N*ORTHWDS* *I*ntegrated *H*ierarchical *M*odel *S*ystem (*NIHMS*) User's Guide

For Version 2.403

Don C. Bragg
Research Forester
USDA Forest Service
Southern Research Station
P.O. Box 3516 UAM
Monticello, AR 71656
Phone: (870) 367-3464
Fax: (870) 367-1164
E-mail: dbragg@fs.fed.us

DRAFT AS OF: October 19, 2005

DRAFT COPY—DO NOT CITE
HAS NOT RECEIVED REVIEWS

NOTE:

This is a working copy of a draft manuscript that has not received technical reviews according to USDA Forest Service policy. This interim copy has been posted to assist users and developers of *NIHMS*, and will be made official at an undetermined later date.

ACKNOWLEDGMENTS

The efforts of David Lytle (USDA Forest Service, North Central Research Station) and Tom Crow (USDA Forest Service, North Central Research Station) have greatly facilitated the development of the *NIHMS*. Dave Roberts (Utah State University) was of tremendous help in the creation of *NORTHWDS*. Jim Guldin (USDA Forest Service, Southern Research Station), was instrumental in allowing me to develop *NIHMS* to its potential. Many other individuals provided critical support, commentary, and other forms of assistance while *NIHMS* evolved: John Bissonette, Hope Bragg, Alan Ek, Jeff Kershner, Jim Long, Jim Manolis, Doug Ramsey, Lisa Schulte, Terry Sharik, ______________.

TABLE OF CONTENTS

NIHMS DESCRIPTION (VERSION 2.403)

Origin of *NIHMS*

As its name suggests, the N*ORTHWDS* *I*ntegrated *H*ierarchical *M*odel *S*ystem (*NIHMS*) has evolved from an earlier model (the *NORTH*ern *W*oodland *D*ynamics *S*imulator, or *NORTHWDS*). *NORTHWDS* itself arose from frustration with existing models of forest dynamics for the northern Lake States region. Few models existed for this region, even fewer had reasonable assumptions, mechanisms, and application space for stand-level questions, and virtually none had attributes that lent themselves to real-world simulations and outputs based on the primary factor driving forest dynamics in this region: timber harvesting. Borrowing heavily from many existing models and other research products, *NORTHWDS* was created to address meso-scale (tens to hundreds of hectares) questions using an ecosystem-process approach. Designed to balance current ecological theory, model specificity, homogeneity of detail, parsimony, and user flexibility, the original version of *NORTHWDS* was able to reproduce numerous ecosystem features (Bragg 1999).

It quickly became apparent that *NORTHWDS* could serve as the kernel for a larger hierarchical model system, and, in this manner, allow for many other topics to be considered. For example, although *NORTHWDS* is an ecosystem model dependent on processes greater than the scale of an individual tree, this subsystem (a tree) could easily be extracted from the larger *NORTHWDS* model and operated independently as an individual response model. Thus, the N*ORTHWDS* *I*ndividual *R*esponse *M*odel (*NIRM*) was born. This model could be used to conduct small-scale sensitivity analysis for model tuning, or be used as a mean to gauge how an altered environment would affect individual tree behavior. Because its routines and algorithms are identical to those incorporated in *NORTHWDS*, *NIRM* maintains the continuity between model levels lacking in many instances where separate models developed for completely different application spaces have been merged to form a hierarchical model systems (Bragg et al. 2004). The same principles helped guide the development of the N*ORTHWDS* Landscape Model (*NLM*), with steps take to retain the integrity of the model structure.

NIHMS Model Structure

Unlike some hierarchical models (e.g., ________), *NIHMS* does not operate as a unified simulator. Rather, *NIHMS* is an umbrella description of three separate computer programs representing each hierarchical level (Bragg et al. 2004). This relationship is necessary in part for ease-of-use, but also because of the fundamentally different questions asked at each level, and the scale-dependent nature of these levels. For example, one does not need to know the details of annual growth increment for a given tree to predict landscape response to large-scale disturbance.

Changes from Version 2.201

As with any active modeling effort, various *NIHMS* components changes as refinements become available. The version (2.201) used in Bragg et al. (2004) has since been replaced by the current version (2.403), which contains a number of improvements, bug fixes, and added features, some of which are listed below:

Additional species (ACESAA, FAGGRA, FRAPEN, POPDEL, QUEALB, QUEMAC)

New height-diameter equation

New individual tree sawtimber and total merchantable volume model

Base level mortality parameter adjustment

New source for specific gravity (OD_i)

Added output values in basal area and stand condition files (SP_SI, ______)

New species

The most notable change to version 2.403 is the addition of six new species, which include silver maple (*Acer saccharinum*), American hornbeam (*Carpinus caroliniana*), American beech (*Fagus grandifolia*), green ash (*Fraxinus pennsylvanica*), white oak (*Quercus alba*), and bur oak (*Quercus macrocarpa*). Their addition has widespread ramifications for study area extent and cover type definitions.

For each species added, a new set of parameters was also included. When possible, the original species parameter sources were utilized. However, in some instances, additional sources were necessary to incorporate the six new species. Site index maximum values for silver maple, American beech, green ash, and white oak, for instance, were taken from Carmean et al. (1989). Site index for bur oak and American hornbeam were unavailable and thus were approximated. Mortality coefficients for these new species were also taken from a different source because the original did not list them (Bush and Brand 1995).

It was necessary to derive parameters for the optimal diameter growth models of each of these species. The Michigan (1993) Eastwide Forest Inventory Database (EFIDB), the 1990 Minnesota EFIDB, and the 1996 Wisconsin EFIDB served as the source for the potential relative increment (PRI) models. Table ? list their parameter estimates and related information.

Table ?. Sample size and PRI parameter estimates for the new species to *NIHMS* version 2.403.

	Sample size (n)		5 yr cyclic parameters[a]		
Species	original	final	b_0	b_1	b_2
Silver maple	368	10	1.608840	-0.340928	0.981459
American hornbeam	86	9	5.246250	-1.468650	0.945587
American beech	347	6	1.886140	-0.626792	0.988546
Green ash	668	11	2.494930	-0.441538	0.969053
White oak	1114	14	1.523910	-0.645537	0.992685
Bur oak	1744	13	5.940355	-0.982827	0.989223

[a] All parameter estimates were significant at $\alpha = 0.01$.

New crown width model parameters were also required for these new species. Since it was not possible to conduct the field sampling for these species, existing crown width models were adapted from the literature (Table ?).

Table ?. New adjusted non-linear crown width parameters.

Species	b_1 [a]	b_2	b_3	b_4	*NIHMS* STS [b]	Source
Silver maple	-0.000042	0.713091	0.765597	-0.031148	4.0	Donnelly et al. (2001)
American hornbeam	1.034360	0.094053	0.999997	-0.021208	9.0	Donnelly et al. (2001)
American beech	4.686377	0.166855	0.999996	-0.019816	9.7	Canham et al. (1994)
Green ash	1.131683	1.103180	0.660798	-0.033136	3.0	Ek (1974)
White oak	-0.000036	1.819670	0.501398	-0.031148	4.0	Ek (1974)
Bur oak	0.903398	0.916262	0.654298	-0.037112	1.0	Ek (1974)

[a] $CW = b_1 + b_2 DBH^{b_3} + b_4 LBA$, where crown width (CW) is in meters, DBH is in cm, and local basal area (LBA) is expressed in m^2/ha.

[b] Shade tolerance score (STS) estimates.

Shade tolerance scores can be used to estimate the stand density component of the *NIHMS* crown width model (adapted from Figure 2 in Bragg (2001)):

$$b_4 = -0.0391 + 0.001988 * STS \quad [?]$$

This formulation assumes that shade tolerance scores range from 0 (completely shade intolerant) to 10 (maximum shade tolerance).

New height-diameter model

A new exponentially-based height-diameter model replaces the Ek et al. (1984) originally used in *NIHMS*. This change was made to improve the prediction of larger diameter trees, for which the original formulation can substantially underestimate, especially for very big trees. Since we lacked the resources for a massive new sampling of trees, the Ek et al. (1984) predictions for small to moderate diameter trees was used to define the initial shape of the curve, and a champion-sized tree was used to delineate the upper end.

NOW INCLUDES THE B6 PARAMETER FOR LOCAL DENSITY HEIGHT ADJUSTMENT (CANNOT SHRINK IF BA DROPS, HOWEVER)

New individual tree volume model

The original individual tree volume formulation of *NIHMS* was adapted from Raile et al. (1982). For this particular equation, coefficients for the Upper Peninsula of Michigan were used. The new version of the tree volume model is a simple exponential model for gross volume developed by Hahn (1984):

$$V = b_1 + b_2 DBH^2 HT \quad [?]$$

Where b_1 and b_2 are species-specific regression parameters and *HT* is merchantable height, which is currently assumed to be 98% of total tree height given the individual's diameter at breast height (*DBH*). The regression parameters for equation [?] depend on whether sawtimber volume (International ¼" rule) or total merchantable volume (in ft^3, converted to m^3 by *NIHMS*) is being predicted.

Switching to the Hahn models was facilitated by the improvements in the height-diameter model reported earlier in this guide. The major advantages to the Hahn (1984) models included greater geographic range (derived from inventories from all over Michigan, Minnesota, and Wisconsin, not just the Upper Peninsula of Michigan) and the exponential equation form, which does not asymptote at moderately large tree diameters, as occurs with the Raile et al. (1982) model. Note that Raile et al.'s models were for net (gross minus cull) volume, as opposed to Hahn's models, which report gross volume. Hahn (1984) included conversion factors to convert gross to net volume, if desired.

Additionally, the minimum DBH thresholds for sawtimber and merchantable yield calculations have been changed from the fixed 20.0 cm and 6.0 cm, respectively, to a user-defined limit (found in the species attribute file (COEF_TR1.CSV) of both *NORTHWDS* and *NIRM*). Currently, version 2.403 applies a default sawtimber threshold of 22.9 cm (9 inches) DBH for conifers and 27.9 cm (11 inches) DBH for hardwoods (as used in Hahn (1984)). For merchantable volume, a 10 cm (4 inches) DBH minimum is applied for all species when referring to harvested volume.

Mortality model parameter adjustment

The original mortality functions (______, _______) tended to slightly underestimate mortality. To address this, the base mortality parameter (b_0 in the original paper's description) was rounded slightly downward for most species. Otherwise, the equation form and other parameters were unaltered. This modification improved the longevity patterns, bringing them better in line with published expectations.

New source for specific gravity of wood (OD_i)

To improve source consistency and regionality, wood specific gravity (using oven dry weight and green volume) were taken from Smith (1985), rather than the three original sources. In many cases, the specific gravity values were identical, but others proved slightly different. Smith's data were taken from the 1974 Wood Handbook of the USDA Forest Service Forest Products Laboratory, and are available in more species than the other sources.

N*ORTHWDS* *I*NDIVIDUAL *R*ESPONSE *M*ODEL (*NIRM*)

NIRM represents a unique approach to an individual-based model. Many tree simulators operate at a very fine mechanistic approach, tracking critical sub-organismal processes like stomatal behavior under different moisture, temperature, and wind gradients, photosynthesis, internal carbon allocation patterns, root and/or shoot growth, branch initiation, etc. These physiological process models fill a critical niche in understanding individual plant behavior and work quite nicely under very controlled conditions. However, they do require extremely detailed knowledge of tree physiology, are strongly dependent on initial conditions and subsequent assumptions of weather and site, and are rarely performed on large individuals.

NIRM approaches individual behavior in a much different manner. *NIRM* subsumes all of the tissue and organismal behavior and becomes responsive to how external factors (e.g., local competition, herbivory, site quality) affect tree growth, which in turn dictates mortality and fecundity. This coarsening allows for ecosystem processes to drive the behavior of a tree, and hence does not become nearly as sensitive to initial conditions and other fine-scale attributes. For example, some physiological models operate on a time step of mere seconds, and track photosynthesis at the almost instantaneous level of insolation striking a given leaf. But how is shading from other leaves, neighboring plants, or even a passing cloud accounted for?

NIRM File Management

NIRM requires 5 files to successfully operate:

NIRM2_401.EXE (executable model file)

NIRM_DEF.CSV (*NIRM* model defaults)

COEF_MD1.CSV (*NIRM* model coefficients)

COEF_TR1.CSV (*NIRM* tree coefficients)

Environmental conditions file (user named)

The first four files are specifically required to be present in the same folder using the names given them. The environmental conditions file can be placed elsewhere and named as desired by the user, but must be locatable using traditional DOS file structure. As an executable file, NIRM2_401.EXE cannot be modified by the user. However, all of the other required files can be adjusted to meet specific simulation requirements.

NIRM Operation

NIRM is a DOS-based command line executable that can operate in either a DOS or Windows (via a DOS window) environment. Once initiated, the following screen appears:

The first few lines indicate that *NIRM* has successfully captured model defaults. If one of these default files is missing, corrupted, or opened by a program that does not permit sharing, then an error message will appear and model operation will cease. The user is given a choice of which species in the *NIHMS* application realm is to be simulated. Thirty candidates are listed by their *NIHMS* species alpha and numeric codes (Table ?).

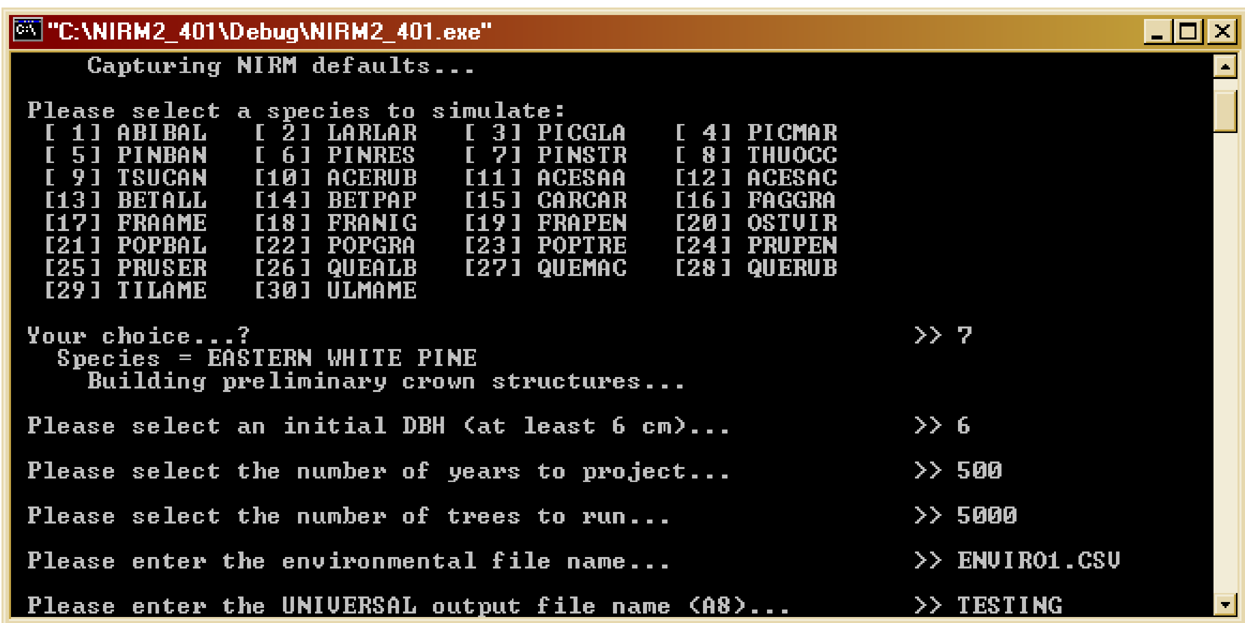
Table ?. Common and species names and identifier codes used in *NIHMS*.

Common name	Species[a]	Alpha code	*NIHMS* code	FIA code[b]
balsam fir	*Abies balsamea* (L.) Mill.	ABIBAL	1	012
red maple	*Acer rubrum* L.	ACERUB	10	316
silver maple[c]	*Acer saccharinum* L.	ACESAA	11	317
sugar maple	*Acer saccharum* Marsh.	ACESAC	12	318
yellow birch	*Betula alleghaniensis* Britton	BETALL	13	371
paper birch	*Betula papyrifera* Marsh.	BETPAP	14	375
American hornbeam[c]	*Carpinus caroliniana* Walt.	CARCAR	15	391
American beech[c]	*Fagus grandifolia* Ehrh.	FAGGRA	16	531
white ash	*Fraxinus americana* L.	FRAAME	17	541
black ash	*Fraxinus nigra* Marsh.	FRANIG	18	543
green ash[c]	*Fraxinus pennsylvanica* Marsh.	FRAPEN	19	544
eastern larch	*Larix laricina* (Du Roi) K. Koch	LARLAR	2	071
eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch	OSTVIR	20	701
white spruce	*Picea glauca* (Moench) Voss	PICGLA	3	094
black spruce	*Picea mariana* (Mill.) B.S.P.	PICMAR	4	095
jack pine	*Pinus banksiana* Lamb.	PINBAN	5	105
red pine	*Pinus resinosa* Ait.	PINRES	6	125
eastern white pine	*Pinus strobus* L.	PINSTR	7	129
balsam poplar	*Populus balsamifera* L.	POPBAL	21	741
bigtooth aspen	*Populus grandidentata* Michx.	POPGRA	22	743
quaking aspen	*Populus tremuloides* Michx.	POPTRE	23	746
pin cherry	*Prunus pensylvanica* L.F.	PRUPEN	24	761
black cherry	*Prunus serotina* Ehrh.	PRUSER	25	762
white oak[c]	*Quercus alba* L.	QUEALB	26	802
bur oak[c]	*Quercus macrocarpa* Michx.	QUEMAC	27	823
northern red oak	*Quercus rubra* L.	QUERUB	28	833
northern white-cedar	*Thuja occidentalis* L.	THUOCC	8	241
American basswood	*Tilia americana* L.	TILAME	29	951
eastern hemlock	*Tsuga canadensis* (L.) Carr.	TSUCAN	9	261
American elm	*Ulmus americana* L.	ULMAME	30	972

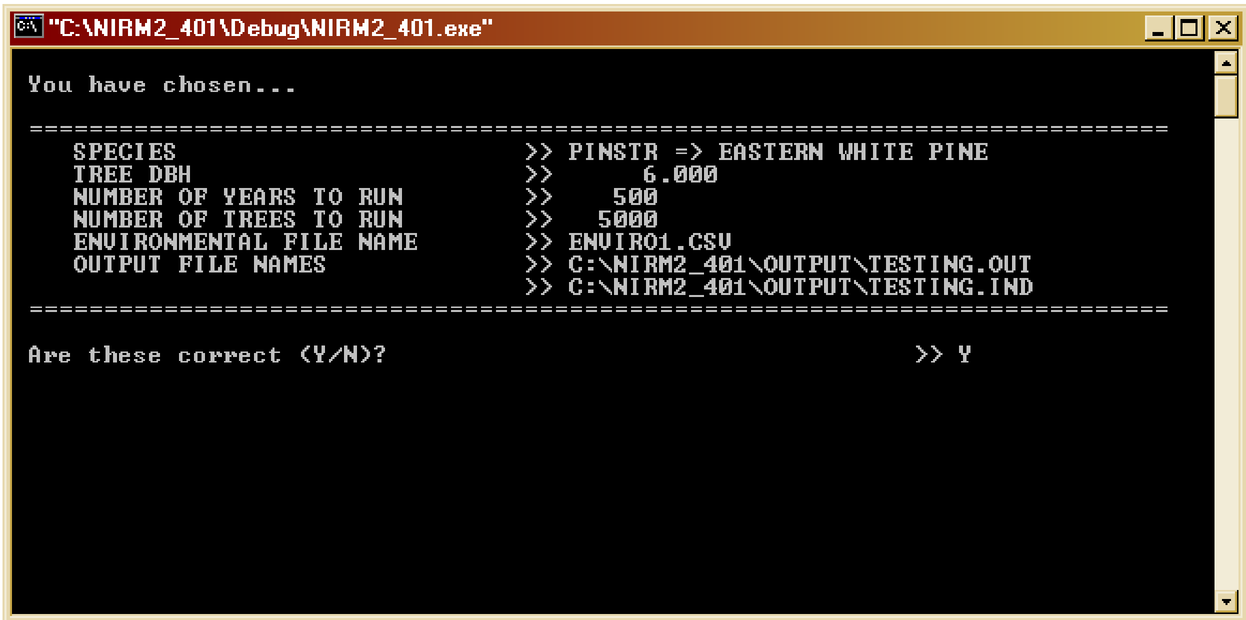
[a] Nomenclature from Harlow et al. (1979).
[b] Numeric codes used by the USFS Forest Inventory and Analysis Program (Hansen et al. 1992).
[c] New for version 2.403.

To continue, the user must choose a number between 1 and 30 corresponding to the species they are interested in (selection of a value outside of the fixed bounds of the question will bring up an error message and restate the question until an acceptable answer is provided). For this example, we will consider eastern white pine (code = 7).

The next prompt asks for the initial tree diameter at breast height (DBH, in cm). This value must be a real number at least 6.0 cm, and can extend up to maximum tree size for that species (most selections will be closer to the minimum tree size, however). The user then must choose the number of years to project. This value must be an integer from 1 to 1,000 years. It helps to know approximately the longevity of the species of interest so that all the individual tree simulations may finish before truncated by an upper time limit. In our example, we shall choose 500 years because very few eastern white pines live longer than this. If you do not know the maximum longevity of the species of interest, entering '1000' should not be problematic because the model stops the processing of an individual once it expires.



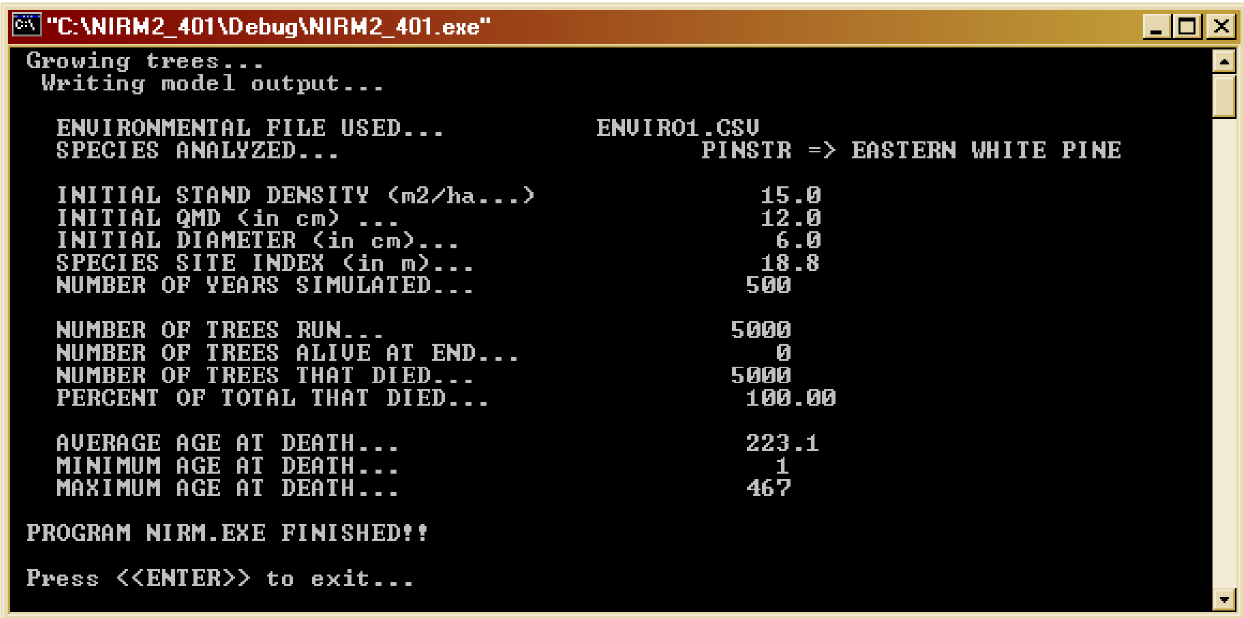
Selecting the appropriate number of trees to simulate is an important decision. *NIRM* processes each individual under the environmental conditions provided (given in this case by the file ENVIRO1.CSV). The more trees simulated, the more reliable the response distribution and oldest tree behavior outputs. However, more trees also results in a longer simulation time (which is a problem only with an older, slower computer). Up to 32,000 individuals can be processed in a single simulation run. In this example, 5,000 eastern white pines will be processed. The universal output file name is an 8 character DOS label (in this case, "TESTING"). No extension should be used, as *NIRM* will create the extensions for all of the output files.



The final screen displayed before processing allows the user to confirm their choices. *NIRM* shows the species, diameter, number of years, number of trees, and output filenames (including their full path). Answering 'Y' (yes) to the question begins *NIRM*'s analysis. A negative response to the question of correctness restarts the data input process all over again.

Once successfully initiated, *NIRM* begins processing for each individual. A 1.8 GHz Pentium4 PC with 1.3 GB of RAM took approximately 5 seconds to simulate the 5,000 eastern white pines in this example. The final results are displayed in an abbreviated form on the final output screen. This output screen reports the initial stand density, quadratic mean diameter, and species site index as specified or derived from the environmental condition file. It also repeats the initial diameter, number of years, and number of trees simulated. After this information, it identifies the number of trees that died before their simulation period expired (in this case, 100%

of the eastern white pines had died. *NIRM* also calculates average, minimum, and maximum age at death to provide the user with an impression of how successfully these trees weathered the environmental conditions under which they were simulated.



Given this particular simulation run, an typical 6 cm DBH eastern white pine under these conditions would survive an average of 223 years, with some dying one year after the simulation began and the oldest survivor living an additional 467 years.

Interpreting *NIRM* output files

Customizing *NIRM* operations

LITERATURE CITED

Bragg, D.C. 1999. Multi-scalar spatial modeling of northern forest dynamics: foundations, theories, and applications. Ph.D. dissertation, Utah State University, Logan, UT. 532 p.

Bragg, D.C. 2001. A local basal area adjustment for crown width prediction. Northern Journal of Applied Forestry 18:22-28.

Bragg, D.C., D.W. Roberts, and T.R. Crow. 2004. A hierarchical approach for simulating northern forest dynamics. Ecological Modelling 173:31-94.

Bush, R.R. and G. Brand. 1995. Lake States *TWIGS* geographic variant of the Forest Vegetation Simulator. USDA Forest Service Forest Management Service Center, online documentation. http://www.fs.fed.us/fmsc/fvs/documents/variant_overviews.php

Canham, C.D., A.C. Finzi, S.W. Pacala, and D.H. Burbank. 1994. Causes and consequences of resource heterogeneity in forests: interspecific variation in light transmission by canopy trees. Canadian Journal of Forest Research 24:337-349.

Carmean, W.H., J.T. Hahn, and R.D. Jacobs. 1989. Site index curves for forest tree species in the eastern United States. USDA Forest Service General Technical Report NC-128. 142 p.

Donnelly, D., B. Lilly, and E. Smith. 2001. The southern variant of the Forest Vegetation Simulator. USDA Forest Service Forest Management Service Center, online documentation. http://www.fs.fed.us/fmsc/fvs/documents/variant_overviews.php

Ek, A.R. 1974. Dimensional relationships of forest and open grown trees in Wisconsin. University of Wisconsin School of Natural Resources Forestry Research Note #181. 7 p.

Ek, A.R., E.T. Birdsall, and R.J. Spears. 1984. A simple model for estimating total and merchantable tree heights. USDA Forest Service Research Note NC-309. 5 p.

Hahn, J.T. 1984. Tree volume and biomass equations for the Lake States. USDA Forest Service Research Paper NC-250. 10 p.

Hansen, M.H., T. Frieswyk, J.F. Glover, and J.F. Kelly. 1992. The Eastwide Forest Inventory Data Base: users manual. USDA Forest Service General Technical Report NC-151. 48 p.

Harlow, W.M., E.S. Harrar, and F.M. White. 1979. Textbook of dendrology. 6th ed. McGraw-Hill Book Company, New York, NY. 510 p.

Raile, G.K., W.B. Smith, and C.A. Weist. 1982. A net volume equation for Michigan's Upper and Lower peninsulas. USDA Forest Service General Technical Report NC-80. 12 p.

Smith, W.B. 1985. Factors and equations to estimate forest biomass in the North Central Region. USDA Forest Service Research Paper NC-268. 6 p.

APPENDIX A: ERRATA FOR BRAGG ET AL. (2004)

Corrections to Bragg et al. (2004)

As with any large paper, errors inevitably slip through. This section is dedicated to rectifying as many of these problems as possible.

- In the first column on page 71, third paragraph (associated with equation 62), the Pacala et al. (1995) reference should actually read Kobe et al. (1995).
- The Pacala et al. (1995) reference in the References section should be Pacala et al. (1994).
- Equation 45 should read: $CV = b_{33} SI^{b_{34}} \left[1 - \exp\left(-b_{35} DBH\right)\right]^{b_{36}}$ The minus sign before the b_{35} parameter was omitted from the publication, but is present in the *NORTHWDS* code. NOTE: this volume model has now been replaced by equation [?].

APPENDIX B: BUG FIXES FOR VERSION 2.201

Improved the age step features of *NIRM*.