INFORMATION FOR FOREST PROCESS MODELS: A REVIEW OF NRS-FIA VEGETATION MEASUREMENTS

Charles D. Canham and William H. McWilliams[1]

Abstract.—The Forest and Analysis Program of the Northern Research Station (NRS-FIA) has re-designed Phase 3 measurements and intensified the sample intensity following a study to balance costs, utility, and sample size. The sampling scheme consists of estimating canopy-cover percent for six vegetation growth habits on 24-foot-radius subplots in four height classes and as an aerial view, and measuring tree saplings and seedlings on 6.8-foot-radius microplots. In the past two years, all of the basic submodels in SORTIE, an individual-tree distance-dependent model, were parameterized for the 50 most common tree species in the eastern U.S. by using FIA data. A significant challenge for modelers is that goodness of fit measures, such as the coefficient of determination, for the resulting growth models are often relatively low. Opportunities for using NRS-FIA data for broad-scale models include use of a non-spatial model of seedlings as a function of basal area of the entire subplot, ability to use a mortality model for seedlings, and improvement in knowledge of the impact of the species of neighboring trees. The major benefit of the new NRS-FIA sample design is a fourfold increase in sample size and integration of all vegetation measurements on the subplot (i.e., adult trees, competing vegetation, and seedlings). The primary limitation of using FIA samples is that the subplots are too small for full analysis of distance-dependent seedling dispersion around parent trees.

INTRODUCTION

Broad-scale models of forest dynamics provide projections of future conditions that are used by policymakers, managers, and scientists to understand and implement major decisions. It is challenging to provide forest modelers with information from forest inventories because model structure requirements vary widely. Prominent approaches include individual-tree distance-independent tree, growth/yield (Crookston and Dixon 2005), individual-tree distance-dependent tree (Pacala et al.1996) and imputation (Wear 2002) models. The Forest Inventory and Analysis Program of the Northern Research Station (NRS-FIA) vegetation measurements are reviewed using SORTIE (Pacala et al.1996) to exemplify complex model needs. SORTIE stands for a model of trees as they "take over" a site (not an acronym). SORTIE is an ecological process model that has been parameterized using NRS-FIA measurements (Canham et al. 2006). Broad-scale models that incorporate or "scale up" finer models of ecosystem processes to the scale of FIA are a critical need expressed by clients, particularly for projecting future conditions. The conclusions should be useful to others working at large scales, such as the Forest Vegetation Simulator (Dixon 2002).

In this paper, we focus on models that "mimic" growth and composition change for forest trees, or "process" models. The goal is to emphasize needs for models of tree recruitment, or regeneration models. The SORTIE model is used here to illustrate requirements for models that operate at finer scale than FIA, because it includes basic components needed for most process models, including a complex set of submodels.

[1] Senior Scientist (CDC), Institute of Ecosystem Studies, Millbrook, NY 12545; Research Forester (WHM), U.S. Forest Service, Northern Research Station. CDC is corresponding author: to contact, call 845-677-7600 or email at ccanham@ecostudies.org.

METHODS

NRS-FIA Vegetation Sample

NRS-FIA ceased collection of Phase 3 (P3) data in 2011 for budgetary reasons. Based on an evaluation of costs, time, and efficiencies, a modified suite of P3 variables and new Advance Tree Seedling Regeneration (ATSR) protocols were implemented in 2012. The sampling intensity for the modified suite will be up to 1/24,000 acres, which is between 1/96,000 acres for P3 samples and 1/6,000 for standard P2 samples, referred to as Phase 2+ (P2+). This intensity is based on the maximum number of plots that can be measured in a 3-month leaf-on summer window. The new P2+ design includes measurement of a Vegetation Profile and adult trees on the 24-foot-radius subplots and seedlings and saplings on a 6.8-foot-radius microplot (USDA Forest Service 2012).

All P2 and P2+ measurements are now integrated in a nested sample for all vegetation, including merchantable trees (greater than 5 inches in diameter at breast height [d.b.h.]) (Fig. 1). The sampling scheme includes estimating canopy-cover percent for six vegetation growth habits on four 24-foot-radius subplots in four height classes and an aerial view canopy cover estimate; measuring tree saplings including total height on 6.8-foot-radius microplots; and measuring tree seedlings on 6.8-foot-radius microplots in six height classes (USDA Forest Service 2012). The P2+ Vegetation Profile measurements are used to characterize vegetation composition and structure, and to develop an estimate of percent cover for competing vegetation. The competing vegetation information is used along with the seedling and sapling measurements to evaluate regenerative capacity.

SORTIE Primer

SORTIE is a spatially explicit, individual-based process model of forest dynamics that emphasizes neighborhood tree dynamics (Pacala et al.1996). Over the past decade, SORTIE has been improved to operate as an object-oriented, open-source platform for simulating forest dynamics. The model can easily be modified, and the source code, executable programs for both Windows and Linux platforms, manuals for programmers and users, sample parameter files, and sample output are all available on the SORTIE Web site (www.sortie-nd.org). Development of the model has been tightly linked to statistical methods to parameterize the model from field data, particularly the landscape-level data available from the FIA sample-plot network (i.e., Canham et al. 2006).

In the past two years, all of the basic submodels in SORTIE have been parameterized for the 50 most common tree species in the eastern U.S. by using FIA data from the entire eastern U.S. (Louisiana north to Minnesota and eastward). This includes functions for seedling recruitment, and growth and survival of seedlings, saplings, and adult trees. The recruitment functions include effects of climate, and indirectly incorporate the effects of shading (using basal area of adult trees within the immediate neighborhood of the seedling microplots within each FIA subplot as a surrogate). Seed production and dispersal are not modeled as separate steps, but as in the original SORTIE model are subsumed within the seedling recruitment functions. The growth and survival functions for saplings and adult trees incorporate effects of competition, climate, air pollution (N deposition) (i.e., Canham et al. 2006).

Regional-scale results are generated for current forest structure, composition, and environmental characteristics of randomly selected FIA plots, using current climate (from bilinear interpolation of PRISM climate data) and N deposition, based on a regional, spatially-explicit model of total wet and dry N deposition (Weathers et al. 2006). Since the FIA plots used to initialize the individual runs represent specific locations and known total areas of forestland, variation in the regional-scale results can be mapped, and can be broken out by sub-region (i.e., states, counties), forest type, or mapped as a function of any of the axes of environmental variation (climate, N deposition, soils) linked to the FIA plots. The model architecture is currently being extended to allow interactions among FIA plots embedded within a region (to allow, for instance, modeling seed dispersal based on regional abundance of tree species).

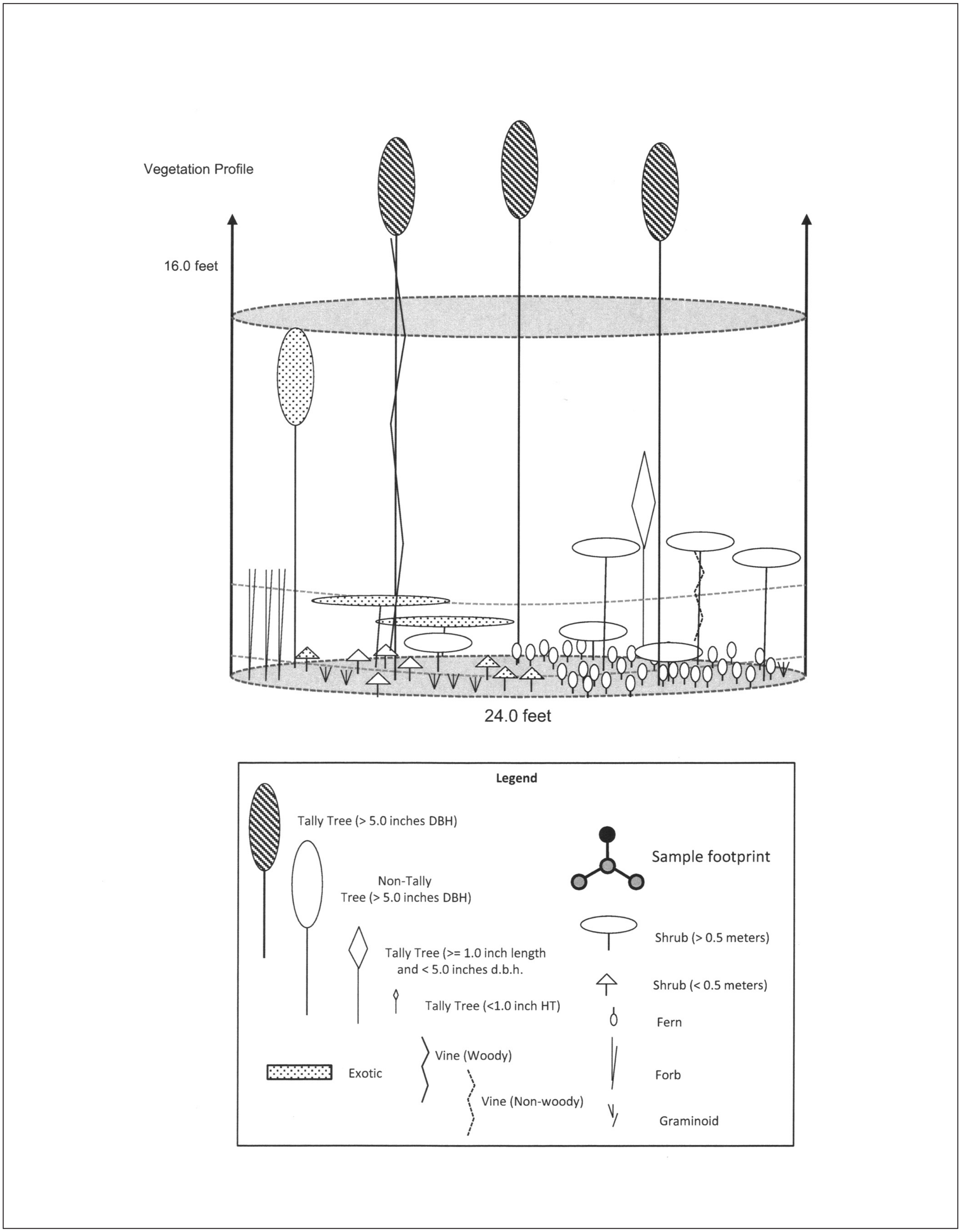


Figure 1.—Example of NRS-FIA forested subplot depicting nested vegetation samples, 2012 (continued on next page).

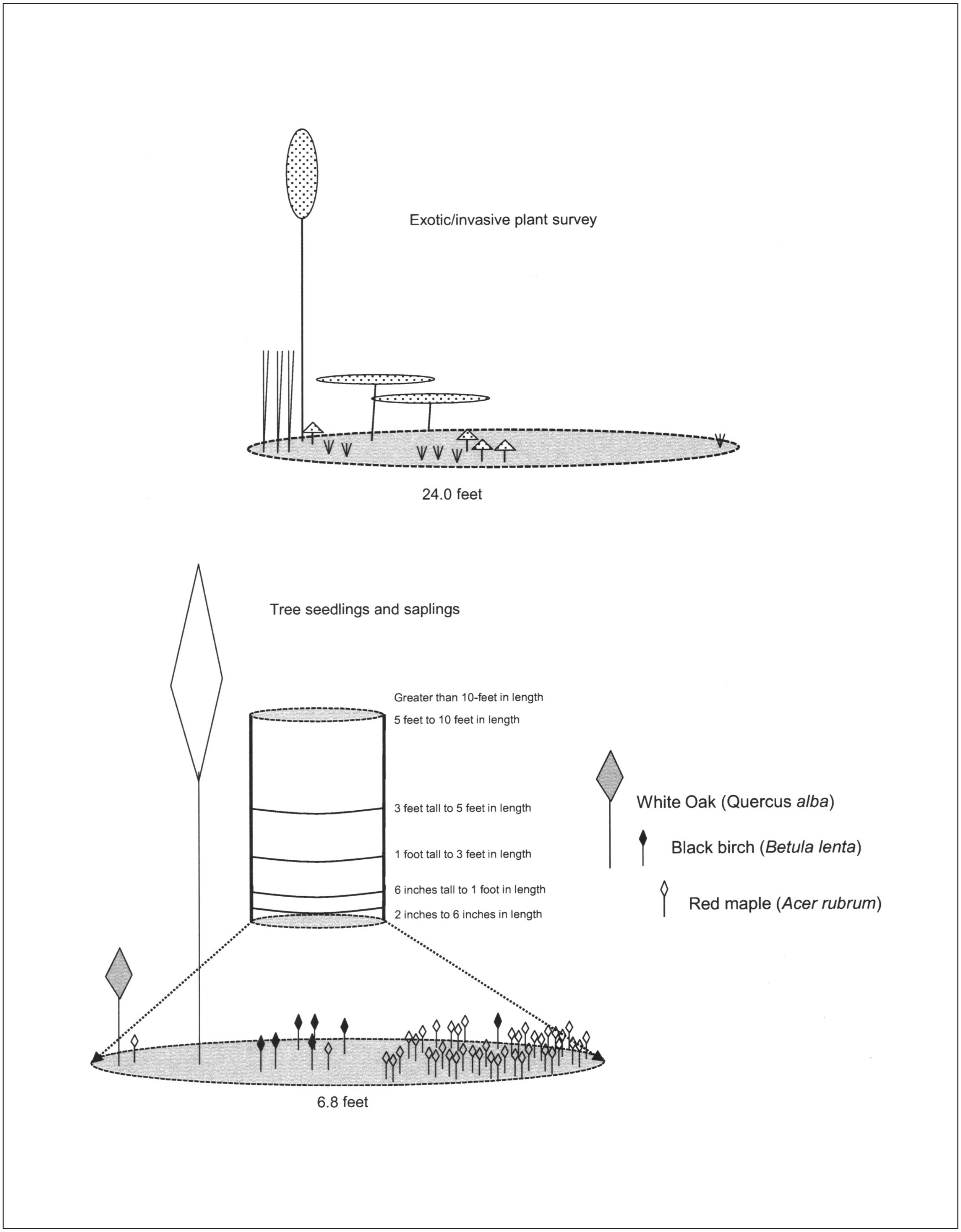


Figure 1 (continued).—Example of NRS-FIA forested subplot depicting nested vegetation samples, 2012.

SORTIE is an individual-tree distance-dependent model that simulates light, tree birth, growth, and mortality for seedlings, saplings, and merchantable trees (Canham et al. 1994). SORTIE consists of four submodels: seedling recruitment (reproduction) function, resource availability (light) (Beaudet et al. 2020), tree growth (Pacala et al. 1994), and tree mortality (Kobe et al. 1996). SORTIE allows development of “behaviors” to fit the user’s forest population or eco-type of interest. Canham et al. (2006) parameterized SORTIE for use in New Hampshire and Vermont using NRS-FIA data. Actual tree growth is a function of potential diameter growth using scalars that quantify growth based on initial diameter, local environmental conditions, and crowding by neighbor trees.

The focus for this discussion is the seedling recruitment submodel and associated needs from FIA. Seedling recruitment models can be complicated considering that they track seed production, dispersal, predation, germination, and mortality. To simplify model needs, using seedlings above a minimum threshold allows a focus on seedlings that have germinated in the current year (Ribbens et al. 1994). The FIA minimum size for counting seedlings is 6 inches long for conifers and 1 foot for deciduous species. Canham et al. (2006) modeled seedling dispersion as a function of the proximity of parent trees. Specifically, NRS-FIA seedling counts and adult tree basal area were merged with climate variables with NRS-FIA sample locations.

DISCUSSION AND CONCLUSIONS

Opportunities for using NRS-FIA data for broad-scale models include use of a non-spatial model of seedlings as a function of basal area of the entire subplot, ability to use a mortality model for seedlings, and improvement in knowledge of the impact of the species of neighboring trees. The NRS-FIA sample design includes several variables associated with SORTIE needs (Figs. 1 and 2).

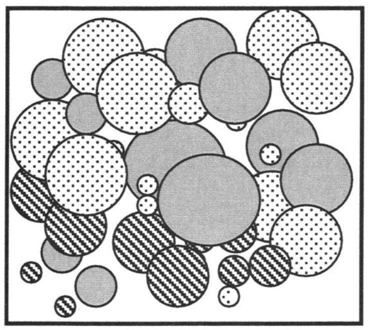
In the past, the NRS-FIA minimum seedling size threshold included cohorts from multiple years and excluded mortality of seedlings before achieving the minimum size. This threshold is no longer a limitation because the Advance Tree Seedling Regeneration (ATSR) measurement protocols include all seedlings that germinated and survived in the past year. Another challenge for modelers is that the coefficient of determination of the growth models is relatively low. The primary limitation of using FIA samples is that the subplots are too small for full analysis of distance-dependent seedling dispersion around parent trees.

Other benefits of the new NRS-FIA sample design are a fourfold increase in sample size and that all vegetation measurements are integrated on the subplot (i.e., adult trees, competing vegetation and seedlings). Although not utilized yet, the information on seedling height and browse pressure should allow for finer model refinement. The height class breakdown has particular value for refining seedling recruitment models. The information could also be used to improve the seedling component of FIA’s stocking and forest type algorithm that uses seedlings to predict future stocking. The basic challenge for modelers is to continue to seek methods for finer scale models to integrate with FIA variables.

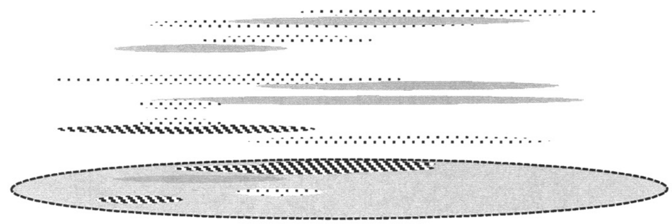
SORTIE

NRS-FIA P2+

Light



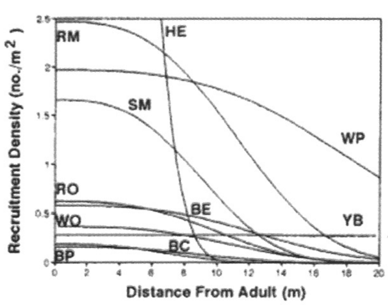
Tree crowns: aerial view



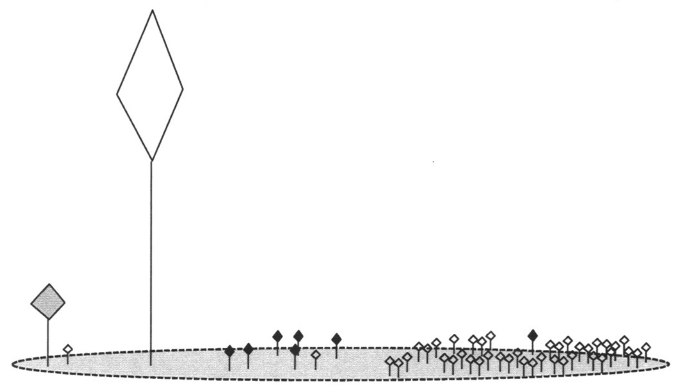
Vegetation Profile: percent cover by Growth Habit
percent cover - Aerial View

P2 Tree Tally: Basal Area and Stocking Percent
Canopy Class

Recruitment



Recruitment densities for nine species (Ribbens and others 1994)



Advance Tree Seedling and Sapling Regeneration (ATTSR)

P2: Seedling: Number
Species
Height class
Competitive status
Browse Pressure

P2: Saplings: Azimuth and Distance
Diameter
Height
Crown
Damage

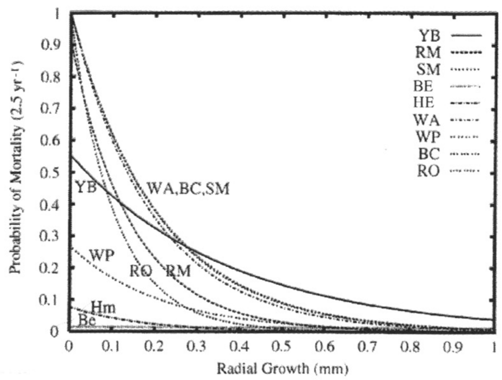
Key to Species Codes: eastern hemlock (*Tsuga canadensis* L.)(HM), red maple (*Acer rubrum* L.)(RM), white pine (*Pinus strobus* L.)(WP), sugar maple (*Acer saccharum* Marsh.)(SM), American beech (*Fagus grandifolia* Ehrh. (BE and BP), white ash (*Fraxinus americana* L.)(WA), black cherry (*Prunus serotina* Ehrh. (BC), white oak (*Quercus alba* L.)(WO), northern red oak (*Quercus rubra* L.)(RO), and yellow birch (*Betula alleghaniensis* Britton.)(YB)

Figure 2.—SORTIE submodels and associated FIA vegetation measurements, 2012 (continued on next page).

SORTIE

NRS-FIA P2+

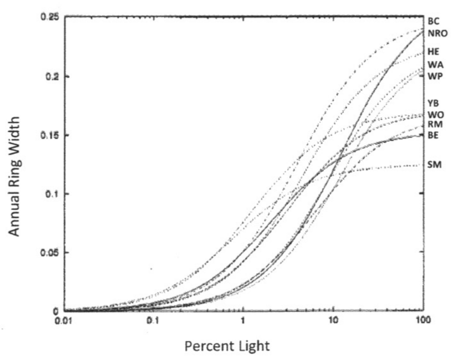
Mortality



Estimates of growth-related mortality functions
(Kobe and others 1995)

P2: Merchantable Tree: Species
Diameter and Tree Length
Azimuth and Distance
Tree History
Damage Code
Crown Density
Down Woody Material

Growth



Sapling growth estimates for 10 species (Pacala and others 1994)

P2: Merchantable Tree: Species
Azimuth
Distance
Diameter
Height
Volume
Weight
Carbon

<u>Key to Species Codes</u>: eastern hemlock (*Tsuga canadensis* L.)(HM), red maple (*Acer rubrum* L.)(RM), white pine (*Pinus strobus* L.)(WP), sugar maple (*Acer saccharum* Marsh.)(SM), American beech (*Fagus grandifolia* Ehrh. (BE and BP), white ash (*Fraxinus americana* L.)(WA), black cherry (*Prunus serotina* Ehrh. (BC), white oak (*Quercus alba* L.)(WO), northern red oak (*Quercus rubra* L.)(RO), and yellow birch (*Betula alleghaniensis* Britton.)(YB)

Figure 2 (continued).—SORTIE submodels and associated FIA vegetation measurements, 2012.

LITERATURE CITED

Beaudet, M.; Messier, C.; Canham, C.D. 2002. **Predictions of understory light conditions in northern hardwood forests following parameterization, sensitivity analysis, and tests of the SORTIE light model.** Forest Ecology and Management. 165(1-3): 231-244.

Canham, C.D.; Finzi, A.C.; Pacala, S.W.; Burbank, D.H. 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.

Canham, C.D; Papaik, M.J.; Uriarte, M.; McWilliams, W.H.; Jenkins, J.C.; Twery, M.J. 2006. **Neighborhood analysis of canopy tree competition along environmental gradients in New England forests.** Ecological Applications. 16(2): 540-554.

Crookston, N.L.; Dixon, G.E. 2005. **The Forest Vegetation Simulator: a review of its structure, content, and applications.** Computers and Electronics in Agriculture. 49(1): 60-80.

Dixon, G.E., comp. 2002. **Essential FVS: a user's guide to the forest vegetation simulator.** Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 248 p. (Revised: June 27, 2012).

Kobe, R.K. 1996. **Intraspecific variation in sapling mortality and growth predicts geographic variation in forest composition.** Ecological Monographs. 66: 181-201.

Pacala, S.W.; Canham, C.D.; Silander, J.A., Jr.; Kobe, R.K. 1994. **Sapling growth as a function of resources in a north temperate forest.** Canadian Journal of Forest Research. 24: 2172-2183.

Pacala, S.W.; Canham, C.D.; Saponara, J.; Silander, J.A., Jr.; Kobe, R.K.; Ribbens, E. 1996. **Forest models defined by field measurements: estimation, error analysis and dynamics.** Ecological Monographs. 66: 1-43.

Ribbens, E.; Silander, J.A.; Pacala, S.W. 1994. **Seedling recruitment in forests: calibrating models to predict patterns of tree seedling dispersion.** Ecology. 75: 1794-1806.

USDA Forest Service. 2012. **Forest inventory and analysis national core field guide, Volume 1 Supplement: field data collection procedures for Phase 2+ plots, version 5.0.** Available at http://www.nrs.fs.fed.us/fia/data-collection/. (Accessed June 7, 2012).

Wear, D.N.; Griesbusby, J.D. 2002. **Southern forest resources assessment.** Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.

Weathers, K.C.; Simkin, S.M.; Lovett, G.M.; Lindberg, S.E. 2006. **Empirical modeling of atmospheric deposition in mountainous landscapes.** Ecological Applications. 16: 1590-1607.