SECTION III: IMPLEMENTATION AND BEHAVIOR OF THE SPATIAL COMPONENT OF THE MASTING MODEL

III.1 INTRODUCTION

The objective of this section is to examine the performance of the spatial component of the masting model. Specifically,

i) How do the modeled intermediate values (*e.g.* diameter distributions, number of trees per cell) compare to real world inventories and how do these values change through simulation time (iteration)?

ii) How sensitive is the model to variation in parameter values in terms of intermediate values, such as tree diameter distributions, and ultimately mast production at the stand level?

iii) How are the intermediate values and masting predictions influenced by simulated management regimes, *e.g.* uneven-aged management versus even-aged management?

iv) What does the model predict about acorn production across the landscape?

To accomplish this, since possible permutations of the model are infinite, I limited the comparisons by examining model output from only the 30-year and the 90-year LANDIS iterations and by evaluating the relative influences of parameter variation on mast production. The MOFEP stands were established between 70 and 90 years ago (D. Larsen, pers. comm.). The 90-year iteration was selected to facilitate comparisons to MOFEP inventory data and the 30-year iteration for demonstrating changes in estimation through time. Parameter influences were evaluated by varying their distribution properties (mean and standard deviation) while holding all other parameters at their base values. Detailed methods are specified along with the results in the section following this introduction.

To increase the capacity of the mast model to process extensive landscapes, most of the individual "tree" level data is discarded when no longer needed for subsequent calculations. The WINDOWS™ based version of STATA limits the number of variables to 2,047 and running the mast model on the 10 iteration test-case would attempt to produce more than that limit and thus fail. In addition to failing due to variable number limits, model performance would be curtailed by RAM requirements. One version of the test-case model, retaining about 1,700 of the variables for the 36,237 cells required more than 200 MB of RAM. Thus, STATA if run on a computer with less hardware memory begins to use virtual memory and operates very slowly. There are several solutions to these problems. The model could be re-formulated to limit the number of iterations that are processed; however, I have chosen not to do this because I envision a future version of this model where some values assigned to cells are influenced by previous cell values. For example, under the current formulation, the ratio of white oaks and red oaks for any particular cell is re-estimated for each iteration. Clearly, forest structure ten years from now is influenced by current forest structure. Despite this limitation, the current formulation is still appropriate for evaluating mast production across the entire landscape rather than at the cell level. I have chosen instead to run all the iterations but retain information only for the first tree generated for each cell. With over 36,000 cells for the test-landscape, an adequate number of trees are retained to examine distributions and characterize model performance across the range of ages and land types.

For parameter comparisons, the output from the even-aged management was examined. A separate sub-section addresses the differences in predicted mast production due to management regimes.

III.2 MODEL PERFORMANCE

III.2.1 Model performance: Methods and results

In general, I will address the behavior of the model in the order in which it develops the landscape and mast production indices (Figure III.1) emphasizing the output of the 90-year iteration since it is presumed to most closely approximate the age of the MOFEP stands. The topic in this section bears an interesting relationship to that of the previous section. In Section II, I specified and justified the relationships among the important variables in the model. In this Section, I describe the intermediate variables and ultimate mast production that is estimated in the model. Therefore, in essence, since I defined the model behavior through a programming language, most of this Section is a validation of the code itself. If the mast model does not generate reasonable predictions, then the code may be faulty. The influence of land type on the ratio of oak sub-species, TPC, and diameter is addressed in the sensitivity analysis

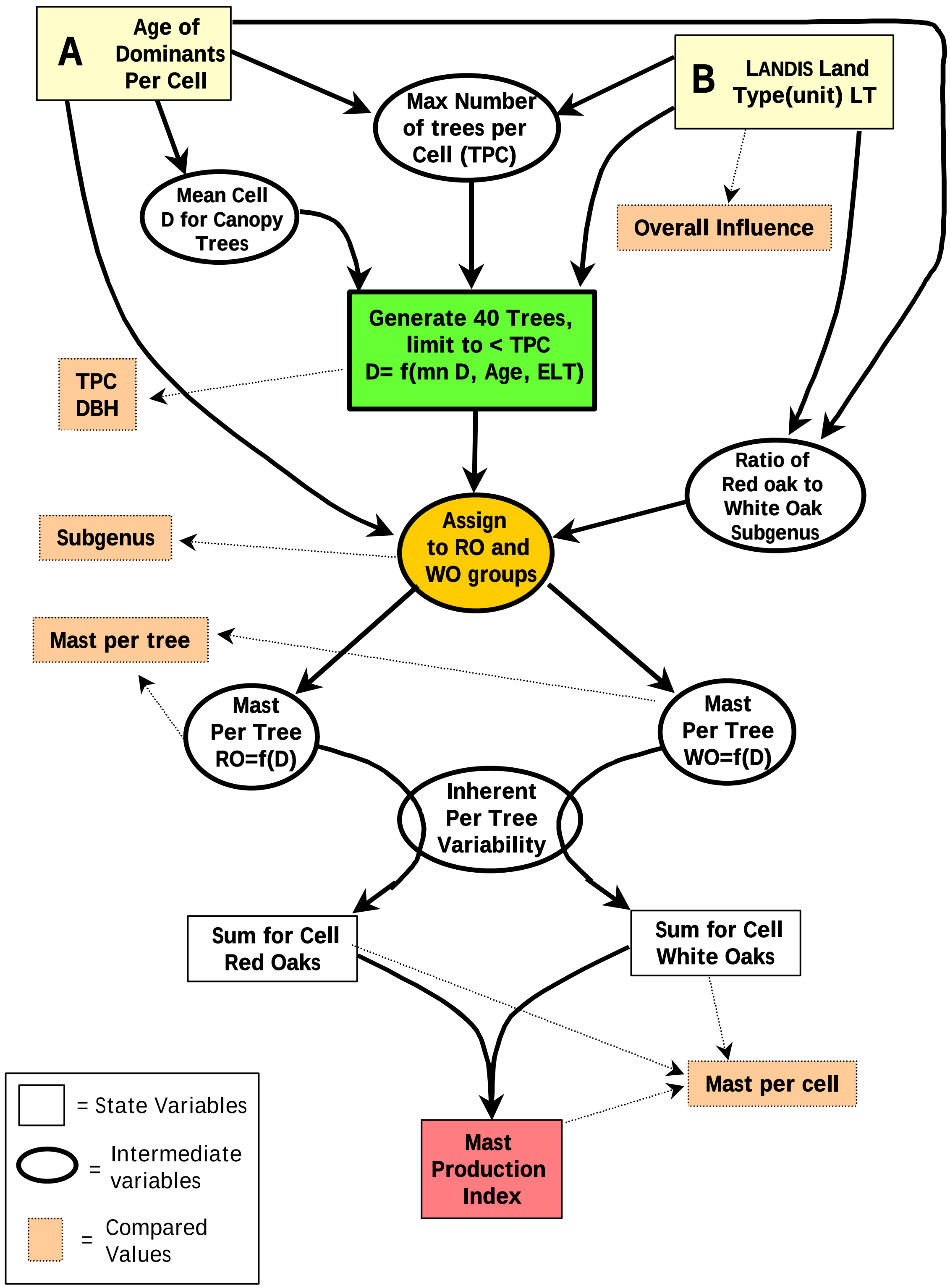

Figure III.1 . Flow Chart of mast production model for sites in southern Missouri with values compared highlighted.

III.2.2 Model Performance: Trees per cell

To begin, Table III.1 lists simple descriptive statistics for important variables for the test landscape for the 30 year and 90 year iterations. These values are compared to similar statistics generated from the MOFEP and FIA inventories as well as the applied values (often an amalgam of the MOFEP and FIA inventories along with. expert opinion and interpretation of values present in the literature). Comparison of these values to the MOFEP inventory is complicated by uncertainty about the age of the MOFEP stands. I am presenting the 90th year of simulation, although the mean age of dominants as specified in the LANDIS output is about 84 years. On average, the MOFEP sites are probably younger than 84 years; therefore, one might expect differences between the values generated in the mast model and the values generated from the inventories.

The mean TPC (trees per cell) generated by the model is 18.6 and 16.3 for the 30 and 90 year iterations, respectively. About 6 percent of the assigned values are 0 or less (Figure III.2) for the 30 year simulation (e.g. 2192 of 36235 cells) and slightly less (5%) for the 90 year simulation. Having zero trees per cell does not imply a forest cell without trees, rather, it is a cell without any oaks in a canopy position. About 7 percent of the FIA plots statewide do not have oaks in canopy positions; however, all but one of the 645 MOFEP plots have oaks in canopy positions. In Section II, I reported 14.3 as the mean TPC for the MOFEP sites. The values estimated and used in the model are higher than similar statistics for the MOFEP sites. In fact, if the TPC values below 0 are disregarded, the mean TPC is even further (17.4 at 90 years) from the mean MOFEP TPC. However, this value for TPC is generated prior to assignment of a diameter and some number of the individual trees included in TPC are assigned DBH values of less

Table III.1 Summary of intermediate estimated values and mast production index for the even-aged management alternative for the Oregon County 36,235 cell test landscape.

Variable	Simulation Year	N	Percent of Total	Mean Index Value	Std Dev	Minimum Value	Maximum Value
Age of Dominants (yr)	30-year			63.6	30.0	10	100
	90-year			84.6	49.1	0	160
Trees per Cell (0.09 ha)	30-year			18.6	12.4	-40	82
	90-year			16.3	12.0	-39	84
Dbh (>5 cm)	30-year	33787	93.2	31.91	12.70	2	99
	90-year	34150	94.2	33.96	13.85	2	1109
Cell Fraction Red Oak	30-year			0.56	0.06	0.47	0.64
	90-year			0.47	0.14	0.19	0.64
Cell Fraction Red Oak	30-year			0.59	0.09	0.22	0.89
(land unit and random variability adjusted)	90-year			0.50	0.16	0.02	0.92
Tree Mast Index							
Red Oak Group	30-year	13998[1]	38.6	2.53	3.42	0	15.15
White Oak Group	30-year	11079	30.6	2.02	2.49	0	14.01
Red Oak Group	90-year	11987	33.1	2.74	3.65	0	15.15
White Oak Group	90-year	14410	39.8	2.56	2.88	0	14.01
Cell Mast Production							
Red Oak Group	30-year			17.24	22.61	0	164
White Oak Group	30-year			6.95	11.96	0	99
Red Oak Group	90-year			12.67	19.26	0	162
White Oak Group	90-year			10.28	15.06	0	115
Cell Total	30-year			24.19	20.36	0	164
	90-year			22.95	18.36	0	162

1. Number of trees with assigned mast production greater than 0

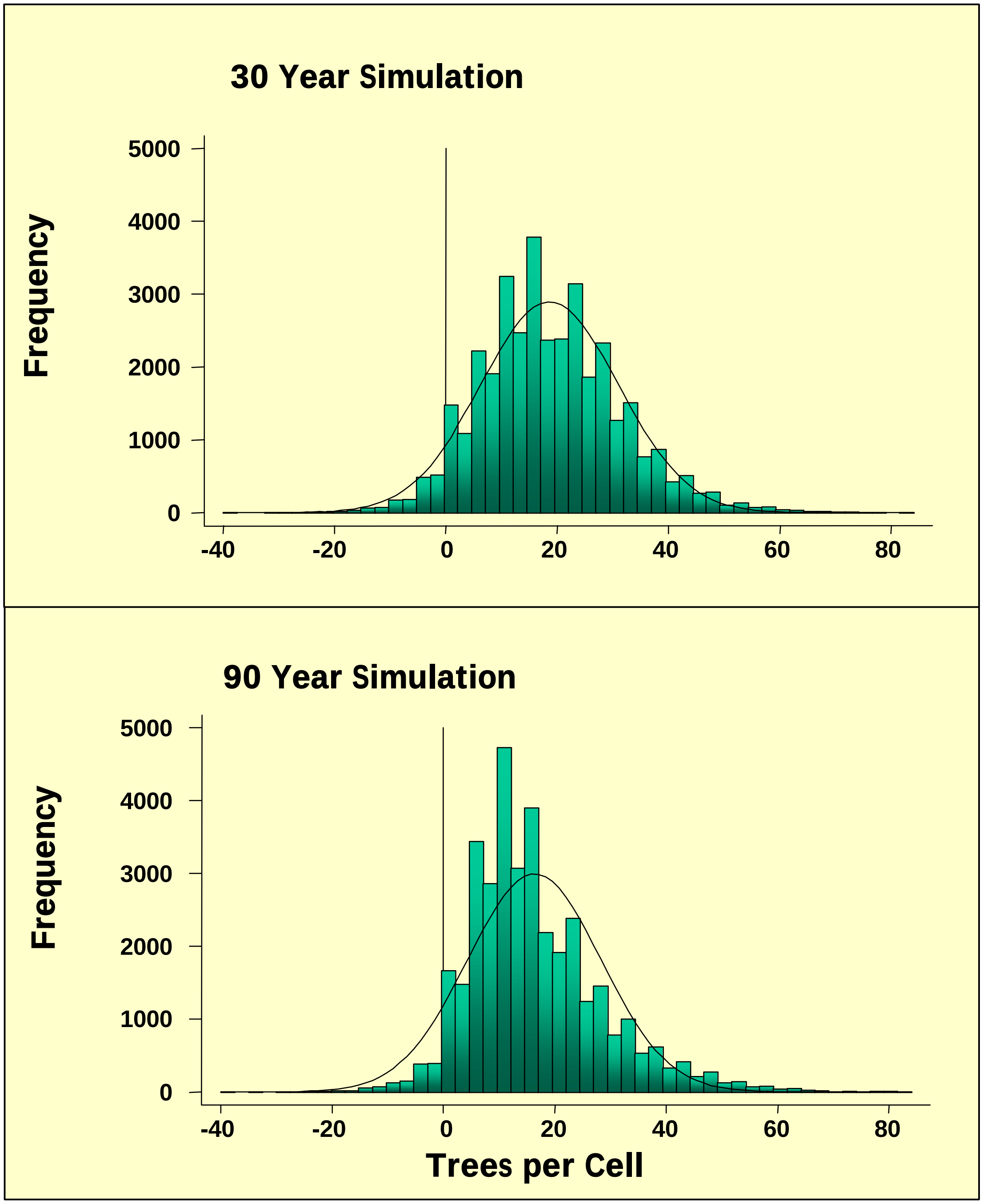

Figure III.2 Frequency distributions of the number of trees (canopy oaks) per cell for two iterations of the masting model. The 36,237 cell test landscape was divided into 50 bins to produce the bars. The superimposed curve is an idealized normal distribution based on the mean and variance.

than 0 and thus become “non-trees”.   It is not possible to determine the TPC that acts in the model without re-writing the model to retain all canopy “tree” data.   Since the objective of this model is to produce a relative index, determining the applied TPC may not be worthwhile.   For this model, a slightly higher TPC may be justified since I have subjectively limited acorn production to dominant and co-dominant trees and ignored potential production by trees in intermediate and other canopy positions.

In terms of more common expressions of tree density, the TPC for the 90th year iteration converts to 181 and 71 canopy trees per hectare and acre, respectively. Factoring all species, the MOFEP plots average about 370 trees of all species (>12.7 cm in DBH) per hectare (150 trees per acre).

III.2.3 Model Performance: Diameter Distributions

The overall applied mean DBH for canopy oaks is about 32 cm for the 30th year of simulation and about 34 cm for the 90th year of simulation.   It should be noted that while the simulations are 60 years apart, the landscape base data set does not begin universally at age 0, that is, there are a range of ages in the initial landscape. Also, management and natural sources of landscape change are taking place. This is exemplified by noting the mean age of cell dominants (Table III.1) that differ by only 21 years between the 30- and 90-year iterations.   In addition to having a higher mean DBH, a higher standard deviation is attached to the 90. This is due in part to fewer trees being assigned a negative diameter and thus becoming non-producing trees (the normal distribution is curtailed).   From a pragmatic perspective, the slightly higher DBH and wider standard deviation produces a greater number of trees in the larger diameter classes and these trees are particularly important for producing acorns. Since the diameter values are assigned randomly to the trees for each cell for each iteration independently, there is limited value in comparing values between the 30- and 90-year simulations. However, when summarized by stand (the organizational unit upon which management treatments are performed), while mean DBH still only differs by about 2 cm, the maximum mean DBH differs by about 12 cm (38 cm at 30 years and 50 cm at 90 years). This is a positive indication that the diameter assignment routine is working as intended. The distribution of diameters by cell-age-of-dominants is shown in Figure III.3. The increased presence of white oak in higher age classes is indicated by the increasing point density.

The general procedure for parameterizing the mast model involved examining both MOFEP and FIA data, each inventory having different inherent interpretational problems, and developing and adjusting parameters with consideration for both inventories. Therefore, the values generated by the model are not expected to match either inventory.

Regarding diameter assignment relative to inventory data, the mean DBH for canopy oaks on MOFEP sites is 29 cm (SD = 10.5) whereas it is slightly higher as applied in the model (34 cm for 90th year [SD = 13]). Again, given the uncertainty regarding the age of the MOFEP stands, that FIA data were largely the source of the age-diameter relationship, and the overall objectives of the model (predicting relative mast production), the difference between the MOFEP data and the values in the model is probably not important. The use of the normal distribution for assigning tree DBH is aided by two characteristics of this modeling situation. First, since only canopy trees

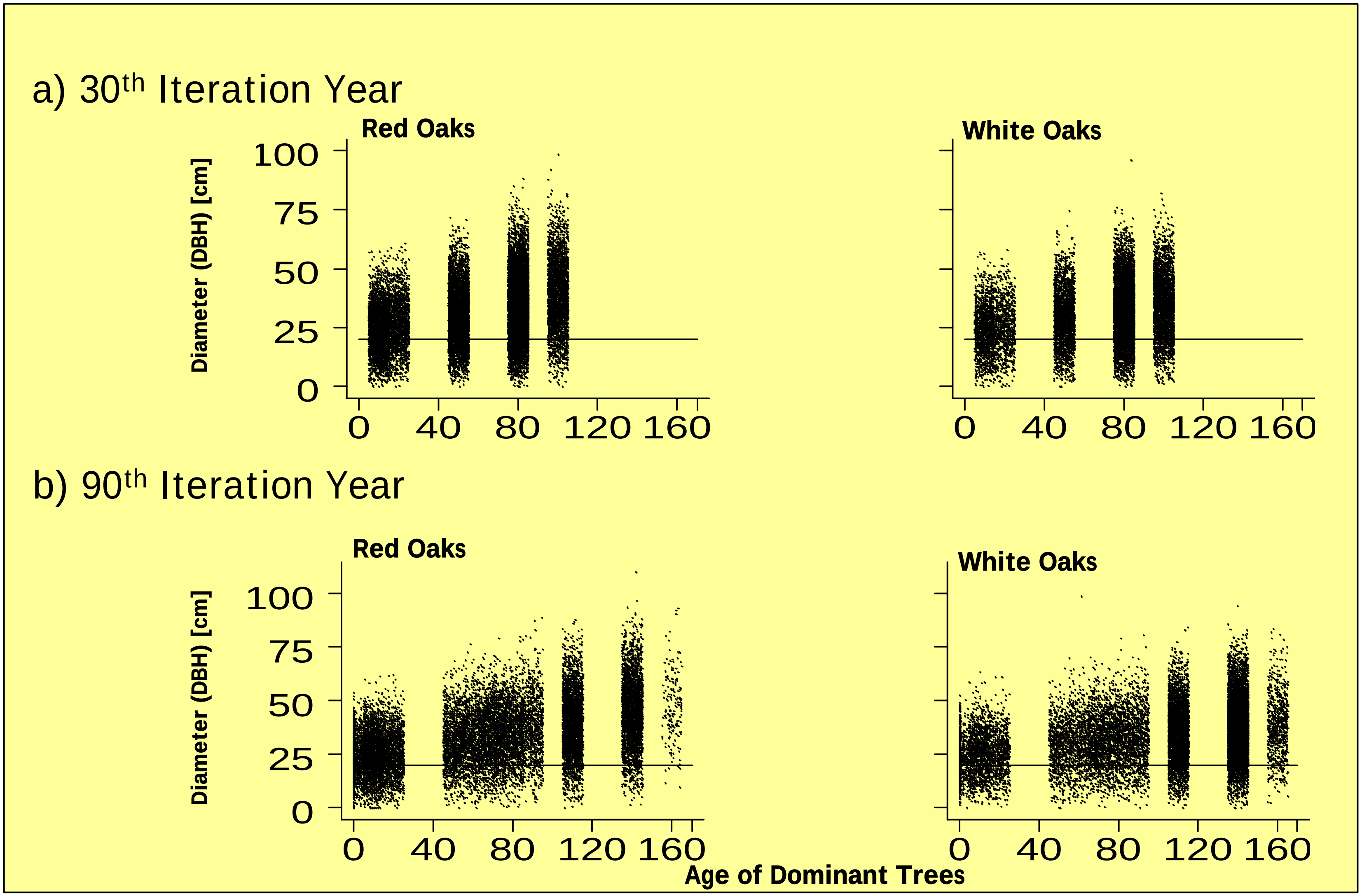

Figure III.3 The variation in age diameter assignment at each age class and among species groups and simulation iterations. Random noise has been added to accentuate point density differences (i.e. each point, when plotted was shifted slightly so that points would not be superimposed).. Each point represents the value assigned to the first tree generated by the model. The horizontal line at 20 cm indicates the minimum tree size for mast production.

produce acorns, only canopy trees are modeled, thus the usual inverse-J shape of diameter distributions takes on a more normal appearance for the assigned diameters (Figure III.4-a). Second, since smaller diameter trees do not produce many acorns, the underestimation of the number of trees between 20 and 30 cm (Figure III.4-b) is not important to mast estimate.

As mentioned in the introduction, the influence of Land Type on diameter and TPC is addressed in the sensitivity analysis below. That is, there are differences due to land type because of the influences landtypes have on these factors.

III.2.4 Model Performance: Subgenus assignment

The subgenus assignment routine is carried out by estimating the proportion of canopy oaks that are in the red oak group using the age of dominants and land type and adding random variability. This value is referred to as Cell Fraction Red Oak (CFRO). The beginning value is based on FIA and MOFEP data and changes with stand age. In general, more than half of the canopy oaks are in the red oak group in stands less than 90 years of age and less than half are red oaks in stands greater than 90 years in age (Section II: Table II.15). Unadjusted, the values in the model reflect this relationship with 56% of the canopy trees assigned to the red oak group for the 30th year iteration and 47% for the 90th year (Table III.1).

When adjusted for Land Type influence and adding random variability, the CFRO value is increased by about 3 percent. This is probably due to the uneven distribution of area among Land Types. The CFRO adjustment scalers for Land Types 1, 2, and 3 are all at or above 1.0 (Table III.2) and these land types comprises 95 percent of the test

Table III.2 Influence of Landis land-type for the three factors where land-type alters mast production.

Land Type		Test Case Number of Cells	Hectares	Trees per Cell	Diameter	Fraction Red v. White Oak
				--------------*Scale Factor*----------		
1	South and West	13367	1203	1.119	1.001	1.040
2	North and East	12720	1145	0.993	1.082	1.040
3	Flat	8335	750	1.164	1.164	1.169
4	Savanna/Glade	133	12	0.856	0.870	0.912
5	Upland drainage	1507	136	0.867	0.956	0.830
6	Limestone	38	3	1.105	0.964	1.028
7	Mesic	135	12	0.895	0.965	0.982

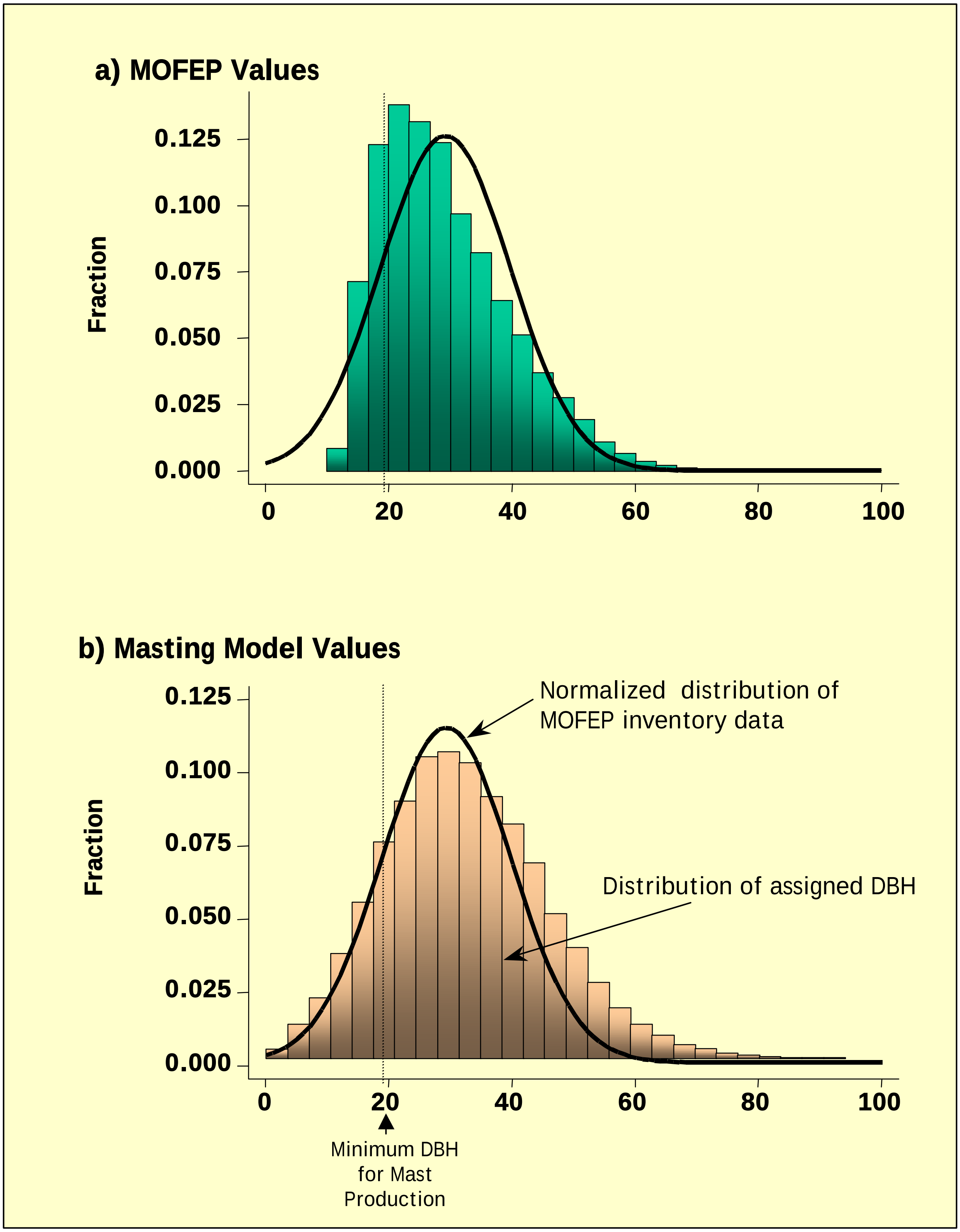

Figure III.4. A comparison of MOFEP diameter distribution (a) (dominant and codominant oaks >12.7 cm DBH) and DBH values assigned in the masting model (b).

landscape. After the adjustment for the age of dominants and Land Type, the distributions of CFRO begin to take on some interesting characteristics. As simulation time passes, practices such as even-aged and uneven-aged forest management alter the age distributions across the landscape resulting in different application of CFRO. The distributions are relatively normally distributed at 30 years but are flattened and may become bi-modal after 90 simulation years (Figure III.5).

III.2.5 Model Performance: Tree mast production indices

The mean tree mast production index (TMPI) generated in the model is higher for the red oak group than the white oak group for both the 30 and 90 year iterations although the difference at 30 years (2.53 – 2.02 = 0.51) is greater than the difference at 90 years (2.74 – 2.56 = 0.18) (Table III.1).   The closing of the gap is expected since older (larger) red oaks produce fewer acorns and the fraction of red oaks (CFRO) declines by about 9 percent between the 30th and 90th years of simulation.   The maximum values are identical for each species, since production is modeled by diameter to reach a maximum value when the tree is at its most vigorous age and then decline. The influence of tree diameter is shown in Figures III.6 and III.7. Random variability was not added to these values since diameter was already randomized. The effects of modeling randomly assigned inherent differences in tree level mast production are also shown. The decreasing point density at higher diameters and TMPI indicate the modeled relative rarity of tree with high mast production potential.

The value given for the number of mast producing trees listed in Table III.1 is interesting but difficult to interpret (*e.g.* 13,998 for 30th year red oak). Only the values

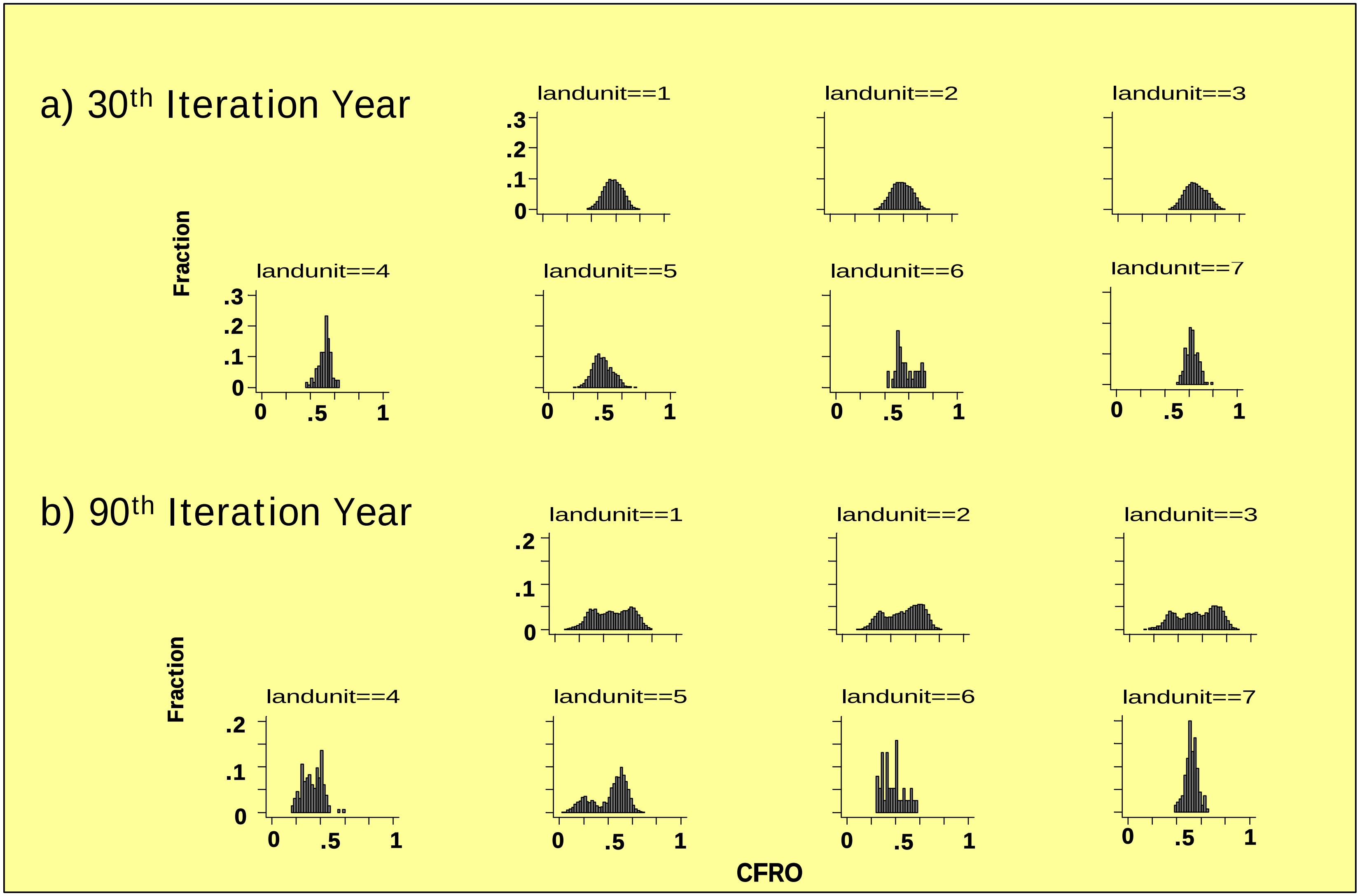

Figure III.5 The effect of Land Type on the distributions of the fraction of canopy oak trees assigned to the red oak group (CFRO). The values are a function of the age of dominants and are presented after adjusting for land type and adding random variability. The effect of differing management practices becomes more apparent for the 90th simulation year.

for the first tree generated by the program (maximum 40 and realized mean of about 17 trees) are retained. Therefore, when tree level data are reported (diameter and mast production), the statistics are for only that first tree which may be assigned non-acorn producing status due to diameter or inherent genetic variability. The cell-level values include the mast production from that first tree, if any, and from all the other trees that were discarded. Nonetheless, the relative values are informative. At 30 years into the simulation, the number of mast producing red oaks exceeds the number of white oaks by about 2900 or 26 percent. At 90 years, the number of mast producing red oaks is 16 percent less than the number of white oaks. That value coupled with the mean index value suggests that across the landscape, not only is the difference between the species decreased at 90 years on an average basis, but white oaks actually produce more acorn mass than red oaks.

III.2.6 Model Performance: Cell mast production indices

The Cell Mast Production Indices (CMPI) are merely the sum of the individual tree level indices by cell. Since the differences between mast of the red and white oak groups are important, the values are reported both separately and combined. At the 30-year iteration (Table III.1), when red oaks are the more vigorous producers of acorns and more abundant, red oaks on average out-produce the white oaks (CMPI = 17.2 versus 6.95). However, at the 90 year iteration the gap has closed to only about 2.5 CMPI (Table III.1). The lower productivity of red oaks with advancing age results in an actual decrease in average total cell mast index (24.19 versus 22.95).

This cell level total mast index (CMPI) is the first predicted value generated that is based on an area (a cell = 900 m^2). Until this stage in the model, the index has not been related to any absolute values (*i.e.* number or mass of acorns). The CMPI is largely determined when the range of the scale is assigned for factoring the acorn production by diameter relationship. This scale is currently set for a maximum value of about 15. Random variability allows the value to slightly (0.15) exceed the set point of 15 (Table III.1; Figures III.6 & 7). This maximum amount (15) was chosen because on an area basis the predicted mast production begins to be similar to a particular metric often reported in the literature, kg ha^{-1}. For example, the maximum production of acorns that I found in the literature was about 1620 kg ha^{-1} for a site in Indiana (Johnson 1975). If the per cell total value is converted to a similar unit (divide by $900m^2/10000m^2$ ha^{-1} or 0.09), the maximum CMPI (163) value is about 1800 kg ha^{-1} and the mean value about 256 kg ha^{-1}. Gysel reported a similar average for masting years from 1953 to 1956 in Michigan (1957). Drake (1991) reported an average of about 250 kg ha^{-1} for sites in Pennsylvania. Dickson (1990) noted a lower mass (about 162 kg ha^{-1}) for oak sites in Arkansas. Acorn production in Michigan, Illinois, and Pennsylvania might be expected to exceed that of Missouri due to site quality differences. However, the index values generated by this masting model at this point in the modeling process are before any modifications associated with the influence of climate. Thus, the predicted realized acorn production will usually be lower once climate influences are factored.

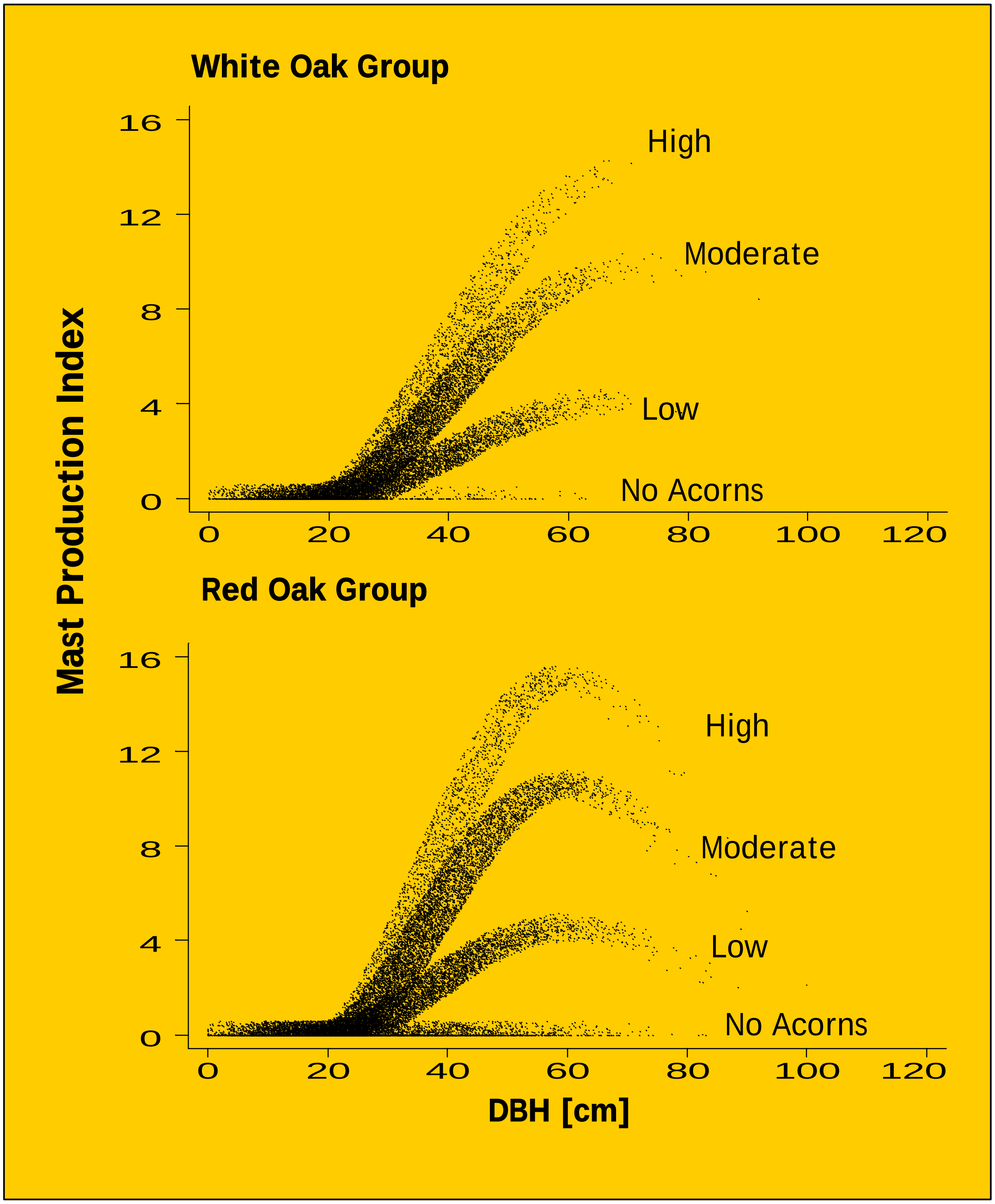

Figure III.6 . Mast production index per tree for red and white oak groups by productivity class for the Landis 30th -year of simulation. Random noise was added to each point to accentuate point densities (i.e. each point, when plotted was shifted slightly so that points would not be superimposed).

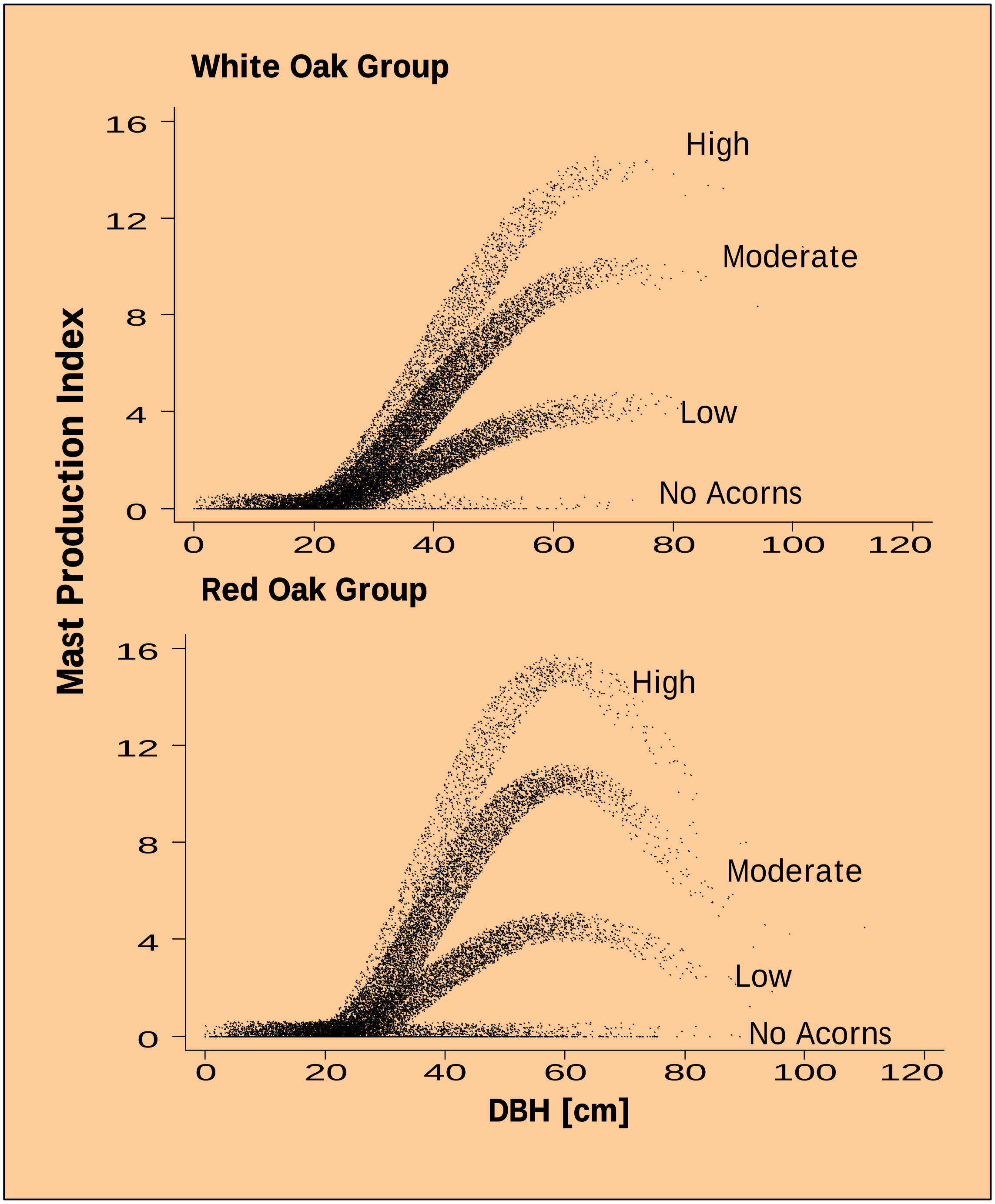

Figure III.7 . Mast production index per tree for red and white oak groups by productivity class for the Landis 90th -year of simulation. Random noise was added to accentuate relative point density (i.e. each point, when plotted was shifted slightly so that points would not be superimposed).

III.3 SENSITIVITY ANALYSIS

III.3.1 Sensitivity analyses: Introduction

Sensitivity analysis was performed to help identify crucial relationships in the model. That is, to help determine the magnitude of change in mast production if parameters are changed; thus, sensitivity analysis helps identify those relationships that are most important and those relationships for which more or better information is needed. In addition, factors that have little influence on mast production may be eliminated from the model.

Sensitivity analysis was not done on all the coefficients in the model. Tables III.2 and III.3 list all the coefficients. Sensitivity analysis was performed by simply altering individually many of the coefficients by ±15 percent while keeping all other coefficients at their base level (the values applied in the original model). For example, the slope of the relationship between TPC and the age of dominants was altered from -0.099 to -0.084 (Table III.3) for the first sensitivity test. Since some of the altered parameters are slope coefficients in linear regression models and these coefficients may be negative, the effect of a negative adjustment on mast production may be positive. Consequently, I will concentrate on the absolute value of the resultant change in mast production rather than the sign of the change. However, the positive and negative changes in the model coefficients do not result in changes in estimated mast production of equal absolute change. This is due to the nature of the model. For example if a coefficient increase

Table III.3 A listing of the coefficients used in the masting model and the coefficients substituted in the sensitivity analysis. If no alternative coefficient is listed, this type of analysis was not performed.

				Change in Coefficient for Sensitivity Analysis	
Relationship			**Base Coeff.**	**-15 %**	**+15%**
TPC					
	Mean	slope	-0.099	-0.084	-0.114
		constant	24.1	20.485	27.715
	SD	slope	-0.08	-0.068	-0.092
		constant	16	13.600	18.400
Age-Diameter					
	Mean	slope	0.14	0.12	0.16
		constant	21.5	18.28	24.73
	SD	slope	0.04	0.03	0.05
		constant	9	7.65	10.35
Sub-genus division of Oaks					
	Age Class				
		slope	-0.0000179	-0.000015215	-0.000020585
		constant	0.644	0.5474	0.7406
Variation in sub-genus division					
			0.05	0.0425	0.0575
Species Diameter Adjustment					
		slope	-0.0010492	-0.00089182	-0.00120658
		constant	1.010843	0.85921655	1.16246945
Mast Production per tree = f(D)					
	Red Oaks				
		d	-3.361032		
		d^2	0.1279035		
		d^3	-0.0017115		
		d^3	7.52E-06		
		constant	28.65		

Table III.3 (continued)

White Oaks	
d	-1.4629095
d^2	0.0567975
d^3	-0.000705
d^4	2.84E-06
constant	11.85
Inherent Variability	
Fraction of Population	
non-prod	0.15
low prod	0.30
mod prod	0.40
high prod	0.15
Relative Production Rate	
non-prod	0
low prod	0.3
mod prod	0.7
high prod	1

widens the range of the distribution of diameters from which trees are assigned values, all trees assigned to be < 20 cm in diameter will have zero acorn production; whereas there will also be an increase in large diameter trees but there is not a linear relationship between tree size and mast production (the largest trees are not the most productive in terms of mast). Since, increasing and decreasing the parameters might have different effects, both were tested ($\pm$15%)

III.3.2 Sensitivity analyses: Land type

Sensitivity analysis did not examine differences due to Land Type influences. Land type affects three variables: trees per cell, diameter, and the fraction red oak. Altering these scaler variables (Table III.2) would, in essence, be testing the sensitivity of the model to TPC, DBH, and CFRO, parameters for which sensitivity analysis is conducted below. However, examination of these scaler variables reveals patterns of potential acorn production. For example, Land Type 5 (Upland Drainage) would tend to have 15% fewer canopy oaks per cell (factor 0.856), trees of reduced diameter (0.956), and a lower fraction of red oak (0.830). In most circumstances, reduction of all these factors would result in lower mast production, although in the higher size classes, a reduction in diameter would increase mast production.

III.3.3 Sensitivity analyses: Tree level mast production and inherent variability

Sensitivity analysis has not been conducted on the relationship between tree size and mast production. The nature of the function used to model the relationship is such that simple analysis would be difficult without substantially rewriting the model. To a limited extent the sensitivity testing on factors that affect diameter are also testing mast production sensitivity. For example, an alteration that increases (on average) the diameter would shift the functions shown in Figures III.6 & 7 to the right, since the diameter is greater, the functions would also generate higher index values (usually).

Sensitivity analysis with respect to inherent variability would not be particularly interesting and informative in terms of sensitivity since most of the variability in the model is implemented through random assignment of TPC, DBH, and CFRO. Altering the rates of production and the distribution of trees among productivity classes would merely alter the mast production by the amount specified by the selected coefficients that were applied. However, altering these values relative to management practices does have mast production implications. For example, reducing the proportion of trees that do not produce acorns should increase acorn production. This issue is addressed at the end of this section along with other management consequences.

III.3.4 Sensitivity analyses: Results

As stated above, the model was run for the 30th and 90th iterations using the base parameter values and then run an additional 26 times, each time increasing or decreasing by 15 percent. At the end of this analysis the mean mast index value per cell by species group was evaluated relative to the base values (Table III.4(a)).

Table III.4 includes a column that reflects the percentage of change in the response variable (mast index by species) relative to the base parameter conditions. In addition, I have added a column that graphically indicates the magnitude of the effect. An asterisk is added for each 7.5 percent change in the mast index greater than 15

Table III.4 Results of parameter sensitivity testing of LANDIS even aged output. Each parameter was varied by 15 percent and the mean cell mast index value per species is the test variable. The magnitude of changes greater than 15% are indicated by the asterisks.

	Test Parameter		Simulation Year	Species Group	Parameter Variation Percentage	Mean Mast Index per Cell	SD	Maximum	Percentage change from base	7.5% difference per asterisk over 15%
a)	**Base Coefficients**		**30**	**Red Oak**		17.24	22.61	164.43		
				White Oak		6.95	11.96	98.53		
			90	**Red Oak**		12.67	19.26	162.33		
				White Oak		10.28	15.06	114.53		
b)	**Trees per cell: Mean**	**Slope**	**30**	**Red Oak**	+15%	16.28	21.71	147.90	-5.59	
					-15%	17.81	23.09	154.52	3.31	
				White Oak	+15%	6.48	11.45	98.97	-6.74	
					-15%	7.58	12.74	94.63	9.07	
			90	**Red Oak**	+15%	11.85	18.57	160.19	-6.48	
					-15%	13.68	20.29	155.53	7.96	
				White Oak	+15%	8.86	13.41	102.49	-13.86	
					-15%	11.83	16.86	133.10	15.10	
		Constant	**30**	**Red Oak**	+15%	20.34	25.26	182.75	17.97	
					-15%	13.92	19.99	156.89	-19.28	*
				White Oak	+15%	8.36	13.76	107.31	20.25	*
					-15%	5.63	10.38	96.95	-19.00	*
			90	**Red Oak**	+15%	15.26	21.89	177.83	20.48	*
					-15%	10.30	16.96	159.11	-18.72	
				White Oak	+15%	13.52	18.52	130.86	31.50	**
					-15%	7.38	12.01	100.60	-28.20	**

Table III.4 **(cont.)** Sensitivity analyses results**.**

c)	**Trees per cell: Variation**	**Slope**	**30**	**Red Oak**	+15%	17.14	21.93	154.09	-0.60	
					-15%	17.13	22.87	163.02	-0.65	
				White Oak	+15%	6.87	11.68	90.41	-1.10	
					-15%	6.96	12.35	98.24	0.11	
			90	**Red Oak**	+15%	12.82	18.91	146.69	1.20	
					-15%	12.90	19.90	152.54	1.82	
				White Oak	+15%	10.20	14.30	117.79	-0.77	
					-15%	10.25	16.00	132.23	-0.25	
		Constant	**30**	**Red Oak**	+15%	17.11	23.75	171.74	-0.77	
					-15%	17.22	21.25	150.04	-0.10	
				White Oak	+15%	7.03	12.76	107.76	1.15	
					-15%	6.90	11.38	92.77	-0.71	
			90	**Red Oak**	+15%	12.81	20.45	181.97	1.09	
					-15%	12.82	18.32	164.63	1.15	
				White Oak	+15%	10.39	16.43	123.40	1.05	
					-15%	10.22	13.88	91.77	-0.60	
d)	**DBH = *f* (Age): Mean**	**Slope**	**30**	**Red Oak**	+15%	18.49	24.33	193.67	7.26	
					-15%	15.62	20.64	152.40	-9.42	
				White Oak	+15%	7.78	13.41	123.31	11.98	
					-15%	6.34	10.98	82.25	-8.71	
			90	**Red Oak**	+15%	13.60	20.83	163.37	7.37	
					-15%	11.71	17.79	146.68	-7.56	
				White Oak	+15%	11.71	16.92	116.20	13.88	
					-15%	8.96	13.27	92.13	-12.80	
		Constant	**30**	**Red Oak**	+15%	21.62	27.35	172.99	25.40	*
					-15%	13.21	18.24	145.08	-23.37	*
				White Oak	+15%	8.72	14.63	107.24	25.47	*
					-15%	5.53	9.85	88.46	-20.50	*
			90	**Red Oak**	+15%	15.87	23.44	184.17	25.23	*
					-15%	9.84	15.67	139.20	-22.32	*
				White Oak	+15%	12.37	17.61	135.50	20.33	*
					-15%	8.42	12.82	103.51	-18.07	

Table III.4 (cont.) Sensitivity analyses results**.**

e)	**DBH = *f* (Age): Variation**	**Slope**	**30**	**Red Oak**	+15%	17.46	22.92	177.13	1.29	
					-15%	17.06	22.51	166.07	-1.03	
				White Oak	+15%	7.12	12.35	120.89	2.42	
					-15%	6.96	11.96	105.37	0.12	
			90	**Red Oak**	+15%	12.83	19.47	165.79	1.25	
					-15%	12.92	19.42	152.16	1.97	
				White Oak	+15%	10.49	15.41	114.49	2.05	
					-15%	10.06	14.80	113.02	-2.12	
		Constant	**30**	**Red Oak**	+15%	17.85	23.19	177.86	3.54	
					-15%	16.64	22.01	176.80	-3.50	
				White Oak	+15%	7.25	12.49	93.77	4.25	
					-15%	6.63	11.56	108.12	-4.66	
			90	**Red Oak**	+15%	13.28	19.96	163.78	4.85	
					-15%	12.32	18.91	144.17	-2.76	
				White Oak	+15%	10.47	15.25	118.37	1.80	
					-15%	10.08	14.89	108.06	-1.95	
f)	**Species Group Division: Mean**	**Slope**	**30**	**Red Oak**	+15%	16.21	21.88	154.07	-5.95	
					-15%	18.19	23.43	166.02	5.53	
				White Oak	+15%	7.54	12.74	97.29	8.43	
					-15%	6.50	11.44	95.92	-6.47	
			90	**Red Oak**	+15%	11.59	18.52	163.04	-8.51	
					-15%	13.96	20.13	154.12	10.20	
				White Oak	+15%	11.61	16.24	120.52	12.92	
					-15%	9.06	13.93	116.55	-11.91	
		Constant	**30**	**Red Oak**	+15%	23.37	26.62	174.36	35.57	***
					-15%	11.93	18.46	147.00	-30.83	**
				White Oak	+15%	4.31	9.10	94.18	-37.96	***
					-15%	10.60	15.40	140.08	52.57	*****
			90	**Red Oak**	+15%	17.89	23.10	165.22	41.24	***
					-15%	8.30	15.17	144.04	-34.51	***
				White Oak	+15%	6.94	12.16	91.51	-32.49	**
					-15%	14.39	17.83	130.06	39.99	***

Table III.4 **(cont.)** Sensitivity analyses results**.**

g)	**Species Group Division: Variation**	**Value**	**30**	**Red Oak**	+15%	23.29	26.66	176.11	35.07	***
					-15%	23.22	26.51	201.27	34.66	***
				White Oak	+15%	4.22	9.01	83.37	-39.26	***
					-15%	4.11	8.74	79.12	-40.92	***
			90	**Red Oak**	+15%	17.86	23.28	166.48	41.00	***
					-15%	17.85	23.14	169.45	40.84	***
				White Oak	+15%	7.10	12.37	94.21	-30.89	**
					-15%	6.98	12.23	102.44	-32.06	**
h)	**DBH =** ***f*** **(sp)**	**Slope**	**30**	**Red Oak**	+15%	23.46	26.69	177.69	36.06	***
					-15%	23.33	26.60	194.29	35.34	***
				White Oak	+15%	4.02	8.54	77.23	-42.09	****
					-15%	4.37	9.27	84.43	-37.14	***
			90	**Red Oak**	+15%	17.66	22.92	185.96	39.39	***
					-15%	18.00	23.32	164.85	42.08	****
				White Oak	+15%	6.67	11.68	90.74	-35.16	***
					-15%	7.33	12.75	98.53	-28.73	**
		Constant	**30**	**Red Oak**	+15%	23.61	26.71	175.11	36.94	***
					-15%	23.39	26.65	170.26	35.68	***
				White Oak	+15%	5.97	12.42	104.78	-14.17	
					-15%	2.44	5.44	64.58	-64.96	*******
			90	**Red Oak**	+15%	17.81	23.15	182.96	40.59	***
					-15%	18.14	23.41	170.17	43.21	****
				White Oak	+15%	9.66	16.33	128.81	-5.99	
					-15%	4.18	7.75	69.04	-59.33	******

percent. This may, of course, not be the best approach to examine all the parameters, but it is a relatively simple starting point.

The first thing to notice is that altering many factors by 15 percent does not result in much of a change in the mast index ($CMPI_{sp}$). The slope of the model that predicts a decrease in mean TPC as a function of age usually alters the CMPI by less than 10 percent (Table III.4(b)), whereas altering the constant usually alters the CMPI by more than 15 percent. Likewise, altering the relationship between mean DBH and the age of dominant (III.4-d) showed that the slope was relatively unimportant as compared to the constant value. The modeled relationship that predicts a decrease in variability in TPC as the age of dominants increases hardly affected CMPI at all (III.4-c) with all shifts of less than 2 percent. Likewise the DBH-age relationship (III.4-e) was relatively unimportant with respect to CMPI.

The largest and most important influence on CMPI was related to the division of trees between the red and white oak groups (III.4-f). Again the slope of the relationship predicting the mean CFRO was relatively unimportant and the constant for predicting the mean resulted in a 30 to 50 percent change in CMPI. The sensitivity analysis that altered the variation in CFRO from the base value of 0.05 to from 0.0425 to 0.0575 also resulted in a large change in CMPI (30 to 40 percent (III.4-g)). Altering the DBH with respect to differences in species growth rates (IIII.4-h) also resulted in large percentage differences in CMPI.

III.3.5 Sensitivity analyses: Discussion

A 15 percent change in a parameter would not necessarily result in a 15 percent change in the test variable (CMPI). Each parameter would be expected to behave differently. This is the essence of sensitivity analysis: to identify those parameters that are sensitive to change. In addition to sensitivity to change, one must consider the confidence attached to each parameter estimate initially. For example, I do not have a high degree of confidence in the Age-Diameter relationship I have factored (Figure III.3). Relatively speaking, I have a much higher degree of confidence in the CFRO estimates. Thus, while still more sensitive to change, I am more confident that the base parameters are relatively accurate for sites in southern Missouri.

In addition, the characteristics of the landscape must be considered when evaluating these sensitivity analyses. For example, at first glance the impact of changes in the age of the dominants over time seems to have little impact. However, this test-landscape does not span a wide range of ages. For the 30th year iteration, only five cohorts are present ranging from 10 to 110 years (Figure III.3). The 90th year iteration spans a wider range of ages (0 to 160 years), consequently the percentage change from the base condition is often higher for the 90th year iteration where age is factored. If applied to a landscape with either a wider range of cohorts present initially or for longer simulation periods, the effect of age may increase in importance.

Also, interpreting parameters that affect DBH is confounded by the nonlinear relationship between mast production and DBH and by the absence of production at low DBH levels. That is, a 20 cm increase in diameter between 30 and 50 cm results (on average) in an increase in mast production. A 20 cm increase in DBH between 45 and 65 cm results in little change in the predicted mast index (Figure III.6 and Figure II.20) since the relationship has reached a plateau between these diameters. A 20 cm increase in diameter between 60 and 80 cm would generate a lower mast index. In an extreme example of this problem, for red oaks the mast index for 40 cm trees is identical to that of 80 cm trees (Figure II.20)

The major influence of species distributions on CMPI estimation indicates that this number is particularly important. Since white oaks of larger DBH have relatively high acorn production, whereas large red oaks actually have reduced acorn production, when the model algorithm assigns more trees to the white oak group there is a large effect on mast production. Fortunately, the relative presence of the oak groups is easily estimated from existing inventories.

The response variable used for examining the sensitivity of the coefficients may be too general to adequately describe differences. The changes that occur may shift geographically, whereas the stand average CMPI might tend to mask these differences. This is an area that may warrant further analysis.

III.4 MANAGEMENT EFFECTS

III.4.1 Management Effects: Introduction

In this section I examine mast production as predicted by the masting model across the landscape in general and as a consequence of three management alternatives. Shifley et al. (2000) subjected the landscape to several simulated management regimes.

The masting model program was applied to the LANDIS results (output files) of two of these regimes: even-aged management and uneven-aged management. Under even-aged management, harvests were conducted on entire stands (all cells in the same stand) whereas under uneven-aged management, individual cells were "harvested". In addition, the parameters defining the distribution of trees to inherent mast production classes (no, low, moderate, and high) in the masting model were altered to simulate a silvicultural treatment that reduces the number of trees in the no- and low-production classes.

III.4.2 Management Effects: Introduction – The Oregon County land types

The 3,216 ha test-landscape in Oregon County is comprised of 450 stands as defined in the Mark Twain National Forest management plan (Figure III.8). The landscape is divided from north to south by state route 19. The stands are distributed among 7 land types (Figure III.8). These land types are defined as:

1. S & W Slopes: land with generally southern or western aspects (azimuth 135^o to 315^o) presumably subjected to higher solar radiation, having drier soils, warmer conditions and subjected to drying winds from the south and west.
2. N & E Slopes: land with generally northern or eastern aspects (azimuth 316^o to 360^o and 0^o to 134^o) presumably subjected to lower solar radiation, cooler soils with more moisture and perhaps higher incidence of late spring frosts.

Oregon County Test Landscape:
Land Types and Stand Boundaries

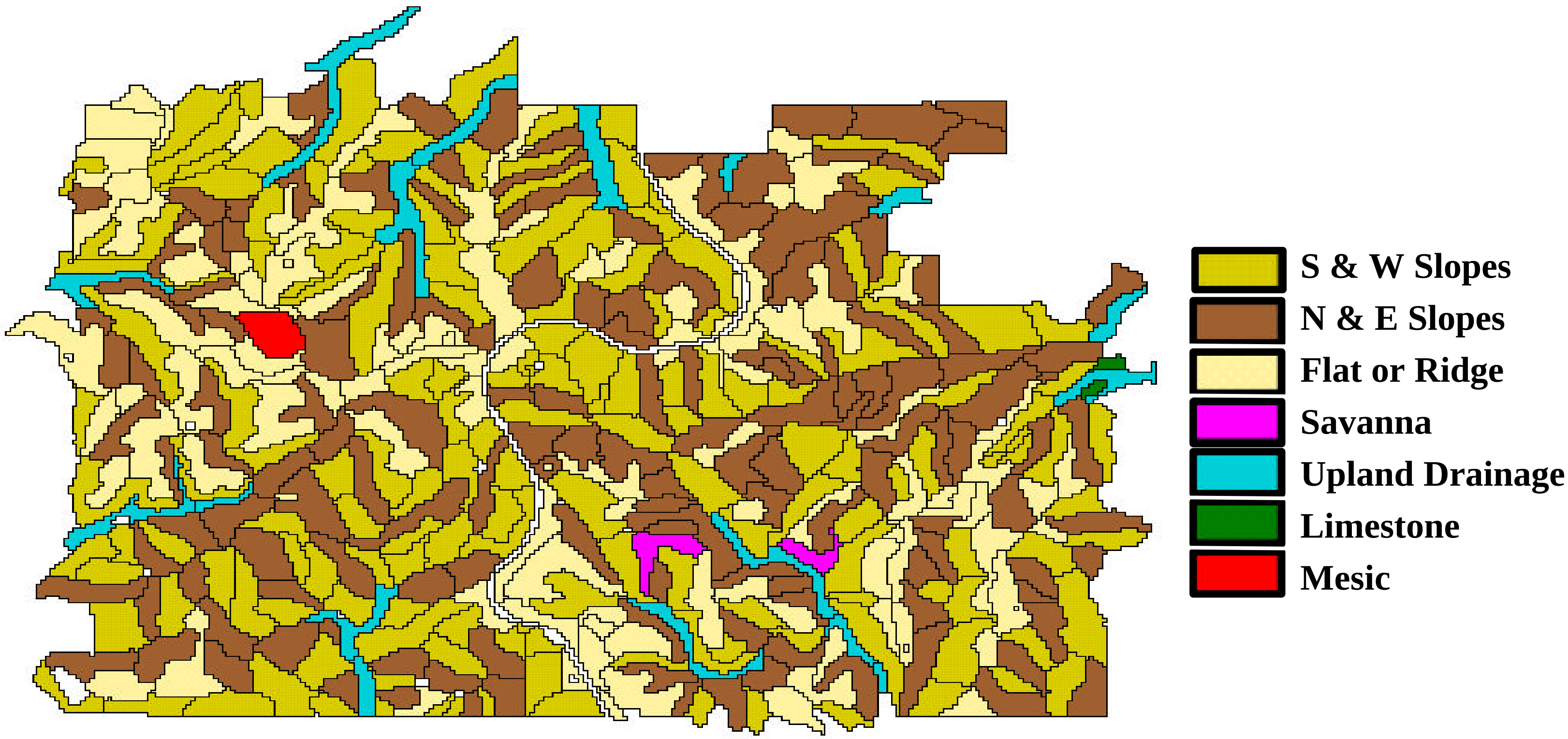

Figure III.8 Land types and distribution as specified for the Oregon County Test landscape in LANDIS base files. Stand Boundaries are included.

3. Flat or Ridge: lands with low slope (0-8 %). A narrow or elongated crest of a hill or mountain or a level or nearly level area of land with little or no topographic relief.

4. Savanna/Glade: relatively dry glade sites.

5. Upland Drainage: stream bottoms potentially subject to frost damage to trees.

6. Limestone: Typically a site with dry cherty soils and limestone parent material

7. Mesic: Typically bottomland forests

Types 1,2, and 3 are dispersed throughout the landscape and comprise most of land area with the remaining land types being relatively rare. The patterns suggest narrow ridges running from east-to-west through the central region. Extensive ridge and flat stands are common in the south-central area and the northwest corner. The upland drainage sites occur throughout the landscape and show the location of the streams large enough to affect the surrounding forest composition. There are two relatively large savanna or glade sites in the south central region of the landscape and one mesic site in the west-northwest region.

III.4.3 Management Effects: Introduction – Oregon County age classes

The distribution across the landscape of the average age of cell dominants (by stand) for the 30^{th} and 90^{th} LANDIS iterations of the even-aged management scenarios is shown in Figures III.9 and III.10. During the first 30 years of simulation there seems to

Age of Dominants – Year 30 Even-aged Management

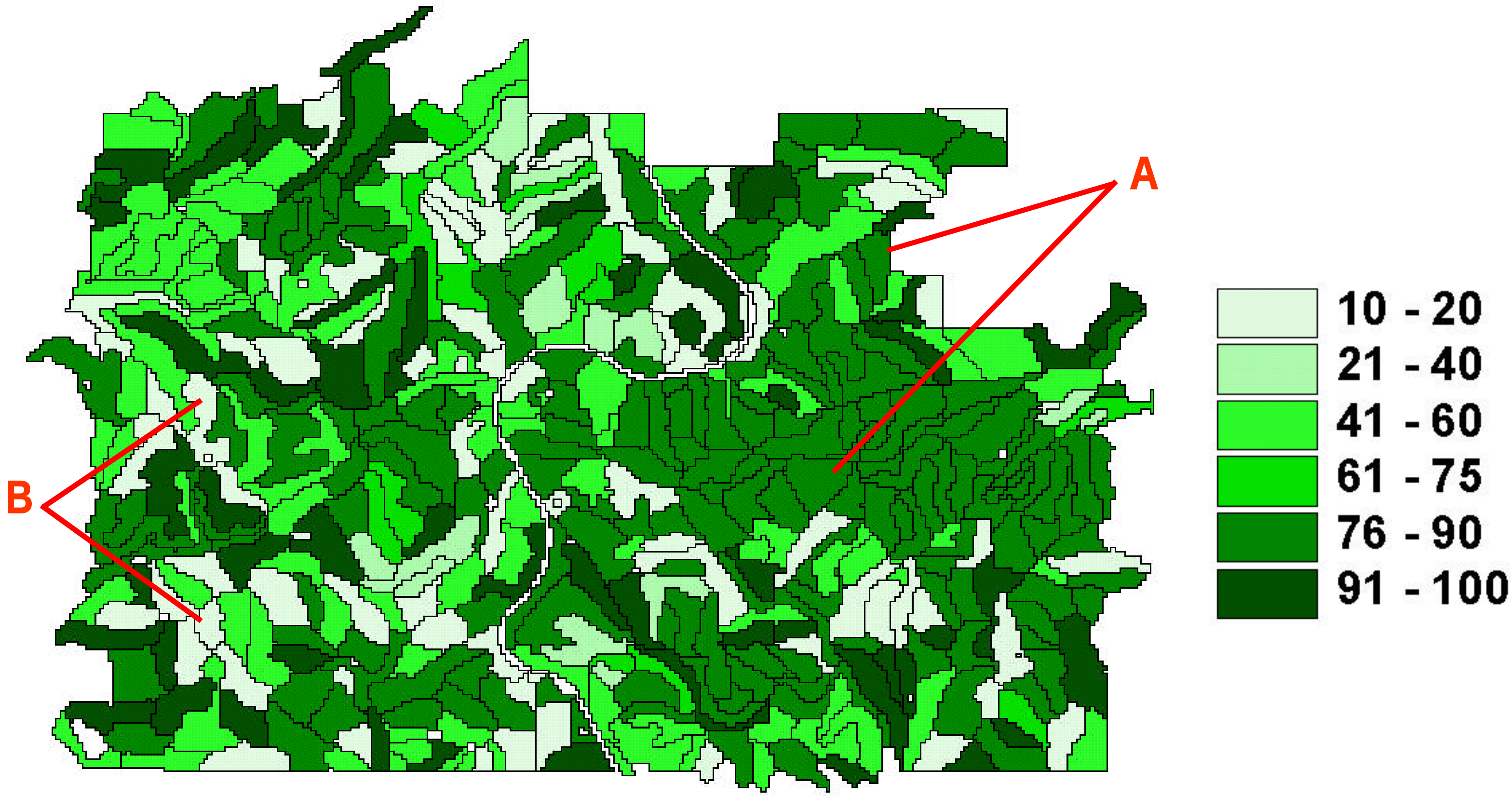

Figure III.9 Average age of dominants by stand for simulation year 30. Map regions A and B are referred to in the text as examples of the changes that occur as a result of applied management.

Age of Dominants – Year 90 Even-aged Management

Figure III.10 Average age of dominants by stand for simulation year 90 for the even-aged management simulation. Map regions A and B are referred to in the text as examples of the changes that occur as a result of applied management.

be a low level of harvest occurring in the east and northeast regions of the landscape (Figure IIII.9 - A), *i.e.* there are large expanses of land with darker shading (>75 years). Younger stands (<20 years) are common in the southwest corner of the landscape (III.9 – B). By the 90th year of simulation (Figure III.10) the stands in the southwest corner of the region having already passed the harvest cycle, have matured (~80 years) and many of the older stands in the eastern region have been recently harvested. These differences in age distributions could also be caused by the stochastic occurrence of wind and fire in the LANDIS model thereby reducing stand age to 0. Regardless of the source of change, the age of the stands have changed and mast production potential is affected. In the even-aged treatment scenario, all cells in a stand (the management unit) are treated equally, *i.e.* either harvested or not for each iteration. Although figures are not included, under uneven-aged management schemes the changes that occur across the landscape are more subtle since harvests do not have to affect all of the cells in a stand; thus the average age of dominants for the stand is reduced by a harvest but not to zero.

III.4.4 Management Effects: Mast production under different regimes

The differences in mast production between even- and uneven-aged management are probably more subtle than it would be in reality. For example, interpretation of the Figure III.10 depicting the age of dominants at the 90th simulation year suggests that there was a disturbance (harvest or natural) that reduced the mean ages of the dominants to less than 20 years for stands in the eastern region of the landscape (map reference- A), an age during which mast production should be very low. However, due to the uncertainty regarding the age-diameter relationship and the higher number of trees assigned to younger cells for which to randomly assign diameters, although the mast index is lower than the overall average (about 175 versus 255), it is probably higher than it should be (Figure III.11; Table III. 5). These subtle differences occur across the landscape. There were separate simulation runs utilized to generate the mast indices for the even- and uneven-aged scenarios. The seed values for generating random values were not controlled. The age of dominants does not appear to have a very well defined impact at the stand level (the age-diameter relationship is ill defined) and yet the simulation runs produced consistent differences in mast indices (shading of treated even-aged management stands typically is lighter than when uneven-aged management is implemented). This supports the assertion that the major source of mast index variation for this landscape and this masting model is due to land type rather than age. The subtle effect of age on mast production and the way it is expressed in these two management regimes can be seen by viewing Figures III.11 and III.12 together. There is a higher degree of overall contrast for the even-aged scenario. Despite this apparent overall difference, when summarized across the entire landscape there is little difference between these management regimes with averages of 255 and 257 CMPI for even- and uneven-aged regimes, respectively (Table III.5). In the Landis simulations, the same total amount of harvest was conducted; however, for the even-aged management all cells in a stand were treated whereas for uneven-aged management only some individual cells in a treatment stand were harvested.

The differences in the raw CMPI values between even- and uneven-aged management regimes is subtle but when expressed as a percentage change by stand, the patterns are much more obvious (Figure III.13). The unshaded stands did not differ to

Mean Mast Index by Stand – Year 90 Even-aged Management

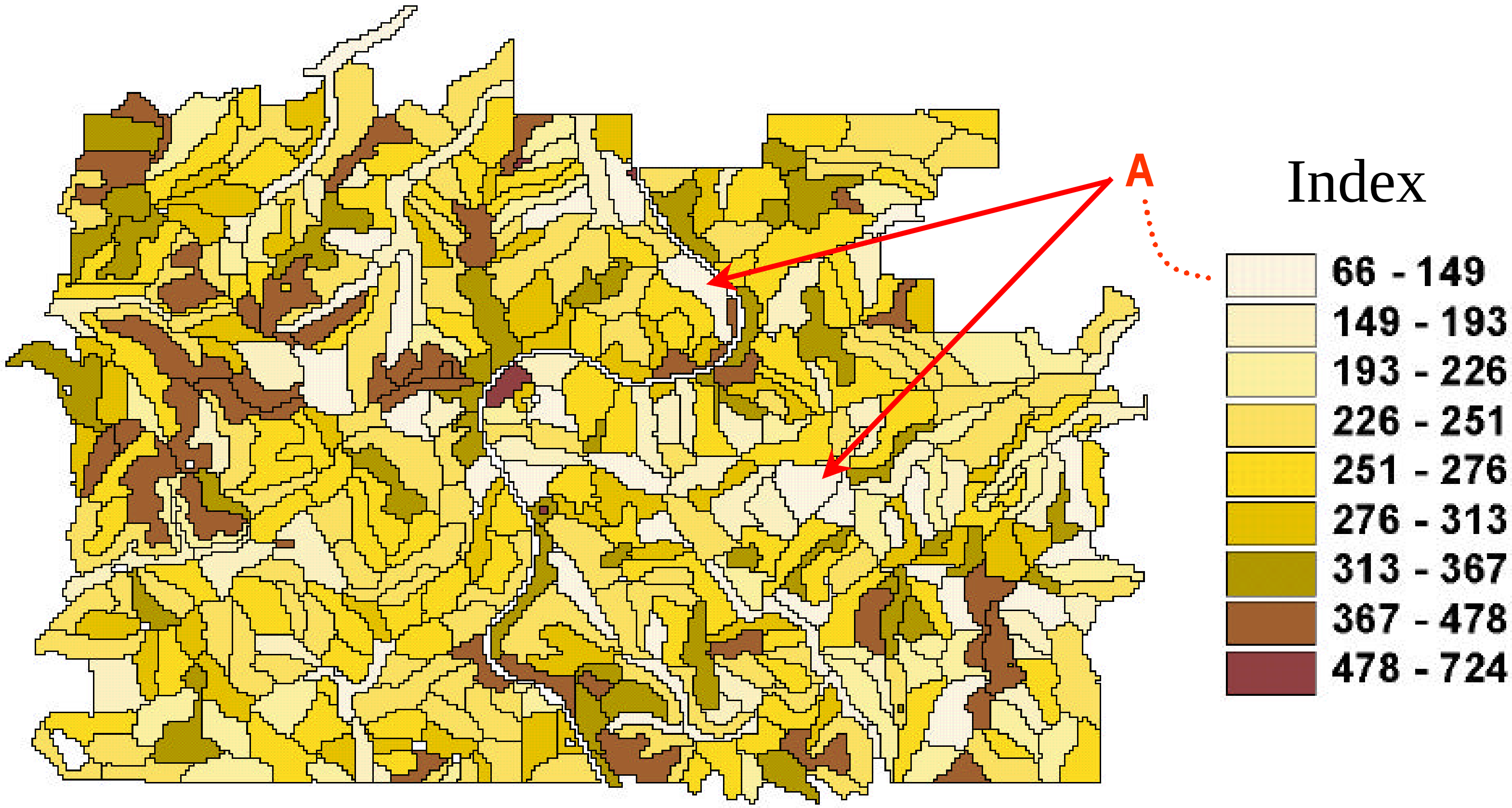

Figure III.11 Mean mast index by stand for the 90th year iteration under even-aged management. Map reference A are examples of two stands on which all cells were harvested.

Mean Mast Index by Stand – Year 90 Uneven-aged Management

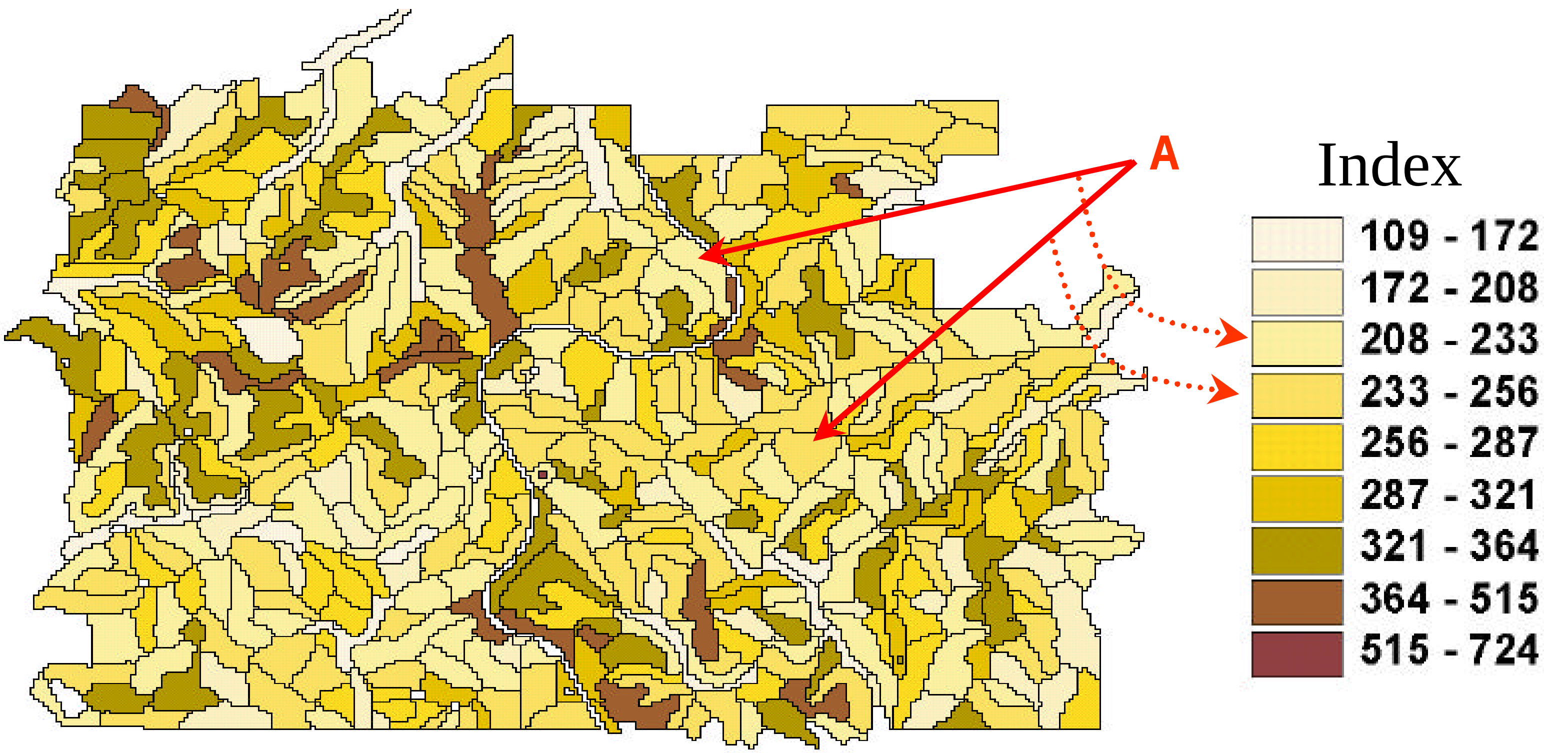

Figure III.12 Mean mast index by stand for the 90th year iteration under uneven-aged management. Map reference A are examples of two stands on which all cells were harvested. And were similar in index vor even-aged management but differ under uneven-aged management.

Effects of Management-Year 90
Consequences of even-aged management

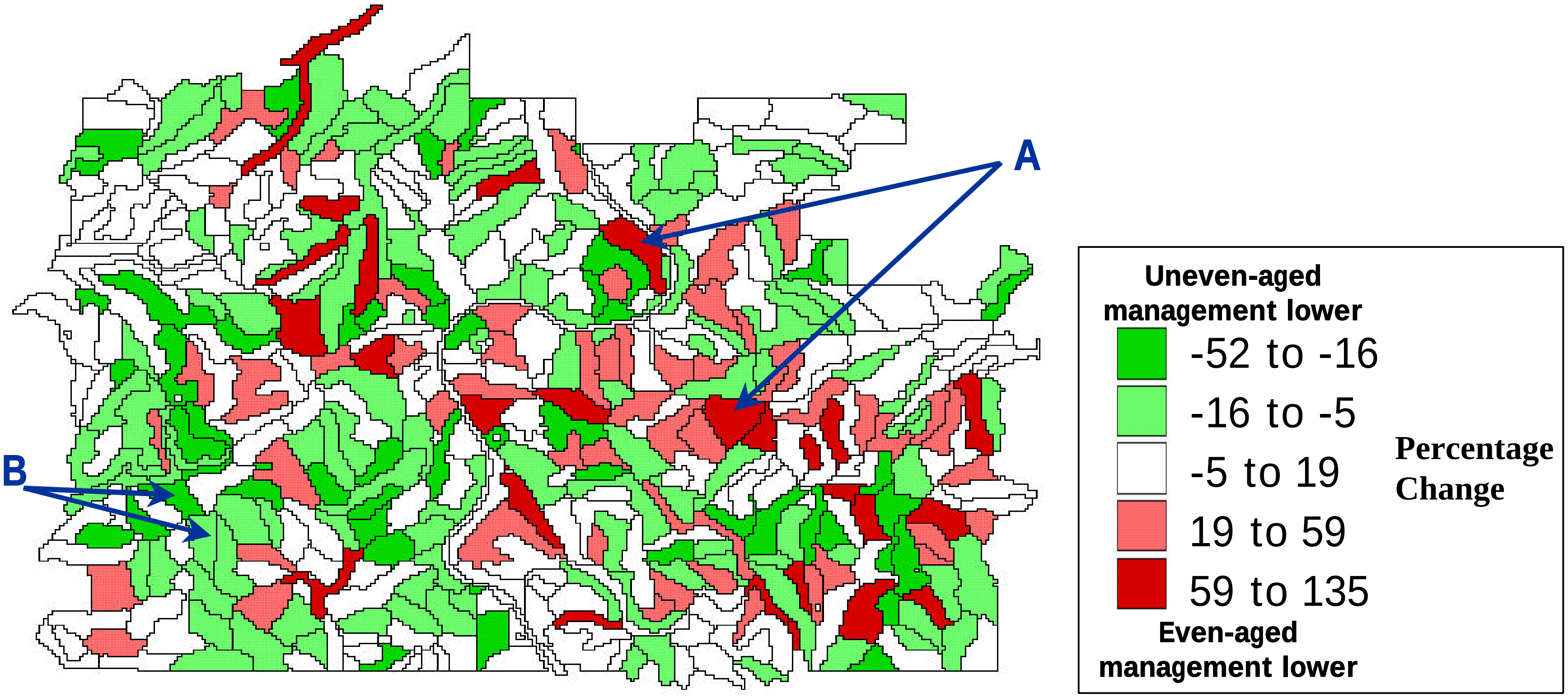

Figure III.13 Percentage change if even-aged management utilized for the 90th year iteration. Reds indicate a percentage decrease in mast production and greens an increase. For example, under uneven-aged management, reference stands "A" were greater than 59 percent higher in mast index than if even-aged management was applied.

Table III.5 The average cell mast production index by management regime and land type for iteration year 90.

Land Type		Base Parameters Even Aged	Base Parameters Uneven-Aged	Reduced number of low mast producing trees Even Aged	Reduced number of low mast producing trees Uneven-Aged
		---- Cell Mast Production Index ----			
1	**South and West**	229	230	274	273
2	**North and East**	238	244	288	290
3	**Flat**	347	342	415	406
4	**Savanna**	135	125	173	165
5	**Upland Drainage**	140	159	161	182
6	**Lime**	248	248	267	218
7	**Mesic**	182	159	214	177
	Mean	255	257	306	305

any great extent between treatment methods. The stands shaded in red indicate those stands for which the even-aged management resulted in lower indices at 90 years and the green for those stand where uneven-aged management generated lower indices. In general, since stands are I influenced in a more concentrated manner under even-aged management, red areas cover a smaller total land area and the range of percentage difference is greater (up to a 135% change). Stands such as indicated by map reference A show a clear difference between even-aged and uneven-age management probably due to the relatively recent harvest cycle (Figure II.10) whereas stands such as those indicated by reference B were harvested prior to the 30th iteration year (Figure III.9) and are estimated to produce a greater amount of mast under even-aged management by the 90th year.

Interpretation of differences in mast production among treatments and across time is difficult and perhaps not very informative. Across the entire landscape, the mast index is about the same (~256: Table III.6). Since even-aged management would tend to produce a landscape with well defined cohorts versus uneven-aged management that would distribute the treatments among age classes, it is not surprising that the differences between CMPI by age of dominants among even- and uneven-aged treatments is not consistent across cohorts (Table III.6). The major differences that occur with respect to age of dominants relate to a general smoothing of the effect of harvest across the landscape under uneven-aged harvest. The amount of harvest is dispersed rather than concentrated, thus CMPI is more evenly distributed.

Land type and the age of dominants explain a relatively small amount of the variation in mast index that occurs across the simulated landscape. The adjusted

Table III.6 The average cell mast production index by management regime and age of dominants for iteration year 90.

Age of Dominants	Even Aged			Uneven Aged		
	Mean	SD	N	Mean	SD	N
	---- Cell Mast Production Index ----					
0	153	147	2048	137	127	1513
10	184	164	3842	180	164	2614
20	190	169	2153	206	185	1409
50	262	220	2020	275	241	1232
60	316	272	2034	286	241	1236
70	274	231	2661	288	243	1721
80	294	235	2384	309	249	1548
90	293	230	1871	286	230	1099
110	284	203	7155	284	203	7167
140	262	177	9146	262	176	9414
160	252	165	921	257	165	7282
Mean	255	204		257	195	

coefficient of variation (R^2) for the even-aged management scenario is about 0.12 (Table III.7) and slightly lower for uneven-aged management (0.10; Table III.8). In STATA the REGRESS command following ANOVA generates a table that separates the sources of variation. Under even-aged management, two of the land types (4-Savanna/Glade and 5-Upland Drainage) that should, based on their characteristics, be distinguishable in terms of CMPI are not statistically different perhaps due to low representation in the landscape. Under uneven-aged management, the savanna sites are statistically significant. The difference between the two management regimes is probably due to the dispersed nature of uneven-aged management. Since harvests were dispersed, a savanna site was harvested and resulted in different mast production. Since there are few savanna sites, treatment on any one site would more greatly affect the population. Under uneven-aged management, the age of the dominants is always a significant predictor of CMPI, whereas, under even-aged management three of the cohorts (40, 90 and 100 years) are not significant. Presumably these are cohorts that were particularly heavily harvested.

III.4.5 Management Effects: Intensive selection to increase mast production

As mentioned previously, the results for the 90^{th} iteration under the even-aged management trial were used in a separate evaluation of the effects of reducing the number of trees that are inherently low mast producers. Healy (1997) and Drake (1991) have proposed management recommendations that include increasing mast production by observing trees, identifying good mast producers, and retaining those trees in the stand. The proportion of trees in the masting model that are poor acorn producers (no or low production) was reduced from 45 percent of the population to 25 percent of the oak

Table III.7 ANOVA statistics for examining the distribution of variation in the cell mass production index among land types and the age of dominants for the 90th year iteration under a even-aged management regime. The overall ANOVA table (a) is followed by a regression table (b) that lists statistics for individual land types and ages classes.

ANOVA Model

a) `.anova cmpi90 by landtype age90`

Number of obs = 36235 R-squared = 0.1161
Root MSE = 191.65 Adj R-squared = 0.1157

Source	Partial SS	df	MS	F	Prob > F
Model	174688023	16	10918001.4	297.25	0.0000
landtype	103400696	6	17233449.4	469.20	0.0000
age90	68858631.7	10	6885863.17	187.47	0.0000
Residual	1.3303e+09	36218	36729.799		
Total	1.5050e+09	36234	41534.688		

b) `.regress`

Source	SS	df	MS
Model	174688023	16	10918001.4
Residual	1.3303e+09	36218	36729.799
Total	1.5050e+09	36234	41534.688

Number of obs = 36235
F(16, 36218) = 297.25
Prob > F = 0.0000
R-squared = 0.1161
Adj R-squared = 0.1157
Root MSE = 191.65

cmpi	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_cons	153.9872	18.14972	8.484	0.000	118.4132	189.5612
landtype						
1	86.47489	17.03539	5.076	0.000	53.08503	119.8647
2	101.7306	17.02918	5.974	0.000	68.35288	135.1083
3	208.9598	17.09273	12.225	0.000	175.4576	242.4621
4	-18.83231	23.80908	-0.791	0.429	-65.49881	27.83419
5	12.84094	17.74408	0.724	0.469	-21.93799	47.61986
6	90.97165	35.46183	2.565	0.010	21.46543	160.4779
7	(dropped)					

(continued)

Table III.7 (continued)

age90						
1	-121.5725	7.652744	-15.886	0.000	-136.5722	-106.5729
2	-93.15086	7.099471	-13.121	0.000	-107.066	-79.23569
3	-64.80661	7.570286	-8.561	0.000	-79.64459	-49.96862
4	2.085416	7.651771	0.273	0.785	-12.91228	17.08311
5	20.85526	7.675723	2.717	0.007	5.81062	35.89991
6	15.74833	7.37839	2.134	0.033	1.286472	30.21019
7	28.38282	7.572311	3.748	0.000	13.54087	43.22478
8	20.55985	7.760063	2.649	0.008	5.349902	35.76981
9	9.41778	6.784979	1.388	0.165	-3.880979	22.71654
10	-7.463396	6.683335	-1.117	0.264	-20.56293	5.636137
11	(dropped)					

Table III.8 ANOVA statistics for examining the distribution of variation in the cell mass production index among land types and the age of dominants for the 90th year iteration under a uneven-aged management regime. The overall ANOVA table (a) is followed by a regression table (b) that lists statistics for individual land types and ages classes.

ANAOVA Model

a) `anova cmpi by landtype age90`

```
                    Number of obs =   36235     R-squared     =  0.1013
                    Root MSE      = 185.249     Adj R-squared =  0.1009

           Source |  Partial SS    df       MS           F     Prob > F
        -----------+----------------------------------------------------
            Model |   140079725    16  8754982.81     255.12     0.0000
                  |
         landtype |  85805873.9     6  14300979.0     416.73     0.0000
           age90  |  50273969.1    10  5027396.91     146.50     0.0000
                  |
         Residual |  1.2429e+09 36218  34317.2212
        -----------+----------------------------------------------------
            Total |  1.3830e+09 36234  38168.0422
```

b) `regress`

```
  Source |       SS       df       MS              Number of obs =   36235
---------+------------------------------           F( 16, 36218) =  255.12
   Model |   140079725    16  8754982.81           Prob > F      =  0.0000
Residual |  1.2429e+09 36218  34317.2212           R-squared     =  0.1013
---------+------------------------------           Adj R-squared =  0.1009
   Total |  1.3830e+09 36234  38168.0422           Root MSE      =  185.25
------------------------------------------------------------------------------
   cmpi         Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
------------------------------------------------------------------------------
_cons        165.9522   15.97026     10.391   0.000         134.65    197.2544
landtype
       1     64.53569   16.07966      4.013   0.000       33.01908     96.0523
       2     79.11945   16.07155      4.923   0.000       47.61874    110.6202
       3     174.6519    16.1173     10.836   0.000       143.0616    206.2423
       4    -48.51181    22.7173     -2.135   0.033      -93.03838   -3.985241
       5    -1.125986   16.66441     -0.068   0.946      -33.78872    31.53675
       6     66.61813   34.09337      1.954   0.051      -.2058847    133.4421
       7    (dropped)
```

(continued)

Table III.8 (continued)

age90						
1	-115.5918	5.244124	-22.042	0.000	-125.8704	-105.3131
2	-75.57408	4.228849	-17.871	0.000	-83.86275	-67.28541
3	-49.56513	5.397016	-9.184	0.000	-60.14344	-38.98682
4	17.33312	5.710312	3.035	0.002	6.140745	28.5255
5	28.67257	5.706076	5.025	0.000	17.48849	39.85665
6	31.06939	4.970372	6.251	0.000	21.32731	40.81146
7	49.90275	5.193635	9.608	0.000	39.72307	60.08243
8	30.64917	6.002207	5.106	0.000	18.88467	42.41367
9	22.13817	3.120767	7.094	0.000	16.02137	28.25496
10	5.810369	2.910593	1.996	0.046	.1055215	11.51522
11	(dropped)					

population (Table III.9). Consequently, the number of moderate and high producers increased by 15 and 5 percent, respectively. The result of this silvicultural management was an overall increase in CMPI of about 50 index points (Table III.5; Figure III.14) with, not unexpectedly, little difference between even-aged and uneven-aged management regimes. The difference between the base even-aged landscape stand level average CMPI and the reduced number of low mast producers is shown in Figure III.15. There is an overall increase (shown in shades of green), but occasional decreases in mast production probably due to the vagaries of random number selection. This is a somewhat fanciful way of looking at increasing mast production by decreasing low mast producers. First, it is applied across the entire landscape, whereas silvicultural treatment in practical terms would occur on only a small portion of the stands in any 100-year period. Second, the algorithm replaces low producing "eliminated" trees with higher producers and the increase in mast production in real terms would certainly not occur within 50 years of treatment. However, when viewed as an indicator of general response, the average increase in mast index was about 20 percent and this should hold for most individual stands although not immediately expressed. In real terms, it would not increase production in stands that have only low producing, perhaps related, populations of oaks.

III.5 CONCLUSIONS

Below is a re-statement of this sections objectives and a brief summary of the findings:

i) How do the modeled intermediate values (*e.g.* diameter distributions, number of trees per cell) compare to real world inventories and how do these values change through simulation time (iteration)?

Mean Mast Index by Stand – Year 90 Even-aged Management
Reduction in Low Mast Producers

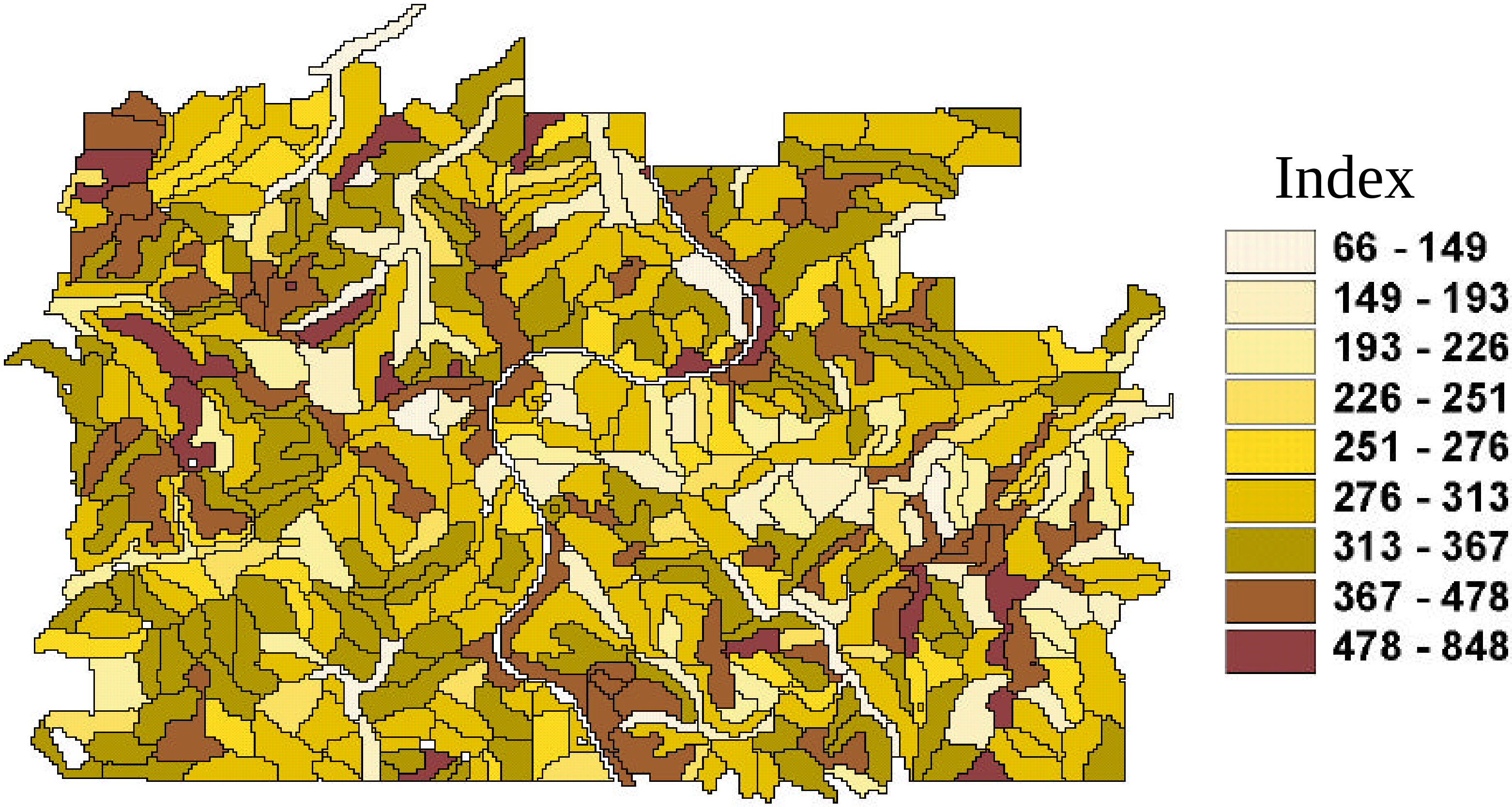

Figure III.14 Mean mast index by stand for the 90th year iteration under even-aged management and reducing the proportion of the oak population that are non- or low-mast producers.

Effects of Management-Year 90
Reduced number of low mast producers

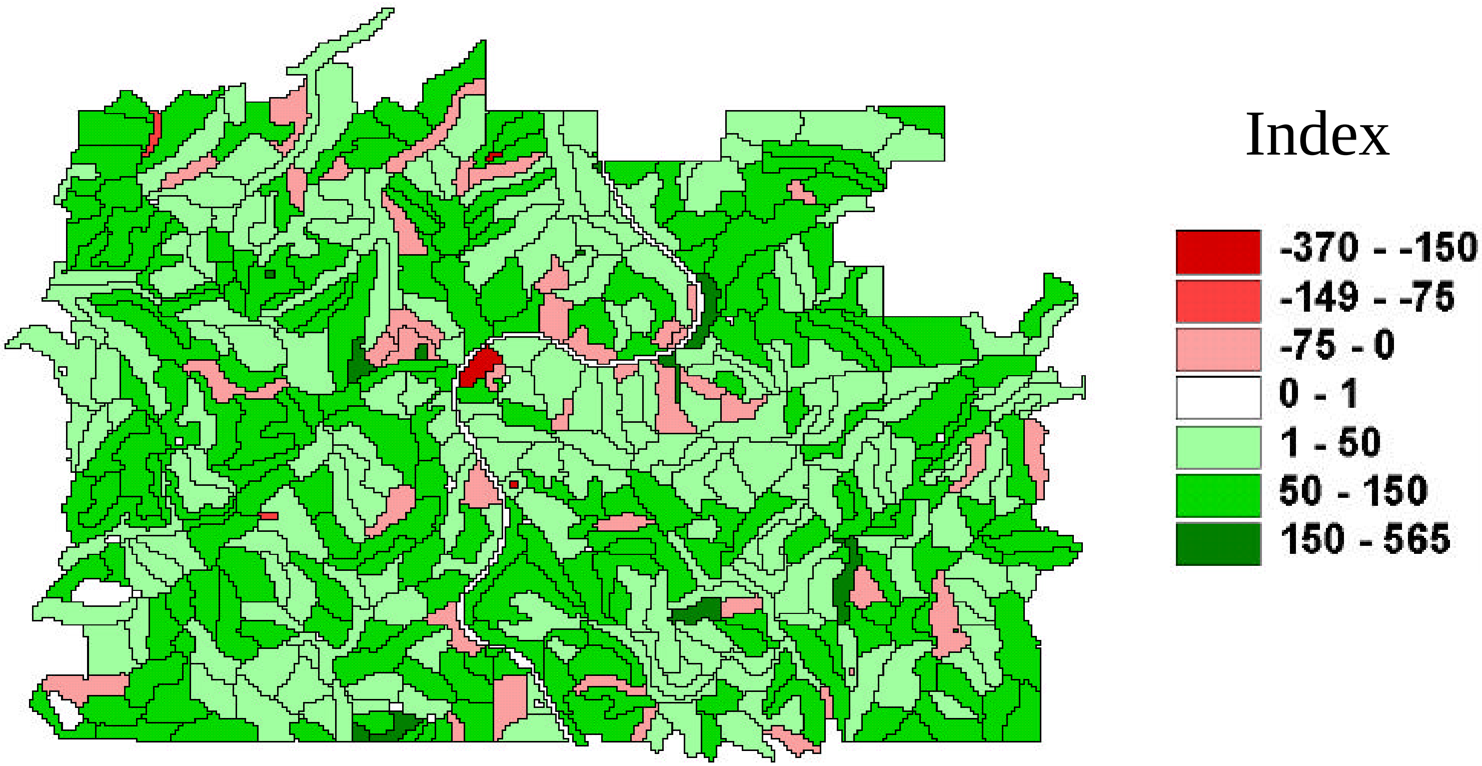

Figure III.15 The increase or decrease (difference) in the mast index following a reduction in the number of low mast producing oaks for the 90th year iteration under even-aged management.

Table III.9 The base parameters and the altered parameters for dividing the oak population into production levels.

Mast Production Rate	**Base Conditions**	**Reduced Low Producers**
	--- Fraction of Population ---	
Non-producers	0.15	0.05
Low producers	0.30	0.20
Moderate producers	0.40	0.55
High producers	0.15	0.20

Diameter distributions and the number of canopy oak trees (TPC) expressed in the model are slightly higher than MOFEP averages. Given the annual variability of mast production this disparity is probably not very important. The distributions of assigned diameters produced cells that either contained no oaks or no mast producing oaks similar in proportion to those found on the MOFEP sites. The scale used in predicting the mast production by tree diameter produces values that, when expressed on an area basis, CMPI is roughly equivalent to kg of mast per hectare.

ii) How sensitive is the model to variation in parameter values in terms of intermediate values and ultimate mast production at the stand level?

Sensitivity analysis was not conducted on land type since the effect of land type is expressed in terms of diameter and species distributions (CFRO) and tree density (TPC). The effect of these three factors varied. The slopes of the relationships were not as sensitive to change, as were the constants. Diameter and TPC were much less influential in affecting CMPI than was the division between red and white oaks, but I have a higher degree of confidence in the CFRO estimate than that of diameter and TPC. The stand average CMPI is a one indicator of model performance but it may mask spatial shifts caused by altering coefficients.

iii) How are the intermediate values and masting predictions influenced by simulated management regimes, *e.g.* uneven-aged management versus even-aged management?

Under the rules of the LANDIS simulations of even and uneven-aged management, the overall landscape level CMPI did not differ by treatment method. Under even-aged management, the CMPI was more localized whereas under uneven-aged management, CMPI was more dispersed.

iv) What does the model predict across a landscape?

Generally speaking, due to the uncertainty surrounding the prediction of tree size given the age of dominants, the landscape is not as variable in mast production as one might expect. When the effects of climate, which vary with topographic position, are factored (*e.g*. some sites are more frost-prone), variability may become more distinct. However, examination of the data in the absence of annual variability since the effect of annual variability may mask problems related to forest structure, e.g. a poorly defined relationship between age and diameter.