

MONITORING HEMLOCK VITALITY USING GROUND-BASED DIGITAL IMAGING

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ABSTRACT

The vitality of hemlock (*Tsuga* spp.) trees needs to be assessed in order to evaluate the effectiveness of treatments that combat hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Homoptera: Adelgidae). Ground-based photomonitoring can be used to assess canopy dynamics, which serves as a visual indicator of tree vitality. Here we propose a sampling strategy using a digital camera with a telephoto lens to examine change in needle count over time. The magnification provided by the lens optics reduces some of the complicating effects inherent in other forms of below-canopy photographic methods and enables direct measurement of the objects of interest, the needles.

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INTRODUCTION

Hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Homoptera: Adelgidae), is rapidly infesting and causing widespread mortality of large areas of hemlock (*Tsuga* spp.) forests in the eastern United States. Due to this epidemic, hemlocks are being intensely studied. Branch counts, needle loss, and crown transparency (Mayer et al. 2002, Webb et al. 2003) are often used to assess individual tree responses to HWA infestations. Defoliation and regrowth dynamics are of interest in studies of hemlock response to HWA infestation. Ground-based photomonitoring can be used to assess these canopy dynamics. In this paper we will address some of the issues involved with ground-based photomonitoring using digital cameras and make suggestions on designing an effective system.

GROUND-BASED CANOPY DATA COLLECTION

Due to access difficulties (Barker and Pinard 2001) crowns are often evaluated from a ground-based vantage point. This presents some challenges in the outdoor environment. Hemispherical (fisheye) photography is often used for canopy openness or photosynthetic photon

flux density (PPFD) estimation (Englund et al. 2000). Oblique ground-based photography has also been used to monitor foliar change (Curtis and Kelley 1993, Lee et al. 1983, Lindsey and Bassuk 1992). Here emphasis will be placed on ground-based methods of individual tree evaluation. Though this paper will concentrate on hemlock (Figure 1), these methods can be generally applied to other needle-leaved species.

As the HWA attack trees, the hemlock foliage dies and abscises. This can happen at the branch, twig, or even individual needle level. It is desirable to see how many needles are removed, retained, or added over time. Thus, we will set the needle as our object of interest and our minimum scale accordingly. Assuming that sampling is performed at the Nyquist frequency, an optical system must be selected which can resolve one-half of the needle width at a tree height distance. It may be difficult to find such an optical system, but that would be the desired precision. For this repeated measures sampling strategy precise controls are needed to monument and maintain the same optical system parameters over time (Davies 2004, Hall 2001). One advantage of digital cameras lies in their ability to immediately examine the image once it is captured. This can allow the operator to adjust the optical parameters to match previously captured images.



Figure 1. Example of ground-based view of hemlock crown.

OPTICAL ISSUES

There are many environmental and photographic factors that affect ground-based canopy imaging. Here, we discuss several of these factors and their impact on evaluating foliage change over time.

ENVIRONMENTAL EFFECTS

Overcast conditions are favored for ground-based canopy applications (Frazer et al. 2001, Englund et al. 2000), having been empirically determined to be less variable. Some reasons for this are that, as the ambient light is diffuse, penumbral effects, specular reflectance, and the

variation of radiant flux density across the scene is more manageable for the imaging sensor. Waiting for overcast conditions can be over-restrictive for our purposes; instead, we suggest a narrow field of view (FOV) to minimize these effects and the probability of imaging the sun directly.

Other objects can interfere with the clear viewing of the object of interest. Objects in the background can affect the contrast needed to delineate the object of interest and foreground entities can block the view completely. Reasonable precautions can be taken during the first sampling cycle; there may be no remedy other than disregarding the sample for subsequent visits. For this reason, we suggest taking a larger number of samples than initially needed, knowing that some may be discarded in future revisits.

PHOTOGRAPHIC EFFECTS

Resolution

Measurement precision in any sampling space (i.e., spatial, spectral, and temporal) is limited by the ability to segment and distinguish between very small changes. As digital sensors are arrangements of discrete sampling areas, not unlike film emulsions, there are limits to spatial precision. There are also spectral precision limits on the ability to measure specific quantities of light of specific wavelengths over specific time intervals.

Many studies attribute digital camera overestimation to the limited spatial resolution of the image (Frazer et al. 2001, Englund et al. 2000). This is of particular concern for needle-leaved species as the needle arrangement creates many very thin gaps. Thus, the measurement scale should be considered at the outset of the canopy study to determine the minimum gap (or leaf) dimension to be considered.

It is important to have the appropriate spatial and spectral resolution to be able to resolve the object of interest: Figure 2 shows two images (a and b) captured with 35 and 280 mm-equivalent focal lengths, respectively. The interaction between spatial and spectral resolution can have serious affects at the analysis stage. Threshold selection can also contribute to variability when images are analyzed: the binary images (Figure 2, c and d) show how spatial resolution and thresholding can have a combined effect on the classification of foliage or sky.

Lens Factors

Lens systems gather, filter, and direct light rays to the optical sensor and play a large part in the usefulness of the output image. Lens focal length affects the spatial and radiometric properties of the captured image: short focal lengths produce wide-angle views with limited magnification; conversely, longer focal lengths cover more narrow views in greater detail (higher spatial resolution). The broader spatial coverage of shorter focal lengths incorporates a greater radiant flux density, allowing small apertures and faster shutter speeds, but greater variation across the scene. The lower amount of light captured with long focal lengths necessitates greater aperture and/or shutter speed adjustments for adequate exposure. The need to adjust focus will be an added complication when using long focal lengths as the depth of field (DOF) will be drastically reduced.

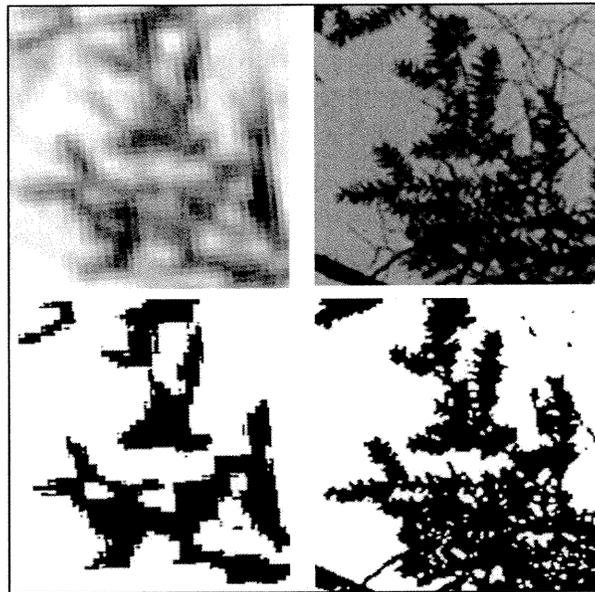


Figure 2. Depiction of a hemlock branch imaged at 35 and 280 mm equivalent focal lengths (a and b) and these same image sections when a global threshold is applied (c and d, respectively).

Short focal lengths tend toward barrel distortion and long focal lengths create pin cushion distortion. Spatial dimensions are not being considered for this crown assessment application so distortion effects are not a primary concern. As repeated measurements are being considered it would minimize variation if the same lens was used for all remeasurements.

Exposure

The understory of a healthy hemlock stand is typically very dark and proper exposure is critical so smaller structures do not get washed out. For taking these zenith-looking images, the aperture should be stopped down as much as possible to improve contrast (Bunnell and Vales 1990). A smaller aperture necessitates a longer shutter speed however if the camera is mounted on a tripod motion blur should be minimal (unless the wind is blowing the tree/needles). Blooming and penumbral effects are reduced in the underexposed image. The stopped down images are more able to detect smaller tree structures amidst a majority sky background (Figure 3).

Digital Camera Factors

Digital cameras have come under scrutiny for below-canopy photography purposes (Frazer et al. 2001, Englund et al. 2000). In addition to their limited and discrete spatial and spectral resolution, other collection and processing anomalies have contributed to the complications of consumer-grade digital cameras. While we recognize these limitations, we believe these difficulties are of limited consequence within our sampling protocol.

Consumer-grade digital cameras are most commonly designed for color image processing using a color filter array applied over the sensing elements. Digital image manipula-

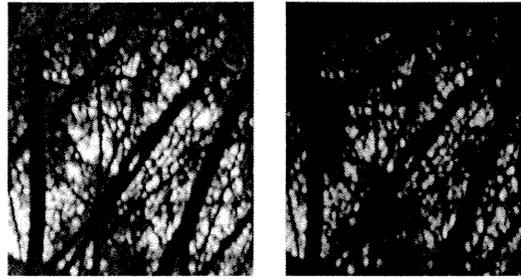


Figure 3. Images captured with different aperture settings. The image on the right is stopped down two f-stops. Contrast is enhanced in the stopped down image and more crown structures are preserved in sky-dominated areas. Blooming is also reduced.

tions including gamma correction, white balancing, sharpening, interpolation, and data compression are then performed to create a visually pleasing output image at a minimal storage size. As the operations performed are normally proprietary methods that differ among manufacturers, it is difficult to determine the actual measured values.

All optical sensors have light collection and recording limitations or dynamic range and significant clipping can occur at very high or very low levels of radiance collection. If a sensing element receives an overabundant amount of light, there is also the potential for blooming (or overflow into adjacent elements). Chromatic aberration, or color blurring, is due to variable refraction of light wavelengths as they pass through the lens optics causing them to focus at different distances (Frazer et al. 2001). These effects are exacerbated at shorter focal lengths.

DISCUSSION

Ground-based photomonitoring provides a cost-effective means of evaluating change in canopy dynamics over time, but is not without difficulties. The sample must be visually unobstructed. The appropriate scale must be selected. After scale determination, the location of the camera and focal length must be determined. For repeated measures sampling the problem of camera relocation must be addressed. As lighting can not be controlled in the outdoor environment, camera settings must be adjusted accordingly.

At low spatial resolutions comparison would have to be made of radiant flux density allowed to pass through the same crown areas. Compensating for the many changing environmental and optical factors at each photo-session would be extremely difficult. It is for these reasons that we propose using a longer focal length such that individual needles can be discerned. At this level, we only need to determine presence or absence of individual needles over time (Figure 4). To do so, we randomly select an azimuth around the stem axis and a random distance between the stem axis and the crown edge in this direction. This point will be marked so the camera setup can be performed easily for subsequent image collection. The

camera will be placed over this point with the camera axis facing the zenith. A focal length will be selected such that individual needles can be discerned. Immediately prior to image collection, a copy of the initial image will be used to re-establish identical camera parameters

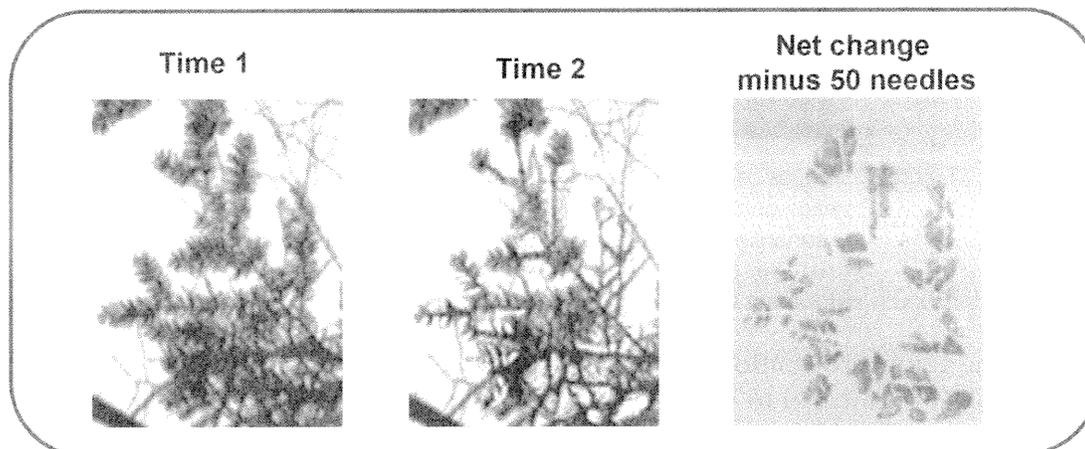


Figure 4. Repeated measures example of foliage change over time.

(i.e., focal length, aperture, position, view angle). Field tests need to be performed at varying levels of foliage change to evaluate the efficacy of this proposed method.

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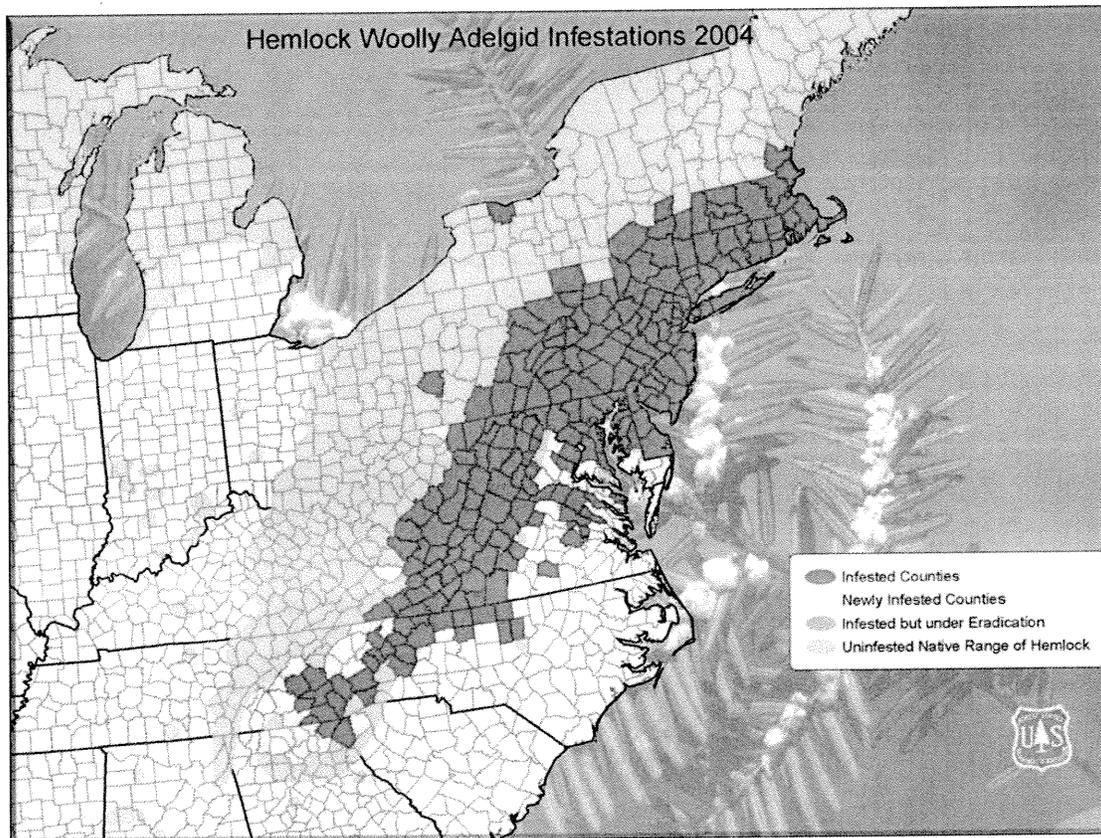
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Forest Health Technology Enterprise Team

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*Hemlock Woolly
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