Current Methodologies

Past pest/disease epidemics
(Dutch Elm Disease, Gypsy Moth, and Chestnut Blight)

Sudden Oak Death
Emerald Ash Borer

Possible future epidemics

The majority of current forest mortality analyses include simple summarizations of tree mortality rates among species groups and causes of tree death. More sophisticated analyses include individual tree logistic models which may not be applicable for large-scale inventory analysis.

Survival Analysis and Forest Mortality

Survival analysis is:

- Class of statistical methods for studying the occurrence and timing of events (death)
- Commonly applied in medical sciences
- Data used: age, time, death, covariates

Central Functions of Survival Analysis:
The Survivor (cumulative risk of mortality) and Hazard Functions (time interval risk of mortality)

Survival Function

\[ S(t) = P(T > t) = 1 - F(t) \]

Hazard Function

\[ h(t) = \frac{f(t)}{S(t)} \]

Forest Survival Analysis Supposition

For forest inventories that examine trees at regular intervals, DBH and ADDBH (time two DBH - time one DBH) may assign individual trees to cells within a matrix of tree size and vigor. The survivor function \( S(t) \) is defined at a time \( t \) as the chance that the time to the event is greater than or equal to \( t \). In this study, the “clock” starts at the first forest inventory, when a tree begins to be at risk for the event or begins to be monitored for the event. Stating this in terms of DBH, the clock is ADDBH (the increase in DBH from initial survey). Our survival function \( S(ADDBH) \) gives the chance that a tree will live after it has grown by at least ADDBH - k cm. For example, \( S(4) \) estimates the proportion of the population of trees that will survive to increase their DBH by 4 cm. The hazard function \( h(ADDBH) \) gives the chance that a tree that has survived and grown \( k \) cm will die at that point. The individual tree variables of DBH and ADDBH may allow application of survival analysis to forest inventories thereby providing a novel method of assessing forest mortality dynamics.

Survival Analysis Surrogates:

Age → Tree DBH → Tree Vigor → DBH Growth

New Mortality Analysis Output

The hazard function estimates the probability of mortality occurring for trees by DBH class and growth rate.

Beyond graphical display of the survivor and hazard functions, log-rank tests for effects of covariates and tests of equality among strata may allow for testing of mortality hypotheses.

Forest inventory analysis has traditionally been geared toward simple summarizations at the landscape-scale and focused on logistic regression modeling at the individual-tree scale. Few advances or technologies have been forwarded for robust analysis of forest mortality dynamics at the landscape-scale. This study proposed a new approach to forest mortality assessment through combination of established survival modeling techniques with survival hazard functions with traditional quantifications of forest stand attributes. Although the technique augments a paradigm shift in forest mortality analysis and non-standard application of survival analysis techniques, a new forest mortality analysis approach may be needed to provide statistically defendable assessments of new mortality across forest types, locations, and varying damage agents.

The hazard function estimates the probability of mortality occurring for trees by DBH class and growth rate.

Separate hazard functions for insect and disease damaged inventory trees indicate differences in dynamics of tree mortality between the two damage agents.

Given the past diseases and epidemics that have greatly altered our North American forest ecosystems and the threats of future forest health hazards, novel and statistically robust techniques for assessing forest mortality would greatly benefit forest inventory analysis.

Study Methods

- Determine Functions
  - Survival: \( S(ADDBH) \)
  - Hazard: \( h(ADDBH) \)
  - SAS → PROC LIFETEST

- Variables: DBH, DBH 2, Tobita, DAM1, DAM2, BAI, CC, and CR
- Data: Minnesota 1977-1990

A New Method for Quantifying Forest Inventory Mortality

Chris Woodall, North Central Research Station, USDA Forest Service, St. Paul, MN
Patricia Grambsch and Will Thomas, School of Public Health, University of Minnesota, Minneapolis, MN

Tree mortality has typically been assessed in forest inventories through summaries of mortality by location, species, and causal agents. Although these methods have historically constituted the majority of forest mortality analyses, they are inadequate for robust assessment of mortality trends and dynamics. In order to afford a new method of analyzing tree mortality in forest inventories, survival analysis techniques were used to estimate survival and hazard functions for FIA periodic inventories in Minnesota. The study’s methodology for applying survival analysis techniques to FIA inventories successfully estimates survivor and hazard functions. Classifying individual trees into classes of DBH and ADDBH growth may facilitate application of survival analysis techniques to forest inventories by providing a surrogate for tree ages and vigor. Applying survival analysis techniques to forest inventories may provide forest inventory analysts with the ability to test tree mortality hypotheses, summarize regional tree mortality trends, and afford a solid foundation for development of individual tree mortality models.