine MSB, effectively simulated realistic size-density combinations when the stand neared the MSB. Managers of relatively pure longleaf pine stands should incorporate the FixMort logic from approach three into their FVS-SN simulations. This approach bridges density-dependent (SDIMax) and density-independent (background mortality) factors for mortality predictions. While our analysis was restricted to longleaf pine, we suggest our results may be broadly relevant and provide a general framework for assessing and improving the accuracy of mortality predictions.

Acknowledgments

We thank the Forestry Branch of the Fort Bragg Natural Resources Division and the U.S. army Environmental Center for funding this project. We extend special thanks to P. Wefel and J. Stancar for their continuing support and D. Donnelly for initial project help. The comments of two anonymous reviewers helped to substantially improve this work.

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