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Estimating the effect of gypsy moth defoliation using MODIS

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ABSTRACT

The area of North American forests affected by gypsy moth defoliation continues to expand despite efforts to slow the spread. With the increased area of infestation, ecological, environmental and economic concerns about gypsy moth disturbance remain significant, necessitating coordinated, repeatable and comprehensive monitoring of the areas affected. In this study, our primary objective was to estimate the magnitude of defoliation using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery for a gypsy moth outbreak that occurred in the US central Appalachian Mountains in 2000 and 2001. We focused on determining the appropriate spectral MODIS indices and temporal compositing method to best monitor the effects of gypsy moth defoliation. We tested MODIS-based Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Water Index (NDWI), and two versions of the Normalized Difference Infrared Index (NDIIb6 and NDIIb7, using the channels centered on 1640 nm and 2130 nm respectively) for their capacity to map defoliation as estimated by ground observations. In addition, we evaluated three temporal resolutions: daily, 8-day and 16-day data. We validated the results through quantitative comparison to Landsat based defoliation estimates and traditional sketch maps. Our MODIS based defoliation estimates based on NDIIb6 and NDIIb7 closely matched Landsat defoliation estimates derived from field data as well as sketch maps. We conclude that daily MODIS data can be used with confidence to monitor insect defoliation on an annual time scale, at least for larger patches (>0.63 km^2). Eight-day and 16-day MODIS composites may be of lesser use due to the ephemeral character of disturbance by the gypsy moth.

1. Introduction

Ephemeral forest disturbances are short lived perturbations from which forests often recover quickly, either within the same year or in the following year. Prominent ephemeral disturbances include insect defoliation, the most spatially extensive forest disturbance on an annual basis in North America, as well as ice and windstorm damage and drought stress. While forests often recover after such disturbances with little mortality, long term effects might still be detectable and multiple subsequent disturbances can be fatal.

Insect and pathogen disturbances are the most expensive disturbances in North America (Dale et al., 2001) but are nevertheless difficult to monitor due to their short nature. The most significant defoliator of hardwood trees in the northeastern US is the gypsy moth (*Lymantria dispar* L.) (Joria & Ahearn, 1991), which was introduced to the United States near Boston in 1869 (Williams et al., 1985). Since introduction, the gypsy moth has spread from New England, south through Virginia into North Carolina and west to Wisconsin. It is estimated that more than 30 million hectares have been defoliated since 1970. Since the potential area that is climatically suitable for the gypsy moth is estimated to be 595 million hectares (Gray, 2004), many state and federal programs have been established to both monitor and mitigate possible impacts of gypsy moth (e.g., the United States Department of Agriculture (USDA) funded Slow the Spread Foundation, www.gmsts.org, and US Forest Service (USFS) Forest Health Protection program). The USFS as well as state agencies also closely monitor the gypsy moth defoliation with annual aerial sketch mapping activities.

Sketch mapping in combination with aerial photo interpretation is the most common method used for monitoring extensive forest damage. Sketch maps are created by the manual delineation of affected forests on aerial photographs or topographic maps based on visual cues. In the U.S., aerial sketch mapping efforts are funded in large part by the USFS, although actual sketch mapping is conducted by individual states. As such, sketch mapping methods are not standardized and may be subject to errors resulting from incomplete coverage or overflights at times not optimal for detection of the disturbance. Sketch maps are also prone to subjectivity due to differences in the experience of interpreters. In addition, comprehensive sketch mapping over large areas is time intensive, while the peak time to observe gypsy moth damage is relatively short (~two to three

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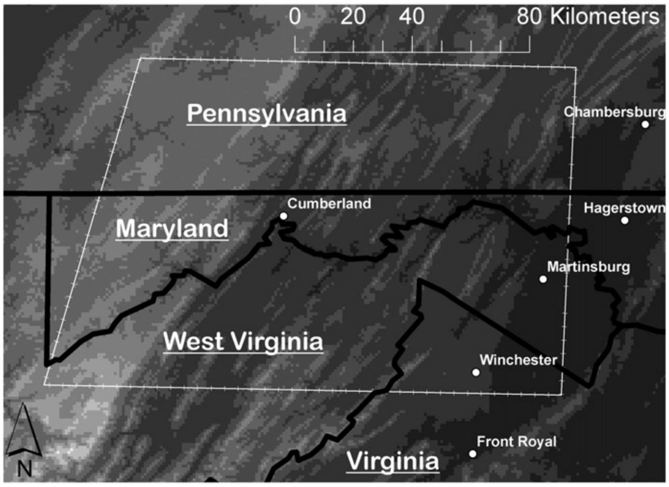

Fig. 1. Overview of the study region, with area having Landsat data outlined. The grayscale background is based on a digital elevation model with the lighter areas representing higher elevations.

weeks) due to subsequent refoliation (Joria & Ahearn, 1991). Finally, sketch mapping is rarely comprehensive, meaning that not all affected areas are monitored every year.

As an alternative, remote sensing techniques have been demonstrated since the mid-1980s to be effective for mapping gypsy moth defoliation using imagery from Landsat and Systeme Probatoire d'Observation de la Terre (SPOT, Williams et al., 1985; Ciesla et al., 1989; Joria & Ahearn, 1991). The resulting maps usually depict degrees of defoliation, e.g. light, moderate and heavy, as well as healthy forests (Williams et al., 1985; Ciesla et al., 1989; Joria & Ahearn, 1991). While the general occurrence of defoliated areas can be identified, the classification of the intensity of defoliation has been less reliable (Ciesla et al., 1989). Only recently have remote sensing techniques advanced to the ability of mapping not only the occurrence of defoliation but also the magnitude of the change (Townsend et al., 2004).

It has been demonstrated that data from Landsat and other synoptic scale sensors have an appropriate spatial resolution for monitoring many types of insect disturbances to forests. However, due the short window for monitoring and the coarse temporal resolution of Landsat imagery relative to cloud cover, it is not possible to create regional-scale estimates of defoliation in any given year. In contrast, MODIS data have a lower spatial resolution than Landsat or SPOT, and are therefore more appropriate for regional-scale analyses. In addition, MODIS data are available at a significantly higher temporal resolution (~daily) while preserving the spectral bands that are available in the Landsat data. Coarse resolution imagery from MODIS, Advanced Very High Resolution Radiometer (AVHRR), and SPOT VEGETATION have been used in other studies for the detection of insect disturbances (Kharuk et al., 2004; Fraser & Latifovic, 2005; Kovacs et al., 2005). Fraser & Latifovic (2005) found that coarse imagery is very effective in mapping large-scale conifer mortality caused by insects, especially in forest patches larger than 5–10 km^2. They also found that the data could be useful for near-real time monitoring, although with substantial commission errors. Kharuk et al. (2004) used 8-km AVHRR pixels, but suggested that the improved radiometric stability and band width of the MODIS data could increase detection accuracy. Kovacs et al. (2005) evaluated MODIS EVI and Mid Infrared (MIR) data for the detection of insect disturbance. However, none of these coarse resolution studies provided links with finer resolution validation data. In addition, the study by Fraser & Latifovic (2005) did not actually look at an ephemeral disturbance. Instead they focused on mortality and severe defoliation (>90%) in a pine ecosystem that was unlikely to refoliate.

In this study, our primary objective was to estimate the magnitude of defoliation using MODIS imagery for a gypsy moth outbreak that occurred in the US central Appalachian Mountains in 2000 and 2001. We tested five indices for their capacity to map defoliation as estimated by ground observations. In addition, we evaluated three temporal periods (daily, 8-day and 16-day). The results were validated through quantitative comparison to Landsat based defoliation estimates and traditional sketch maps.

2. Datasets

2.1. MODIS dataset

For this study we selected MODIS datasets with three levels of temporal processing from collection 4 for tile h11v5 (Fig. 1). The satellite datasets cover an area of deciduous hardwood forests (largely oaks) in Pennsylvania, West Virginia and Maryland where we have extensive data on defoliation extent and magnitude (Table 1). We tested MOD13Q1 data (MODIS/Terra Vegetation Indices) at a 16-day temporal resolution and 250 meter spatial resolution. This dataset contains NDVI and EVI data, as well as a resampled (from 500 to 250 m) mid-infrared (MIR) band (band 7, 2105–2155 nm). Second, we evaluated the 8-day MODIS/Terra Surface Reflectance data (MOD09Q1 and MOD09A1) with a spatial resolution of 250 m and 500 m, respectively. MOD09Q1 contains 3 data layers, surface reflectance for band 1 (620–670 nm), surface reflectance for band 2 (841–876 nm) and the surface reflectance quality control flags, all three at 250 m resolution. MOD09A1 contains the first seven MODIS reflectance bands as well as surface reflectance state flags, all at 500 m spatial resolution. We specifically used the last three reflectance bands from this dataset and resampled the 500 meter bands to 250 meter resolution with nearest neighborhood resampling. Finally, we used the daily MODIS/Terra Surface Reflectance data at 250 and 500 m resolution (MOD09GQK and MOD09GHK). The data layers are the same as those of the 8-day dataset and the same resampling procedure has been applied. All image analyses employed MODIS data from 2000 and 2001.

Table 1
Overview of dataset evaluated in this study

Code	Days	*m*	Spectral	Index
MOD13Q1	16	250	**NDVI**	NDVI
			EVI	EVI
			620–670 nm	NDIIb7
			841–876 nm	
			459–479 nm	
			2105–2155 nm	
MOD09Q1	8	250	**620–670 nm**	NDVI
			841–876 nm	EVI
MOD09A1	8	500	620–670 nm	NDWI
			841–876 nm	NDIIb6
			459–479 nm	NDIIb7
			545–565 nm	
			1230–1250 nm	
			1628–1652 nm	
			2105–2155 nm	
MOD09GQK	1	250	**620–670 nm**	NDVI
			841–876 nm	EVI
MOD09GHK	1	500	620–670 nm	NDWI
			841–876 nm	NDIIb6
			459–479 nm	NDIIb7
			545–565 nm	
			1230–1250 nm	
			1628–1652 nm	
			2105–2155 nm	

Bold spectral bands are used in the creation of the indices.
NDVI and EVI in MOD13Q1 are accepted without alterations.