Assessing the cumulative impact of disturbance on canopy structure and chemistry in Appalachian forests

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Abstract Eastern forests experience a range of disturbance events over time from stand-replacing disturbances, such as clear cuts, to ephemeral disturbances, such as insect outbreaks. By understanding the cumulative impact of disturbances on canopy structure and chemistry, we can gain insight into management strategies, assess a variety of ecosystem services, and even contribute to a larger body of knowledge on global climate change. We used a series of Landsat images covering approximately 25 years to map cumulative disturbance in Green Ridge State Forest and Savage River State Forest in western Maryland. We used AVIRIS imagery flown during the summers of 2008 and 2009 to map canopy nitrogen across both forests Field data collected during both summers served as calibration and validation for the remotely sensed maps of canopy nitrogen and disturbance and also contributed information on forest structure and composition. Through this project, we sought to test the utility of a Landsat-based cumulative disturbance index to map disturbance across a broad spatial scale and to assess the impact of cumulative disturbance on forest nitrogen availability using the canopy nitrogen maps. Our results indicated that cumulative disturbance can be accurately mapped using Landsat imagery. Pilot results show that increased values of cumulative disturbance had a measurable impact on forest canopy structure as well as lead to a decrease in nitrogen availability, particularly at the watershed scale. Thus, our study suggests that Landsat time series data can be synthesized into cumulative metrics incorporating multiple disturbance types, which help explain important disturbance-mediated changes in ecosystem functions.

Background and Methods

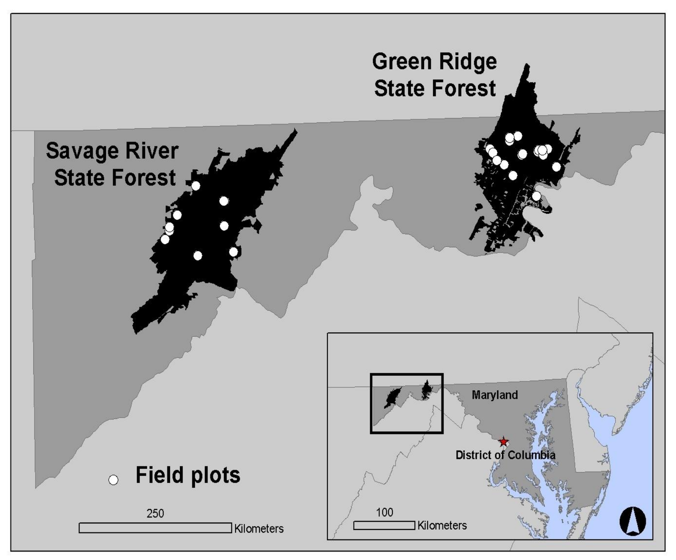

Figure 1: Study areas, with field plots indicated by white circles

Disturbances impact the structure and function of forests, and can leave legacies that last for decades or even centuries after the initial disturbance events. Since these legacies are often manifested in the form of reduced nutrient availability, and through reduced canopy cover, disturbance legacies have significant impacts on the biogeochemical cycling of nitrogen and carbon. Moreover, since most forests are characterized by multiple disturbance types and events through time, it is important to assess the cumulative impact of disturbances on forest structure and function.

Research Questions:

Question 1: Can a Landsat-derived cumulative disturbance index differentiate between disturbance classes?

Question 2: Does % canopy cover decrease as cumulative disturbance increases?

Question 3: Does canopy N decrease as cumulative disturbance increases?

Field Methods

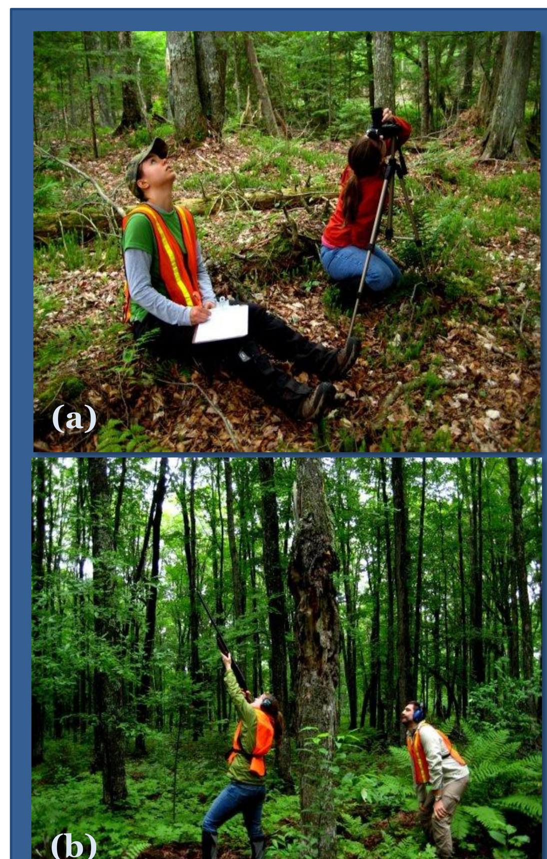

Figure 2 (left): Field data collection methods: (a) plot-based camera point quadrat method for estimating fractional proportion of species in canopy and (b) shotgun method for collecting fresh green leaf samples for analysis of canopy chemistry.

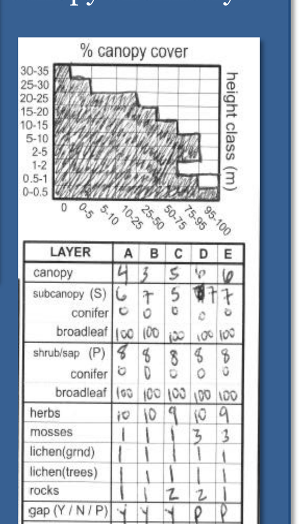

Figure 3 (right): Sample survey sheet used during field data collection. Each plot included % canopy cover estimates for the entire plot and subplot estimates collected at 5 points within each 60 x 60 meter radial plot.

Remote Sensing Methods

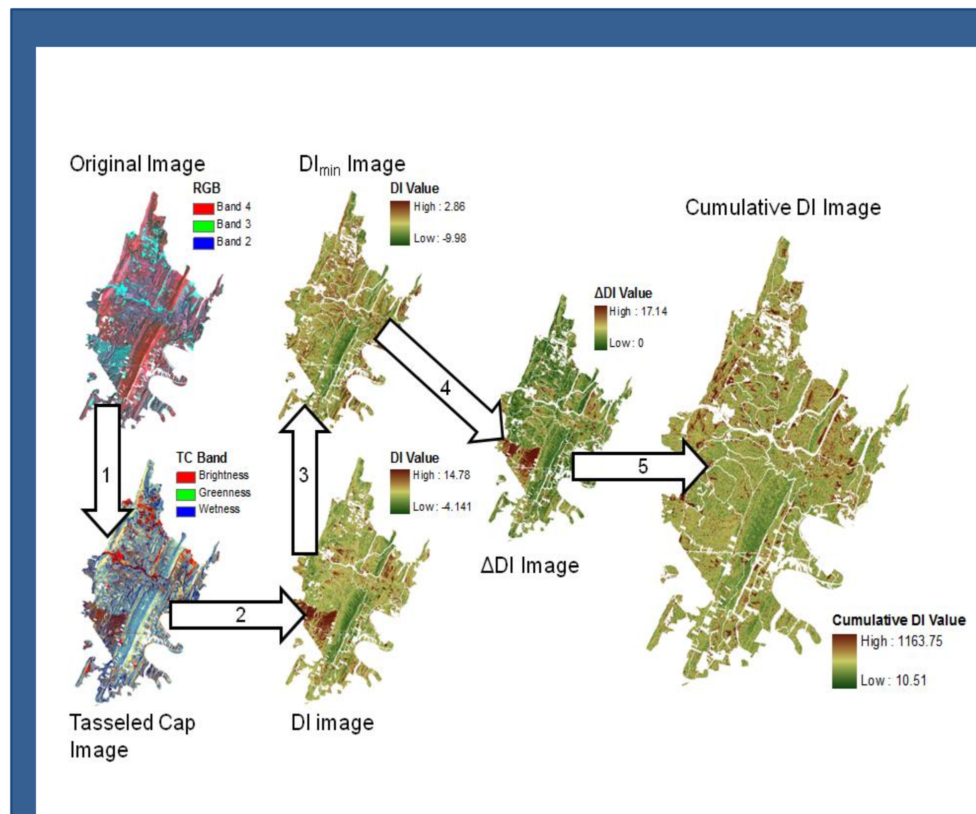

Figure 4: Flowchart of the multispectral remote sensing methods used to create the cumulative disturbance index: 1) Original image transformed using the tasseled cap transformation, 2) disturbance index calculated using the tasseled cap bands, 3) minimum DI values extracted from all images to create the DI_{min} image, 4) a change map, ΔDI, created for each year by subtracting the DI_{min}, and 5) the final cumulative disturbance image created by combining each ΔDI image in a weighted sum.

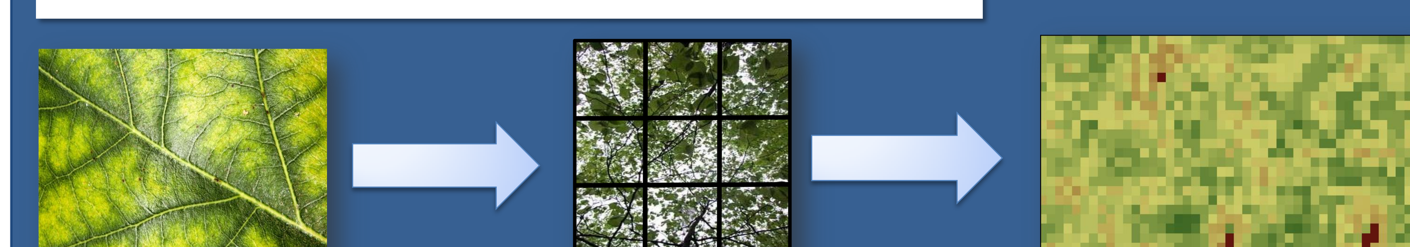

Figure 5: Maps of canopy nitrogen (N) are created using a scaling process that goes from the leaf-level to the plot-level and then to the canopy-level. The process begins in the field, where representative species are sampled and transported back to the lab. Percent N values are derived using a CNS analyzer and then scaled to the plot-level using estimates of species fractional proportion. Partial least squares (PLS) regression relates these plot-level values with AVIRIS reflectance values to create maps of canopy N across broad spatial scales.

Results and Discussion

Question 1: The cumulative disturbance index captures known disturbances (Figure 7) and differentiates between disturbance classes (Table 1)

Question 2: % Canopy cover decreases as cumulative disturbance increases (Figure 6)

Question 3: Canopy N decreases as cumulative disturbance increases (Figure 9)

Table 1: Results of an ANOVA on point-level disturbance class data and zone-level disturbance class data. All results significant at 0.05.

Disturbance Class	Point-level ANOVA		Zone-level ANOVA	
	N	DI	N	DI
Harvested and Defoliated	100	177.028	30	196.145
Harvested	100	169.959	28	175.119
Defoliated Recently	100	144.016	28	172.447
Defoliated Both (recently and early)	100	136.672	30	171.993
Defoliated Early	100	151.980	16	146.634
Undisturbed	100	151.769	-	-

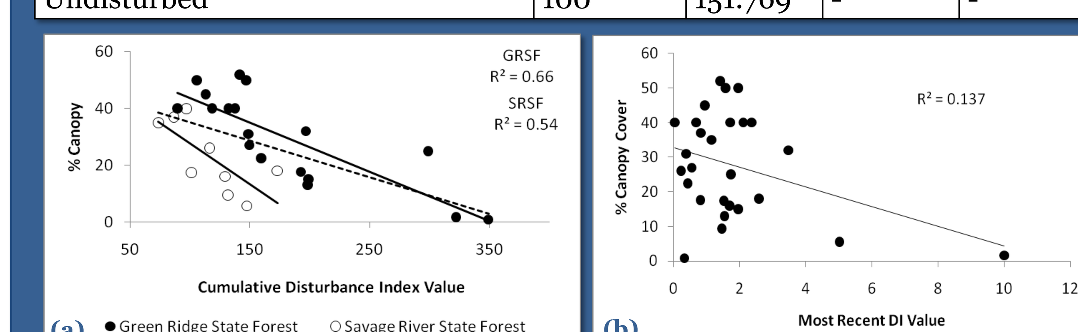

Figure 6: The relationship between (a) cumulative DI values and % canopy cover at both study areas combined, indicated by the dotted trend line (r^2 = 0.35), Green Ridge State Forest, indicated by the closed circles, and Savage River State Forest, indicated by the open circles. (b) percent canopy cover and the most recent DI imagery

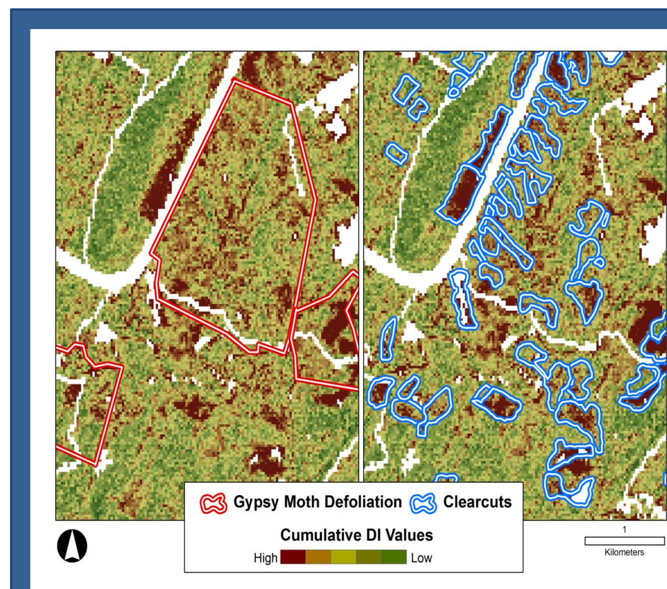

Figure 7: The cumulative disturbance index provides detailed information on the spatial distribution and intensity of historical disturbance compared with the previously available shapefiles generally used to delineate disturbance.

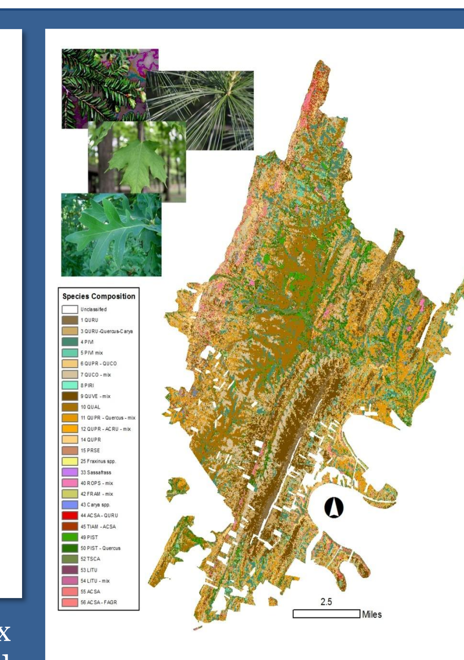

Figure 8: Differences in species composition across the study areas will likely influence the relationship between cumulative disturbance and canopy N.

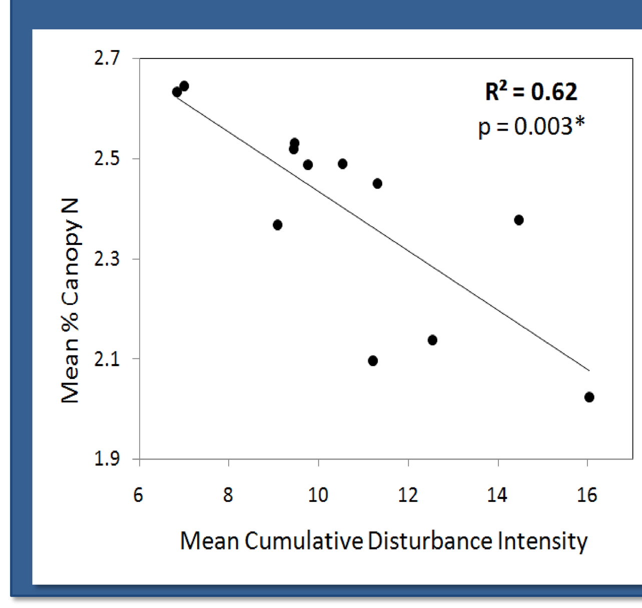

Figure 9: Results from a pilot study assessing the relationship between cumulative disturbance and canopy N (from 2003 AVIRIS imagery) at the watershed scale. This analysis will be replicated using the 2009 AVIRIS imagery that is currently in preprocessing.

Conclusions

- Cumulative maps created using the broad temporal range of Landsat imagery can provide useful insights into a forest's past disturbance history and its impact on current forest structure
- Remotely sensed imagery is a valuable tool that can be used in future studies to assess the impact of cumulative forest disturbances on ecosystem carbon cycling
- Canopy N maps created using AVIRIS imagery presents a valuable method of assessing broad scale patterns of nutrient availability across disturbance gradients

Ongoing Research

- Creation of canopy N maps using AVIRIS imagery acquired during summer 2009 field season
- Analysis on the relationship between canopy N and cumulative disturbance at the watershed-scale
- Interpretation of the role of scale in the relationship between cumulative disturbance and canopy N
- Investigation of the role of forest functional types in relationships between disturbance and canopy N (Fig. 8)

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