TITLE: Monitoring regional impacts of insect defoliators using multi-scale remote sensing.
LOCATION: Northern MN; Mid-Atlantic Highlands (MD, WV, PA, VA)
DURATION: 2005-2006 **FUNDING SOURCE:** Base EM
PROJECT LEADER: Brian R. Sturtevant, U.S. Forest Service, North Central Research Station, Forestry Sciences Laboratory, Rhinelander WI, 715-362-1105, bsturtevant@fs.fed.us

COOPERATORS: Philip A. Townsend, University of Wisconsin, Madison, WI

PROJECT OBJECTIVES: The effect of insect activity on forest productivity and carbon sequestration at annual and decadal scales is poorly characterized. We will monitor defoliation extent and severity using MODIS, Landsat (or similar), and high-resolution imagery. Our specific objectives are to link image-derived estimates of defoliation to measures derived from current forest health Detection Monitoring efforts (i.e., aerial survey and plot-level forest health data) to predict impacts across two representative regions of North America (Upper Midwest/adjacent Canada and Mid-Atlantic Highlands) at the resolution of NASA's MODIS imagery (250m).

JUSTIFICATION: We will quantify extent and severity of insect defoliation (particularly spruce budworm, jack pine budworm and forest tent caterpillar in the Upper Midwest and gypsy moth caterpillar in the Mid-Atlantic Highlands) with respect to forest carbon cycling and productivity. Current aerial survey methods can show extent of defoliation, but cannot assess impacts. Plot-level data (e.g., Phase 3 Forest Health Monitoring FIA plots) can assess local impacts but are currently difficult to extrapolate. Our work will integrate different Detection Monitoring components (i.e., aerial survey, permanent plots) and other data into a geo-spatial framework to understand the consequences of insect activities at a regional scale. Ultimately our approach may be integrated into a more comprehensive and standardized forest health-monitoring program.

DESCRIPTION:
a. Background: On an annual basis, insects severely defoliate more than 20 million acres of forested land in the conterminous United States, affecting a larger area and incurring higher economic costs than any other disturbance (Dale et al. 2001). However, long-term costs and ecosystem consequences of insect outbreaks on forest health and productivity are difficult to quantify at regional scales because of the variety of pests involved, differences in forest types affected, and varying spatial scale and severity of impacts. In addition, there has been a lack of coordinated data collection (through aerial or plot surveys) to facilitate spatially explicit extrapolation of impacts across large areas. As such, the effect of insect activity on regional forest productivity and carbon sequestration at annual and decadal scales is poorly characterized. We will use a multi-scale approach to quantify defoliation and its impacts on forest productivity and carbon cycling using MODIS, Landsat (or similar), and high-resolution imagery in two representative regions of North America (Upper Midwest/adjacent Canada and Mid-Atlantic Highlands).

Our work will provide insect monitoring products through technology transfer of research recently funded to Townsend, Sturtevant and David Mladenoff (University of Wisconsin) to use field monitoring data and remote sensing data to drive landscape models for characterizing insect impacts on forest carbon cycling. Our specific request to the EM program is to fund a post-doctoral scientist for two years to work with Dr. Townsend (at University of Wisconsin) and Dr. Sturtevant to explicitly link remote sensing observations and monitoring data across the larger study regions to characterize the spatial extent and severity of insect disturbance. While map products have been developed to delineate areas of insect disturbance, no consistent products have been developed to represent the severity of that disturbance (e.g., foliar biomass, LAI, and/or productivity decline). NASA has funded our group to continue development of methods that employ multi-scale imagery (e.g., 30m Landsat with 250m MODIS) to map disturbance extent, severity, and disturbance agent. The primary purpose of the NASA work is to map impacts for subregions to drive model predictions of long-term tree species and production dynamics. However, this existing funding does not support explicit linkage to forest health Detection Monitoring data. The proposed work will extend our existing work to yield a spatially explicit, image based insect monitoring product suitable for multiple objectives (e.g., forest products, fire potential, & recreation).

The proposed work will complement that funded by NASA by: (1) identifying across the study regions impacts of emerging disturbances as detected by remote sensing as well as traditional detection monitoring methods; and (2) linking to longer-term inventory data to identify impacts of past disturbances on current forest productivity. For example, we will address (1) by monitoring the current jack pine budworm outbreak detected using aerial surveys in northern Wisconsin, while we would address (2) by using Phase 3 FIA data to address impacts from past events like spruce budworm outbreaks in northern Minnesota. We will demonstrate the generality of this approach by applying the same methods to multiple defoliating species in two study regions (e.g., gypsy moth caterpillar in the Mid-Atlantic Highlands).

b. Methods: *Our specific objectives are to:*
(1) Deliver a prototype regional scale defoliation impact monitoring system using NASA MODIS derived products, trained and tested against finer resolution imagery and field data. MODIS and other data layers will also be employed to discriminate defoliation from other disturbances.

(2) Quantify and map the short-term impacts of defoliation severity on forest productivity. We will detect multi-year trends in defoliation that lead to changes in forest productivity, including mortality.

The NASA-funded research uses similar types of image analyses to quantify current defoliator effects, providing essential parameters to simulate long-term effects of defoliators on the forest carbon cycle and carbon sequestration. Effects of repeat defoliation on C dynamics in large forested landscapes will be evaluated using a linked forest ecosystem model (PnET-II, Aber et al. 1995) and a forest disturbance and succession model (LANDIS-II, Scheller & Mladenoff 2004), that includes a module capable of simulating spatial dynamics of insect effects (Sturtevant et al. 2004).

The proposed work is built on a foundation of extensive existing datasets, including maps of forest species composition from both the Upper Midwest and Mid-Atlantic Highlands, Detection Monitoring data from FHM (i.e., aerial surveys of various insect of disturbances, Phase 3 FIA plots), and our own field observations (plot data) with information on forest composition and both gypsy moth (Mid-Atlantic Highlands) and spruce budworm (northern Minnesota) disturbance. In addition, we have an extensive database of Landsat and similar imagery dating from the early 1980's to the present. MODIS data are available free of charge.

composites (especially

Our analyses will provide estimates of defoliation extent and severity, as measured through seasonal losses in leaf biomass and changes to forest productivity derived from Terra MODIS imagery. The approach is premised on the identification of characteristic trends in forest phenology associated with defoliation that can be applied across years to map defoliated areas and resulting declines in forest productivity (Figure 1). Empirical analyses of field measurements and finer scale imagery will be used to quantify effects on carbon cycling. These effects will be scaled regionally using seasonally integrated measures derived from time series of MODIS the 250m Enhanced Vegetation Index). Specific methods involve the use of change vector statistics (Townsend et al. 2004) to identify and map the intensity of forest change through time, and the use of empirical models to predict the severity of insect damage as a function of image spectral change (e.g., Figure 2).

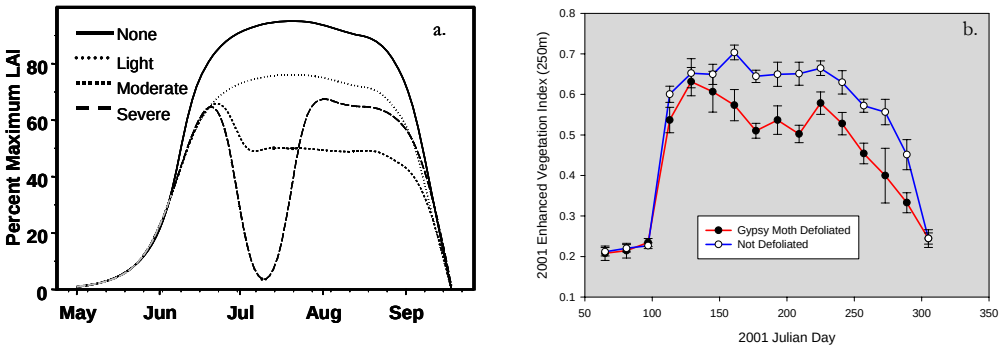

Figure 1. a. Hypothesized effects of a deciduous spring defoliator on satellite-derived measures of measures of forest condition (e.g., LAI). b. MODIS seasonal profiles of 250m EVI for gypsy-moth defoliated and undisturbed areas in 2001. Bars indicate 95% confidence intervals. Note the apparent refoliation in late summer.

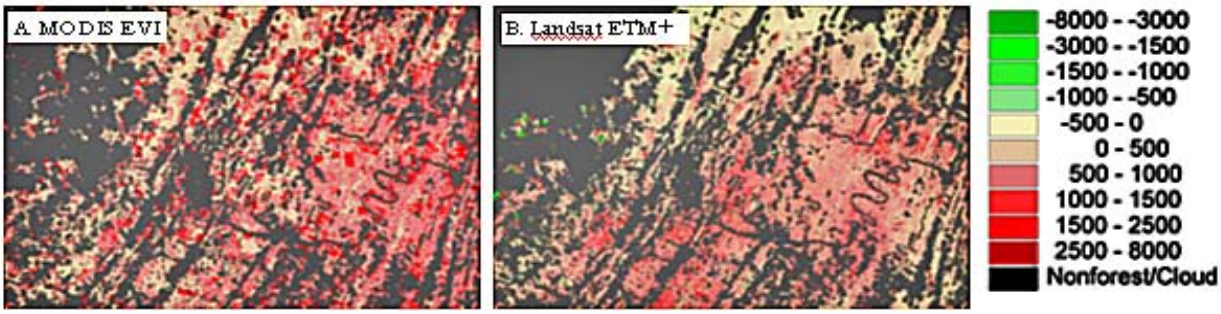

Figure 12 Figure 2. Map of 2001 foliar biomass loss due to gypsy moth activity in Allegany County (MD) from MODIS and Landsat ETM+ Units are biomass lost kg/ha/yr; maps are based on linear relationships between field measures and Landsat change vector statisti

c. Products: Our work will link Detection Monitoring data to remote sensing analyses for automated mapping of the extent and severity of insect defoliation of forests and resulting mortality. Our method will be applied to two regions of

the U.S., and may ultimately be incorporated into a monitoring and measurement system that can be adapted for temperate and northern forests worldwide, providing a tool to facilitate both forest management and policy decisions. By using MODIS, Landsat and other inventory and monitoring data (e.g., plots, aerial surveys), the system will be truly multi-scale and will potentially provide information to help guide future monitoring efforts to assess the severity of the impacts of insect activity. Our products will be bolstered by extensive existing data and analyses, as well as field data and analyses of finer scale imagery that will facilitate scaling from local measurements to landscapes to regions. The work represents a key technology transfer from research funded by NASA in which we will use similar methods to assess carbon cycle implications of insect activity as inputs to forest simulation models.

d. Schedule of Activities:
June-December 2005: Assimilation of monitoring data, image acquisition/processing and analysis, data integration
January-June 2006: Data linkage and analysis, development of empirical relationships for mapping
July-December 2006: Image modeling and automation, production of regional maps
January-June 2006: Map/model evaluation and testing; reporting and dissemination

e. Progress/Accomplishments: Both Landsat TM and MODIS imagery have been acquired in the Mid-Atlantic Highlands, northwestern Wisconsin, and northeastern Minnesota. We have acquired 2004 and 2005 jack pine budworm population data from the Wisconsin DNR, as well as aerial survey data for jack pine budworm, spruce budworm, and tent caterpillar in Wisconsin and Minnesota. Through our related NASA-funded project we have established 30 defoliation impact field plots, 15 in jack pine forest types (NW Wisconsin), and 15 in spruce-fir forest types (NE Minnesota). Data collected at each field plot includes frass deposition, branch samples, weekly estimates of LAI using hemispherical photography, and forest composition and structure. In addition, we have acquired 34 high-resolution (sub-meter) aerial photographs documenting defoliation patterns by both spruce budworm and jack pine budworm, centered primarily on our field plot locations. A highly qualified postdoctoral student has been identified and will start later this year. On September 20 (2005) we will present our remote sensing approach at the North Central Forest Pest Workshop in La Crosse (WI), providing opportunity for feedback from future clients on our research products.

COSTS:

	Item	**Requested FHM**	**Other-Source**	**Source**
YEAR 2				
Administration	*Salary*			
	Post-doc (12mos)	$26,500	$13,250	UW & NCRS
	Townsend (0.66 mos)		$6,061	UW
	Benefits			
	Post-doc (23.5%)	$6,227	$3,114	UW & NCRS
	Townsend (35%)		$2,121	UW
	Overhead			
	U. Wisconsin (45.5%)	$14,891	$3,723	UW
	NCRS (5% of total)	$2,381		
	Travel	$0		
Procurements	Contracting	$0		
	Equipment	$0		
	Supplies	$0		
Total		$50,000	$28,269	

Costs above reflect the Year 2 request. The total of $50,000 is identical to Year 1, though overhead costs have changed because Phil Townsend has changed institutions from the University of Maryland to the University of Wisconsin (UW). NCRS represents the North Central Research Station of the US Forest Service. FHM $ will fund a post-doctoral scientist to work with Drs. Sturtevant and Townsend in the linkage of image mapping to forest monitoring data. Travel, data, software, supplies, and a third of the post-doc salary will be provided through existing NASA and USFS funding.

References

Aber, J. D., S. V. Ollinger, C. A. Federer, P. B. Reich, M. L. Goulden, D. W. Kicklighter, J. M. Melillo, and R. G. Lathrop. 1995. Predicting the effects of climate change on water yield and forest production in the northeastern United States. Climate Research **5**:207-222.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. Bioscience **51**:723-734.

Scheller, R.M., and Mladenoff, D.J., 2004. A forest growth and biomass module for a landscape simulation model, LANDIS: Design, validation, and application. Ecological Modelling **180**: 211-229.

Sturtevant, B.R., Gustafson, E.J., Li, W., and He, H.S., 2004. Modeling biological disturbances in LANDIS: A module description and demonstration using spruce budworm. Ecological Modelling **180**: 153-174.

Townsend, P. A., K. N. Eshleman, and C. Welcker. 2004. Remote sensing of gypsy moth defoliation to assess stream nitrate concentration. Ecological Applications **14**:504-516.