Incorporating Hemlock Woolly Adelgid Impacts into the Forest Vegetation Simulator Model

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BACKGROUND

The hemlock woolly adelgid (HWA), *Adelges tsugae*, is a small aphid-like insect that feeds on the xylem ray parenchyma cells near the base of hemlock needles. This insect, a native of Asia and western North America, was first noted in eastern North America in 1951 and has now spread to infest hemlock in at least 17 states. The increased hemlock mortality driven by this insect requires land-managers and silviculturalists to develop stand management plans that account for the potential impact this invasive species. The Forest Vegetation Simulator (FVS) was developed to simulate stand development through time under a variety of land-management actions and has the flexibility to include impacts by fire, pathogens, insects, and other disturbances. Using available data that describe the timing, intensity, and trajectory of infestations, we have developed two simple event monitor addfiles (*.kcp files) for the north-eastern and southeastern FVS variants.

EVENT MONITOR STRUCTURE

The event monitor adfiles for both FVS variants are based on three key assumptions: the assumed time of infestation, the assumed intensity of the infestation (population growth rate), and the assumed population behavior (cyclical vs. saturated). First, the timing of infestation is determined by the user for a given stand based on the distance from known populations of the hemlock woolly adelgid. Multiple publications, including Souto et al. (1996), Orwig and Foster (1998), Yorks et al. (1999), and Evans and Gregoire (2007), document rates of HWA spread across the landscape. These primary sources should be used as tools for producing an estimate of the anticipated date of arrival—or more specifically, used to bracket the estimated time or arrival. This date or variation around the anticipated date can then be modified by the user by editing the FVS HWA event monitor in any text editing program. Use of bracketing (i.e., running the simulation assuming infestation in the near future and comparing that with simulations based on infestation occurring in the more distant future) can provide examples of "worst" and "best" case scenarios of infestation timing.

The second assumption used to drive the FVS HWA event monitor is the population growth rate expressed by the adelgid in a newly infested stand. At the present, quantitative time-series data for stands growing in varying conditions and in variable geographic locations are not available. However, data collected over the last 15 years at the Delaware Water Gap National Recreation Area (Evans 2004) provide an estimate of the time period between population detection (i.e., date of infestation) and deterioration of host condition. Within the Delaware Water Gap, trees "generally" began to deteriorate in about five years; however, significant variation occurred among stands in the park and even between trees in a stand. Bracketing this variable by running the stand development simulation with varying rates of impact should be done to assess the impact this variation may have and to provide "best" and "worst" case scenarios, though the default in the FVS HWA event-monitor is five years (assuming the user calculates stand state in five-year intervals). Although these data provide a starting point for our understanding of long-term HWA dynamics, it should be noted that these data were collected from a single region in a northern location and may be appropriate only for the northeastern variant or portions of it. In the southeastern United States, HWA populations have been observed to grow much more rapidly, causing the deterioration and mortality of hemlocks in as little as two years. Unfortunately, little quantitative time-series data is available for the South due to its recent infestation, and so estimates of the time between infestation and tree impact are based on qualitative observations. As additional observations and data become available, they will be incorporated into the southeastern variant by including a lag between an infestation event and impact or by shifting the infestation date (i.e., a longer lag-time can be simulated by simply shifting the infestation to a later date).

The third assumption incorporated into the FVS HWA event monitor is that northern and southern populations of the hemlock woolly adelgid have different population dynamics: specifically, that populations in the northeastern variant may cycle through time with gradually reduced population peaks (McClure 1991). In this system, population densities of the adelgid grow to a point that degrades the condition of the hemlock, and in so doing, reduces its ability of the hemlock to support large populations of the hemlock woolly adelgid. As adelgid populations crash due to poor host condition, trees begin to recover, triggering a resurgence in adelgid populations. Populations may not grow to the density of the first wave, however, due to a reduced carrying capacity by the hemlock (i.e. hemlocks may not recover to pre-infestation conditions). Over time, the decrease in hemlock condition produces the gradually reduced peaks in adelgid abundance. In the FVS HWA event monitor, this is effected by allowing only "moderate" to "low" infestations after a "catastrophic" infestation. Population cycles are randomized within the FVS to simulate some of the stochasticity associated with external factors such as climate, but ratings of "zero" adelgid are not allowed, as it is assumed that once a stand is infested, it will remain infested. These cycles may result in tree death in as little as four years or may continue for 15 years or longer. The net affect in northern stands is that hemlocks may be lost from the system over the course of several decades, with tree mortality happening in waves.

In the southeastern United States, however, populations of adelgids may grow so quickly that they reduce the quality of the host hemlock beyond a point at which recovery is possible. In this system, trees may die quickly without repeated cycles of impact and recovery. The current version of the FVS HWA event monitor can be adjusted to reflect these differences in impact, and as additional data becomes available, rates can be adjusted and bracketed to improve estimates of stand development.

SUMMARY

The ecology of stand development is highly complex and is ultimately determined by local, proximate factors. However, the general impacts of an invasive species can often be estimated using existing knowledge, and the resulting estimates of stand impact can be used to forecast stand conditions using known "rules" in the system. Here we have incorporated some basic observations or rules regarding the population dynamics of the hemlock woolly adelgid, and that the resulting changes in tree condition in northern and southern hemlock stands to produce an even monitor that reflects the potential impacts of the HWA.

The resulting benefit for the management of this invasive adelgid is two-fold. First, this simulation can be useful for land managers seeking to understand the potential development trajectories forested systems that include hemlock make take as they are infested and to play "what if" games to evaluate multiple management scenarios. Second, this event monitor highlights areas needing additional research on hemlock woolly adelgid biology and ecology: for example, more data is needed on the relationship between the timing of infestation and the deterioration and mortality of hemlock trees in the Northeast.

In the southeast where infestations are young but often severe, the importance of gathering both pre- and post-infestation data and quantifying the interaction between adelgid arrival and density with tree condition is even more important. As this data becomes available and is integrated into the event monitor, the quality of the simulation will improve. The FVS HWA event monitor should be viewed as a dynamic tool that will evolve in step with our understanding of the biology and ecology of the hemlock woolly adelgid. Only through the continued integration of more specific, site-appropriate data will land managers be able to reduce the size of brackets used for estimating the relevant adelgid and hemlock parameters and refine the scope of potential stand development trajectories.

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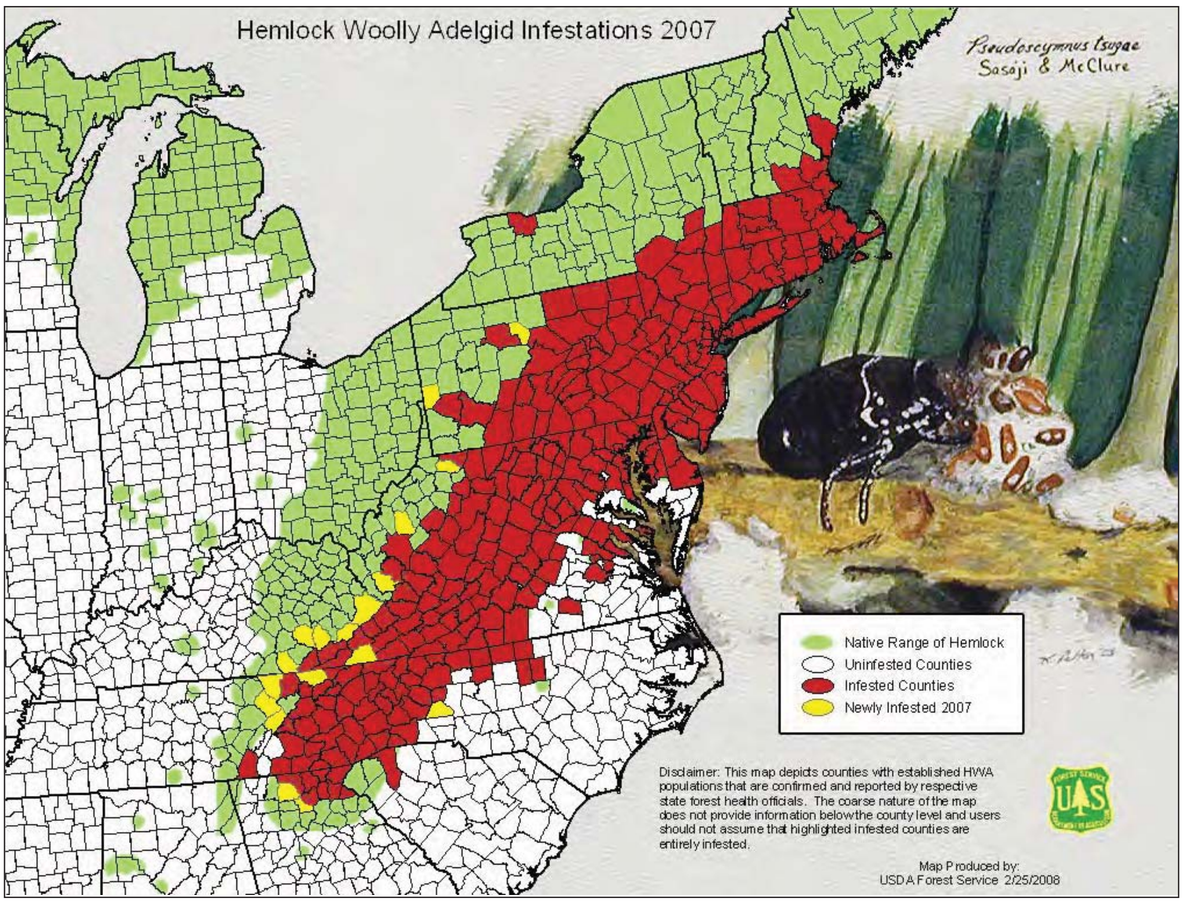

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