SECTION VI: DISCUSSION OF CONCLUSIONS AND IMPLICATIONS

Section I. Introduction and Literature Review

The information provided in Section I provides a basis for understanding the importance of masting in oak dominated forests in terms of potential impacts on wildlife population dynamics and oak reproduction. The data are more extensive than is required in the masting model as it is currently formulated; however, the algorithm may be altered to accommodate a higher degree of detail or applied to different ecosystems where the current formulation is not appropriate.

Section II. Probability and Quantity of Acorn Production: Parameters for the Landis Add-on Module

Section II presents a synthesis of available information on factors relevant to this mast production model in the form of developing and justifying parameters and applying these relationships in the program code of the mast model. The requirements and limitations of the landscape model LANDIS are also summarized. In general, data from local inventories are used to stochastically estimate the diameter, density, and species-group distribution of oak trees in canopy positions on landscape elements (cells) in consideration of differences among local land types. Variability among trees in inherent acorn production is factored and an estimate of an area-based mast production index is generated.

One relationship that is modeled, a prediction of tree size from the age of cell dominants is probably a weakness of the model. While the predictability of the relationship is improved over normal situations by being able to limit analysis of inventory data to only upper canopy trees in dominant and co-dominant positions (since these trees produce the vast majority of acorns), the relationship is still tenuous. For example, while one might expect a large number of small, suppressed trees in a stand where the age of the dominants is relatively old, (*e.g.* 160 years), one might be less willing to accept the presence of large trees on young stands (*e.g.* 20 years). Due to the high degree of variability associated with the age-diameter relationship, this sort of situation is not rare in the mast model output. Therefore, either a better description of the relationship or a more subjective or idealized application of variability may be warranted.

The formulation of the model is specific to forests in southern Missouri. The algorithm may be used in other ecosystem types; however, it is probable that the parameters would need to be altered and some information provided in the LANDIS output that was ignored in my formulation might be re-considered for other situations. For example, I did not utilize the species presence-absence information since an analysis of the local data revealed that oaks were distributed uniformly and predictably though out the forests of southern Missouri. However, LANDIS, as parameterized for other ecosystems, factors many more species (He *et al*. 1999) and since more species are considered, the presence or absence of oaks may be more pertinent.

Another improvement of the mast model algorithm would be to link the estimations of tree-level data among iterations of the LANDIS output. Currently, the algorithm stochastically assigns tree density, diameter, species distribution, and inherent mast production characteristics independently among iterations. Thus, a cell may change in character between the 20th and 30th year iterations. To some degree the algorithm compensates for this effect since the stand-level mast index is estimated from the average of many cells (a 30 ha stand is comprised of 333 cells). Setting the initial “seed” for the random number generator explicitly before running simulations ensures the same random numbers are assigned repeatedly. Thus, comparison among simulated treatments is not affected by stochastic variation among cells.

The relationship between tree size and mast production by species was scaled in a manner that produced a value that is roughly equivalent to a mass-per-unit-area value (kg acorns ha^{-1}). By using these two values interchangeably, I hope to convey the impression that the value is intended to be an index but may have a more tangible interpretation. Table VI.1 presents a summary from three sources of data for converting from the mass of acorns to the number of acorns by some species found in Missouri. If a modeler is interested in the number of acorns produced, the wide range in the relative weight of acorns (*e.g.* 0.4 to 3.1 g, air-dried) among species suggests that in the model, rather than distribution of trees among sub-genera, perhaps canopy trees should distributed among species.

Section III. Implementation and Behavior of the Spatial Component of the Masting Model

The coding of the model seems to simulate the desired relationships in the model algorithm. The tree density (TPC) and species group assignment routines in general assign stand characteristics typical of southern Missouri. The diameter distributions are not as well defined and estimation may need to be improved (see above). The results of ultimate interest (the mast indices) followed the expected pattern with respect to age and species groups. That is, as stands grew older, trees of the white oak group became more important contributors to the mast crop.

Table VI.1 Some conversion factors for estimating the number and mass of fresh and dry acorns per unit area (Adapted from Waller 1979, Downs 1944, and the MOFEP hard mast plot data).

	Interval between large seed crops [years] (Waller)	Acorns per kg (Waller)	Acorn Mass [g] (Waller)	Acorn Mass [g] Fresh (Downs)	**MOFEP** Air Dried Mass 93,95,97,99 [g $acorn^{-1}$]	**MOFEP** Acorns kg^{-1}	Estimated Conversion factor fresh to dry
Quercus alba	7	264	3.8	2.7	1.1	891	0.41
Q. coccinea	4	517	1.9	2.3	1.4	690	0.62
Q. falcata	1.5	1188	0.8		0.4		
Q. palustris	1.5	902	1.1		0.6		
Q. prinus	2.5	220	4.5	6.6	2.3		
Q. rubra	4	275	3.6	5.1	3.1	325	0.61
Q. velutina	2.5	539	1.9	1.9	1.1	927	0.57
Q. stellata					0.4	2816	

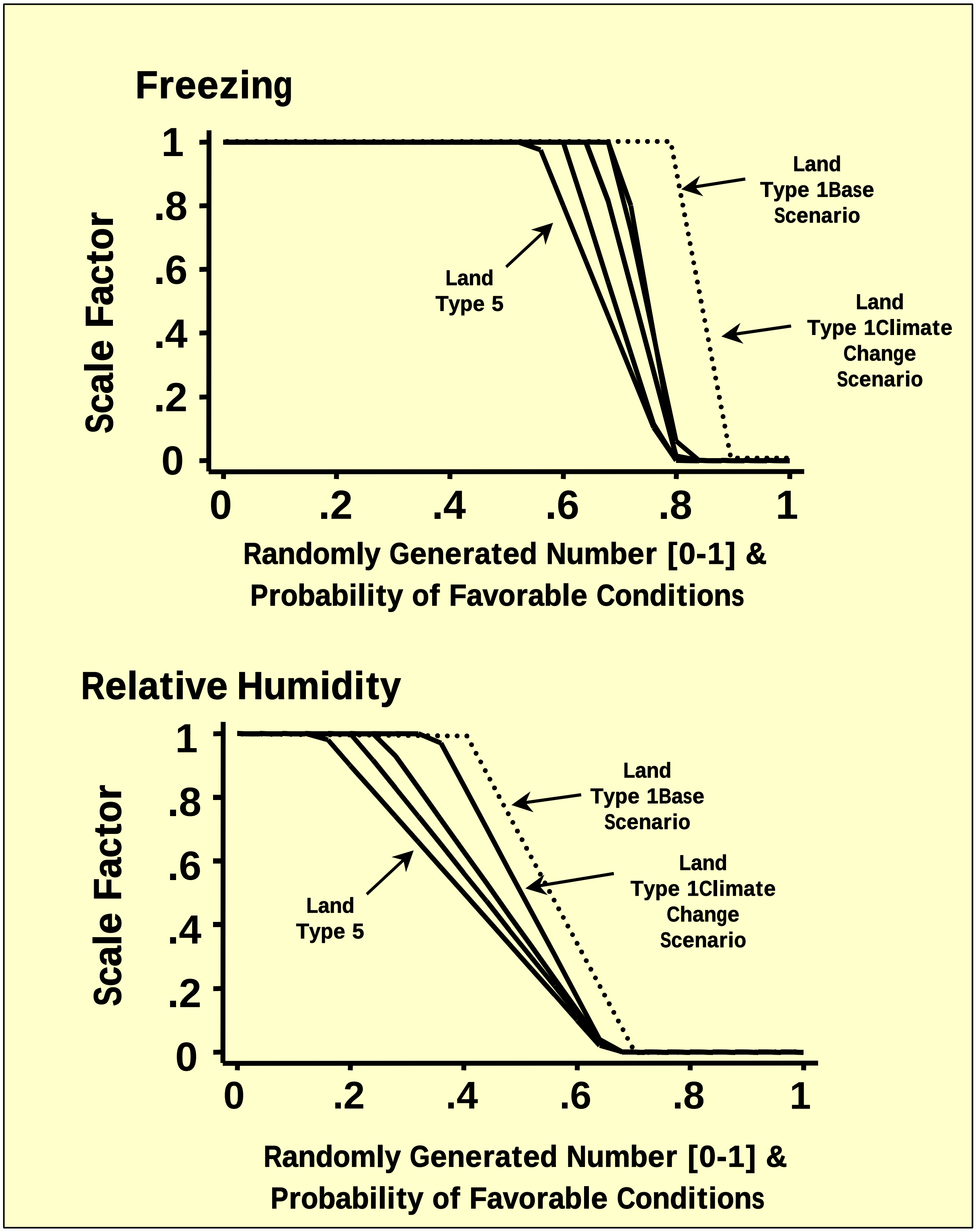
Sensitivity analysis revealed that in terms of predicting cell mast index estimates, the parameters for the distribution of canopy trees among oak sub-genera were the most sensitive to change. The diameter-age relationship and the TPC estimation were not nearly as sensitive to change. This was perhaps due to the application of a relatively small amount of variation to the species-distribution estimate versus the large amount of variation factored in predicting tree size and stand-cell density.

Running the model on the 3,216 ha test landscape provided data for generating maps of mast production. A more parsimonious re-formulation of this first version of the mast model may improve performance in terms of computer time and memory usage. In many cases, temporary variables can be created and immediately discarded rather than retained in active memory and later discarded. Another approach for improving model efficiency, would be to parameterize the model for a situation and run the model on only a sub-sample of the entire landscape and estimate the mean and variation in the cell-level mast production index (CMPI) as a function of the age of dominants and land type. A separate and much simpler model could then apply this relationships (CMPI = *f*(age and landtype) stochastically across the entire landscape. Once summarized at the stand level, the results of the simpler model should resemble the results of the complete model.

Section IV. Implementation of Annual Variability in the Masting Model

The model adding annual variability to the spatial model seemed to produce results similar to those seen in nature. The model could be improved by having more explicit information regarding the probabilities of growing season factors that affect mast production (*e.g.* hail, wind, insect predation, drought etc). Also, for this model the effects of microclimate are only hypothesized. I have subjectively estimated the probability of mast-limiting events and subjectively assigned the degree of influence these events have on different land types. This is clearly an opportunity for further research. The recently evolving availability of precociously fruiting oak trees that are small enough to enclose in greenhouses and growth chambers provides one such opportunity.

To look at how global climate change might affect mast production, I reviewed some internet-based sources of information and ran the mast model on one scenario. There is no general consensus regarding how the climate in the mid-west U.S. will be affected, particularly regarding relative humidity. However, one common prediction is that while, in general, the average temperatures will rise, the weather patterns will become more erratic and relative humidity will rise (Watson et al. 1997; EPA 2000; Green 2000, WMO 2001). For my simulation, I interpret this to mean that, i) since flowering is triggered by cumulative heating in the spring, flowers may mature earlier but since the climate is more erratic, there is a higher probability of freezing damage, and ii) higher relative humidity will increase the likelihood of poor flowering conditions. Figure VI.1 depicts the amount of the change of influence on freezing probability and relative humidity effect that I factored in this simulation. Basically, the probability of freezing was doubled and the influence of relative humidity altered to a lesser extent. The simulation was run on the output of the spatial mast model for the even-aged management 90th year iteration with and without the climate change using the same initial random number seed. The results suggest a relatively small impact of climate change (given this scenario) on total mast production (Figure VI.2). There were some years (2,8,9,10) of the simulation that under the base climate parameters produced a small



Freezing

Relative Humidity

Figure VI.1 Change in the scale factors under the climate change scenario. A random number is generated and the influence of the factor (scale multiplier) is derived from the relationships shown.

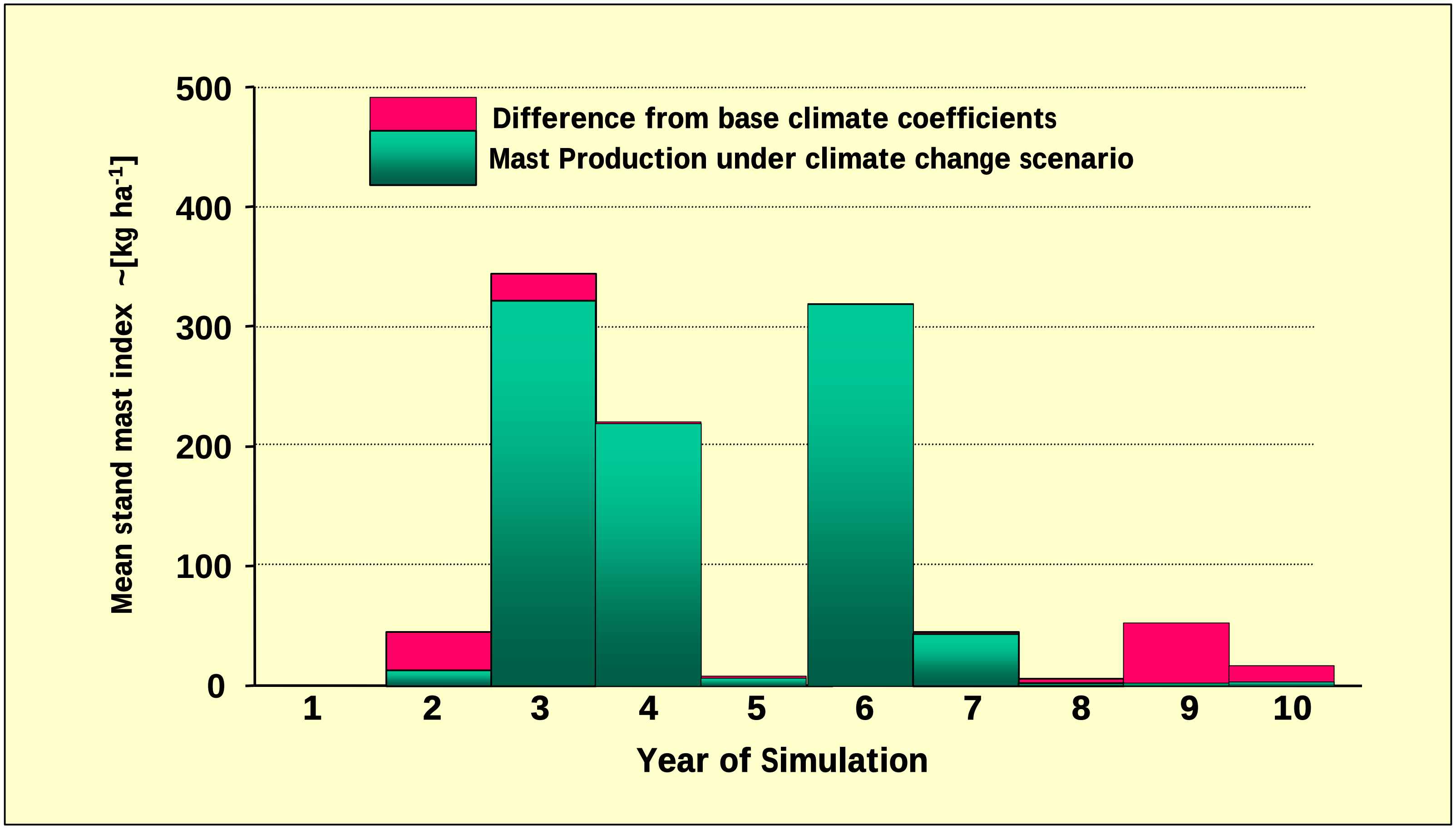


Figure VI.2 The change in mast production under a climate change scenario that increased the frequency of freezing events during flowering stages and increased probability of high relative humidity.

amount of mast (<50 kg ha^{-1}) while during those same years little or no mast production occurred. Most high mast production years were not affected at all.

Section V. Allocation of Resources: The Trade-off Between Vegetative Growth and Acorn Production.

The results of the study of resource allocation to mast production suggest that, although vague, there is reason to suspect that there is a measurable trade-off in resources between acorn production and diameter and following year shoot-length growth. As mentioned above, there may be an opportunity for studying this possible relationship using precociously flowering and fruiting oak trees. Early fruiting is as inherited trait and may also be an indicator of overall tree vigor.

CONCLUSION

The masting model algorithm provides a framework for adding tree-level detail to a landscape model (LANDIS). A mechanistic approach was adopted to assign characteristics to cells that might affect mast production. These characteristics were then used to estimate mast production. While the parameters and formulation would change, this general approach can be used to address other research questions mechanistically.

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VITA

Neal Sullivan was born March 7, 1960 in Peabody, Massachusetts. His first exposure to natural resource issues in an academic setting was at Essex Agricultural and Technical Institute in Hathorne, Massachusetts where he attended high school. After graduating, he entered the military, was stationed in Germany and after three years, returned to the U.S. to continue his education. He received the following degrees: an A.A.S. in Natural Resources Management from Essex Agricultural and Technical Institute at Hathorne, Massachusetts (1985) ; a B.S.-Forestry and an MSc. in Natural Resources from the University of New Hampshire at Durham (1989 and 1993, respectively): and a Ph.D. in Forestry from the University of Missouri at Columbia (2001). He is married to Michelle Boone formerly of Goose Creek, South Carolina and is presently a Post-Doctoral Research Fellow with the Department of Forestry at the University of Missouri, Columbia.