

Spatial Patterns of Forest Disturbance and Consequences for Regional Water Quality

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Research Overview 1

- Disturbance

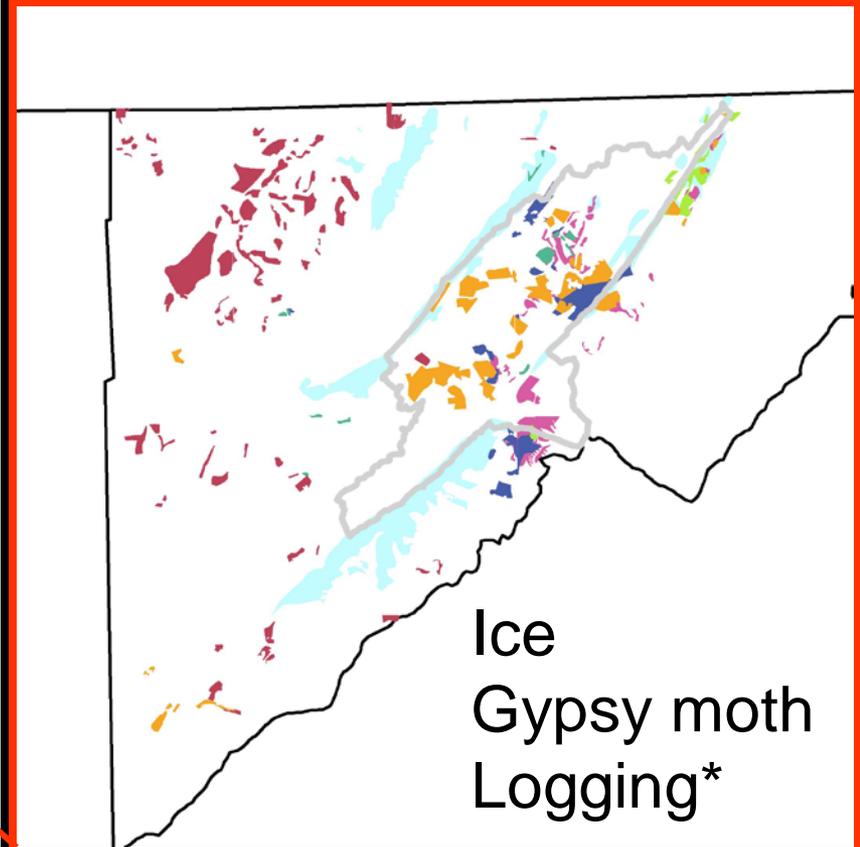
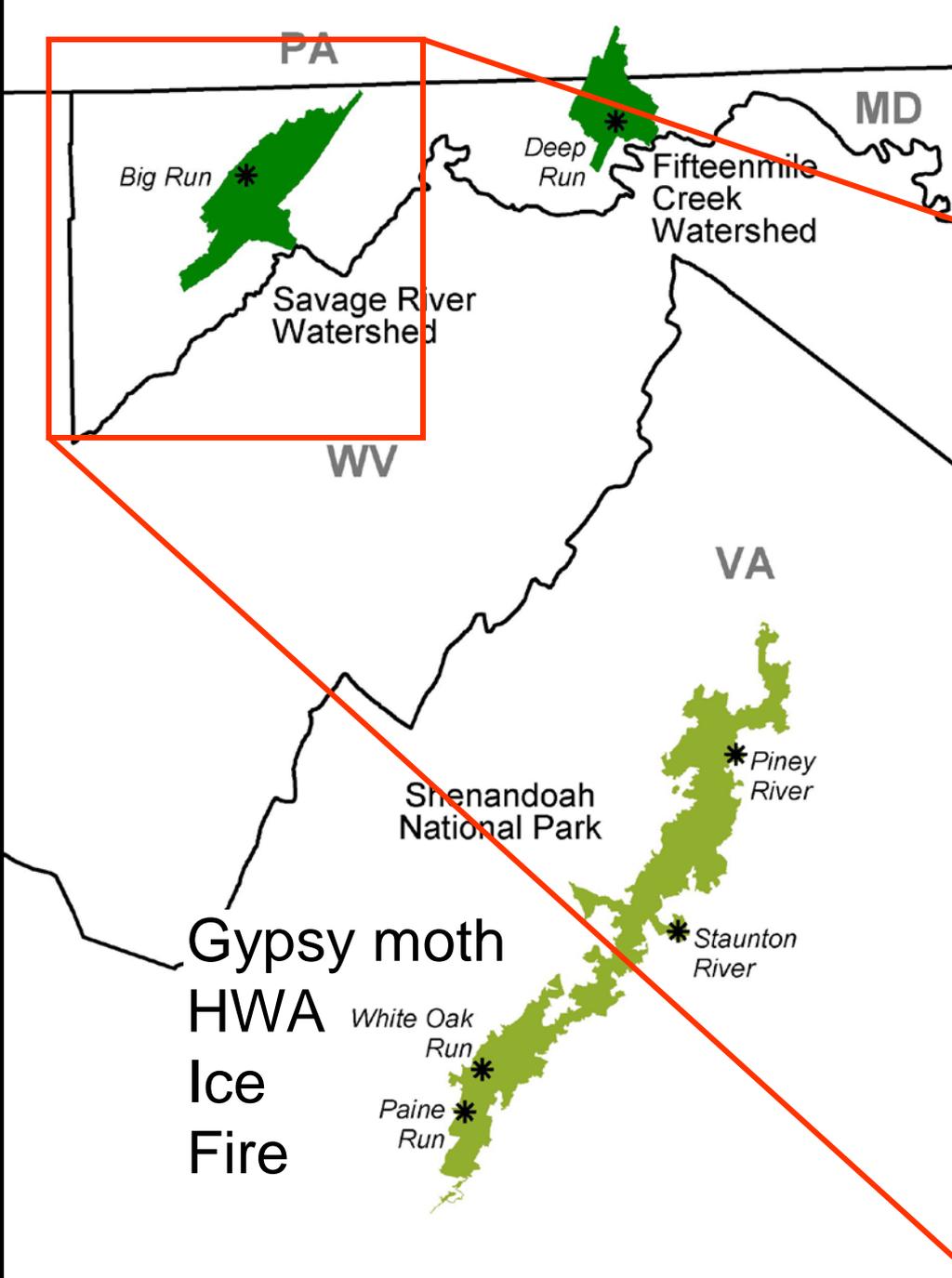
- integral property of forested landscapes
- effects on hydrologic systems:
 - influences water budget (quantity) and water quality (sediments, nutrients, etc.)
 - carefully-controlled experiments (Bormann & Likens, Hubbard Brook; Swift *et al.*, Coweeta)
 - natural “experiments”: fire, logging, mining, land use conversion (suburbanization)

Research Overview 2

- Disturbances are also:
 - ubiquitous
 - transient
 - highly variable in extent, frequency and intensity
 - often “stealthy” and poorly documented in both time and space
 - infrequently associated with demonstrable and quantifiable eco-hydrological effects at scales ranging from small plots to river basins

Example:

**Garrett County in
Western Maryland**



Research Overview 3

- What remote sensing provides...
 - spatially explicit measurements of surface properties related to hydrology of the watershed
 - consistent
 - comprehensive (synoptic in extent)
 - long record
 - ability to assess magnitude of change (and recovery), in addition to whether a change occurred
 - information on changes in the functioning and status of ecosystems within the watershed

Objectives 1

1. Detect the magnitude (intensity, extensity, and frequency), direction and timing of historical and recent forest disturbances at plot (fine), watershed and landscape scales;
2. Does nitrate-N leakage from disturbed plots differ from undisturbed plots (recent & historical disturbances)?
3. Can the history of forest disturbance be used to reliably predict surface water nitrate-N concentrations in streams of 1st-order watersheds?

Objectives 2

4. Does disturbance history explain spatial variations in surface water nitrate-N concentrations in small river basins?
5. Quantify the disturbance legacy at the landscape scale by relating elevated nitrate-N concentrations in soil water and streamwater to spatial differences in forest species composition, forest floor C:N ratios, and foliar N concentrations (assessed using ground data and hyperspectral remote sensing).

Current Project

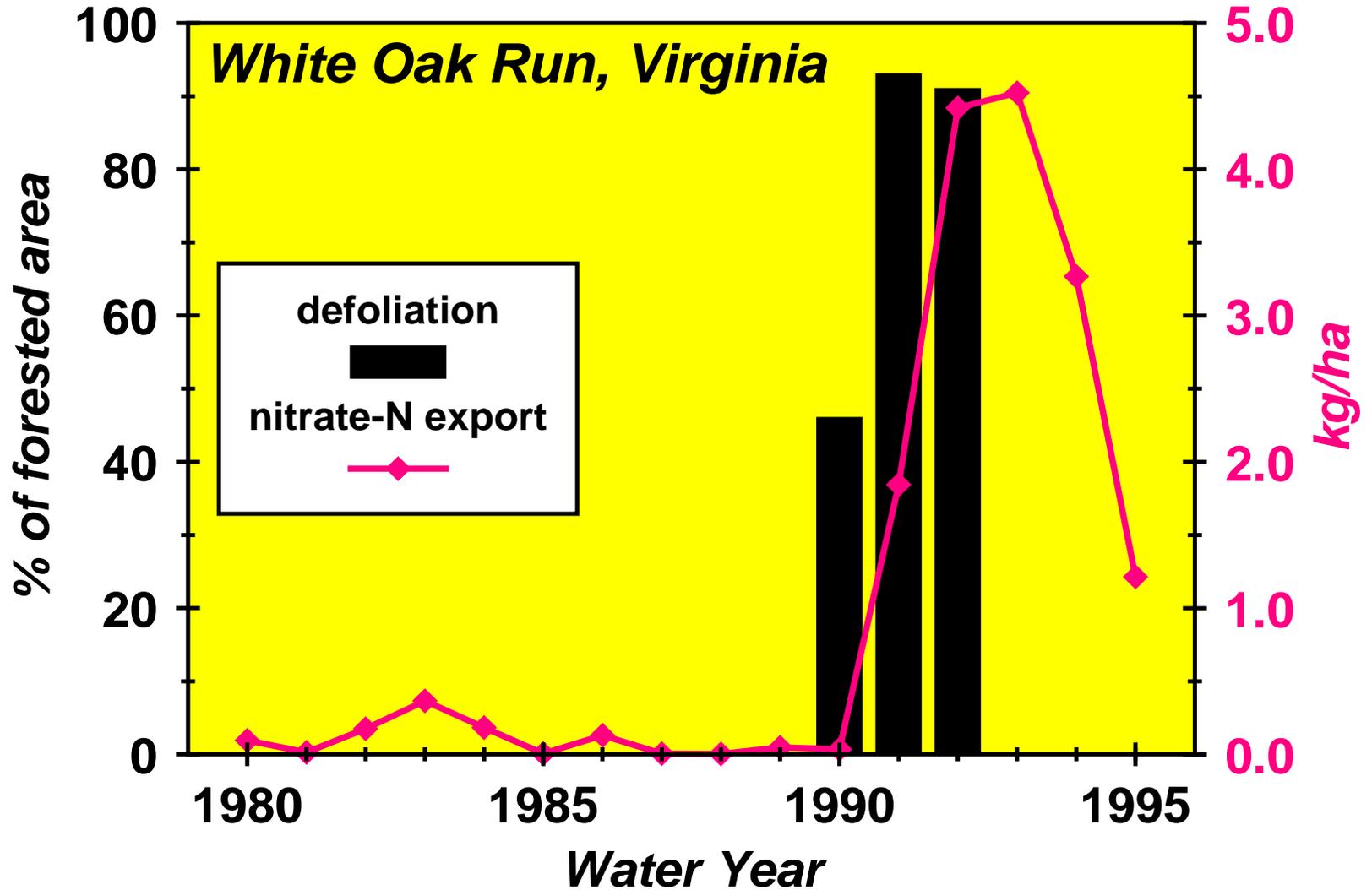
- Funding and fieldwork started in June 2004
- Leveraged on past research (funding from EPA, NASA and NSF) – focus of the results presented here
- Discussion of sample and data collection design for the new work

Disturbances in the Chesapeake Watershed



- Land clearance and conversion are the major large scale changes.
- However, we are dependent on the remaining forests as a water quality buffer against such changes.
- But, disturbances can reduce this forest function.....

Gypsy Moth Defoliation and Annual Nitrate-N Export



“serendipitous” study

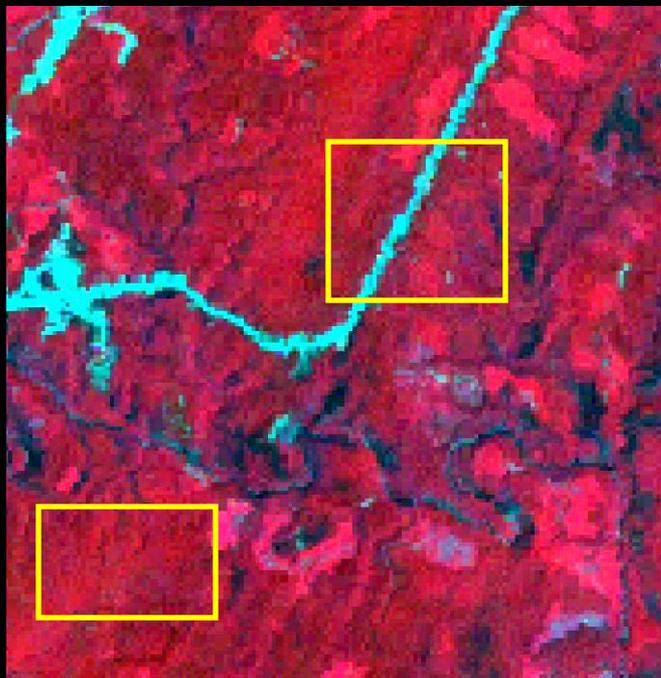
Eshleman et al. 1998



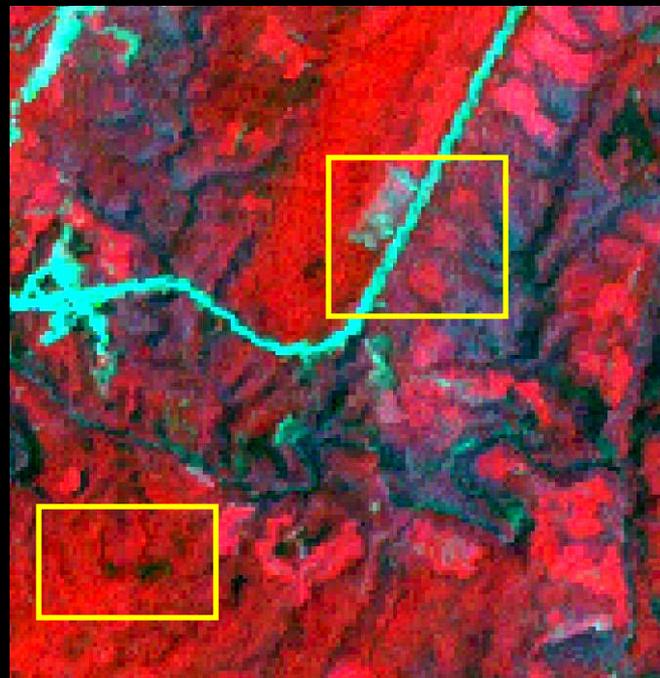
2000-2001
Defoliation event

FRASS SAMPLING

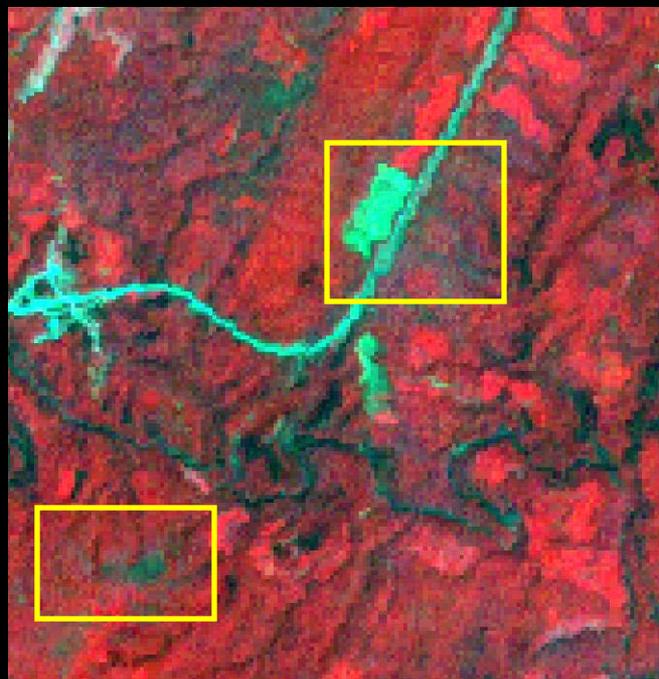




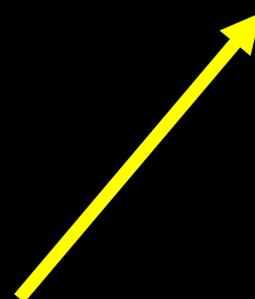
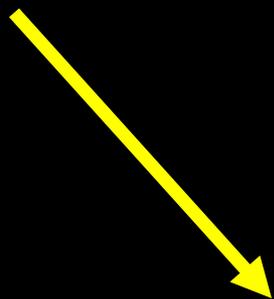
1999



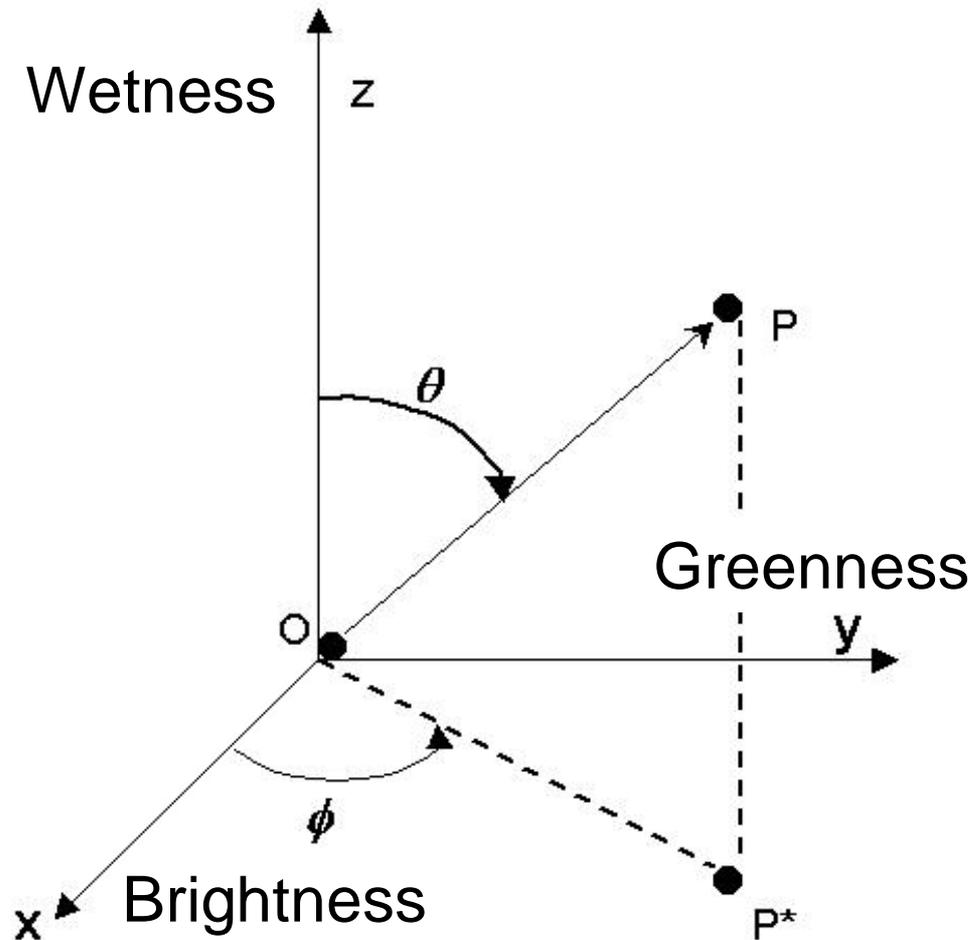
2001



2000



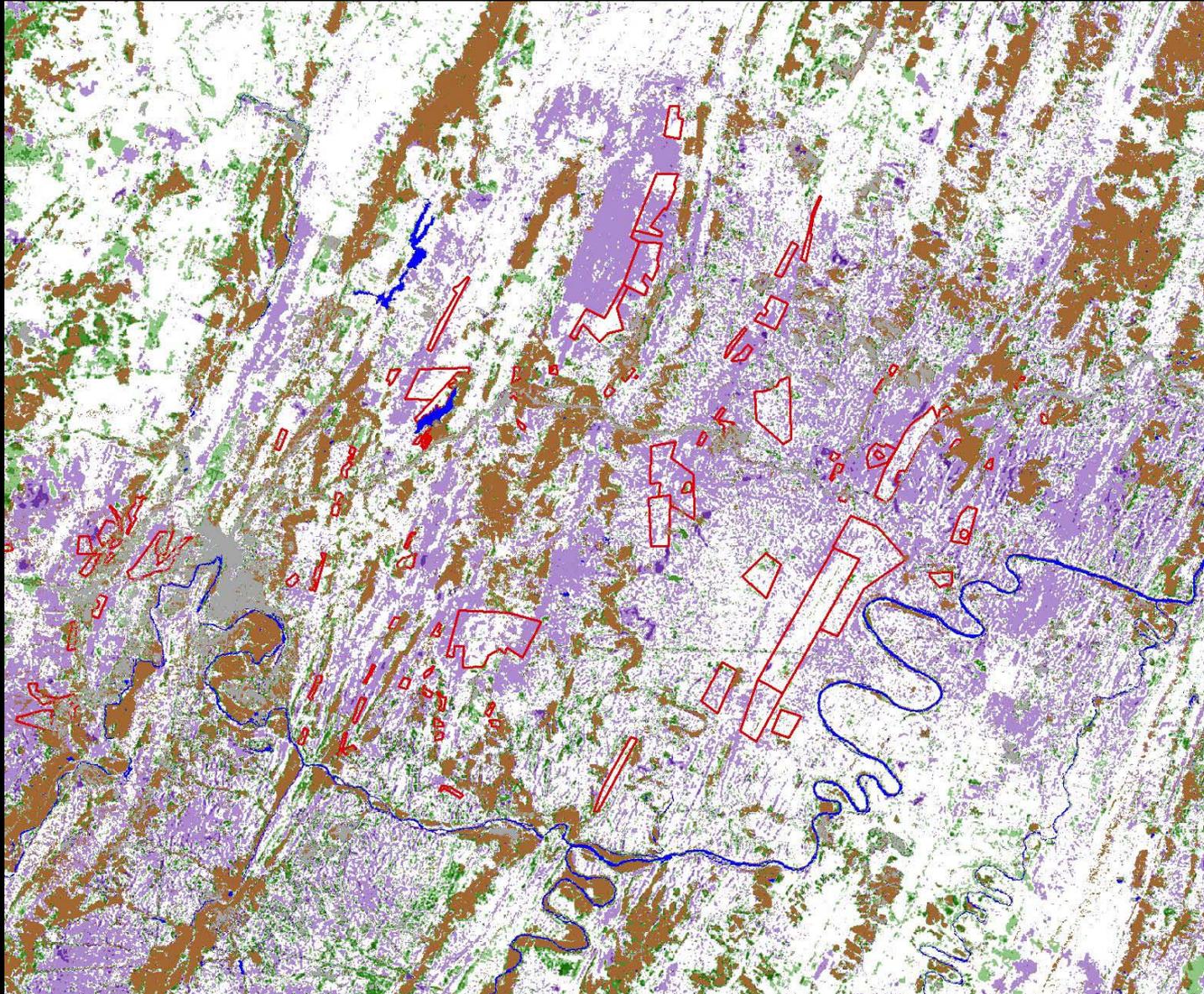
Change Vector Analysis (CVA)



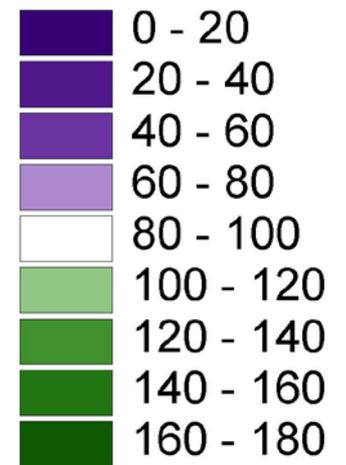
- Most studies focus only on the magnitude of change or on the change class.
- We also examine the direction of change, as measured using trigonometry.

Townsend et al. (2004)
Allen & Kupfer (2000)

Theta (θ): Angle of change in wetness and greenness



Angular
Measurements
0 - 180°



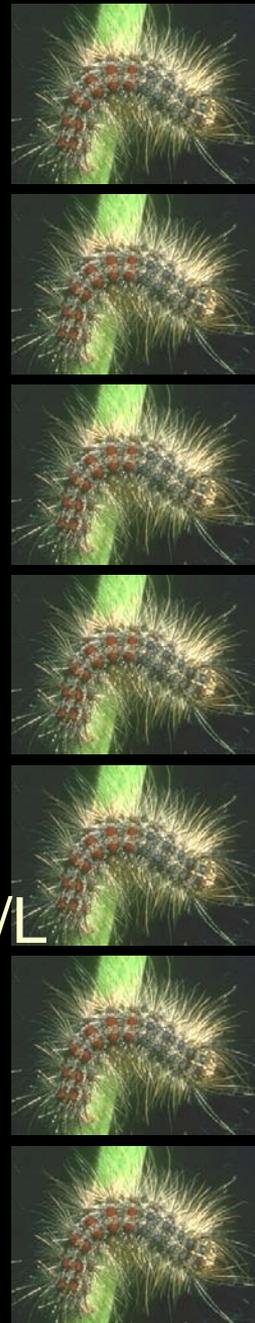
Overall Approach

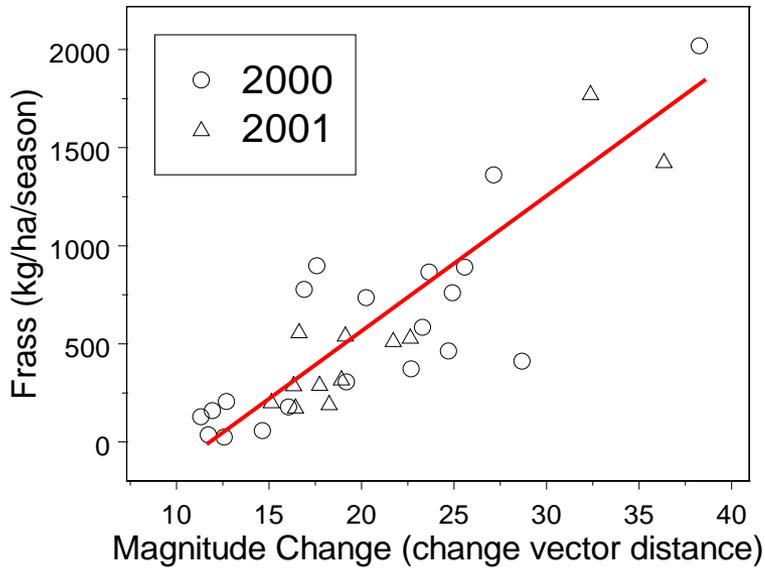
- Assess forest disturbance
 - Plot level measurements (frass, lysimeters)
 - Extrapolate using remote sensing
- Assess stream nitrogen concentrations
 - 4-6 baseflow samples per year of subwatersheds
 - Analyzed in lab for nitrate-N, dissolved organic N, etc.
- Use statistical approaches to predict
 - Stream N as function of RS measures
 - N input from to system from frass

Prediction Results (NO₃-N)

	Apr'01	Annual	May'02
Land Use R ²	0.18	0.15	0.27
R ² using CVA	0.79*	0.72	0.80
Efficiency	0.72	0.52	0.60
CV-MAE	0.08 mg/L	0.08 mg/L	0.15 mg/L
Range	0.002 – 0.93	0.02 – 0.77	0.0 – 1.6

Ecological Applications 14(2): 504-516 (2004)

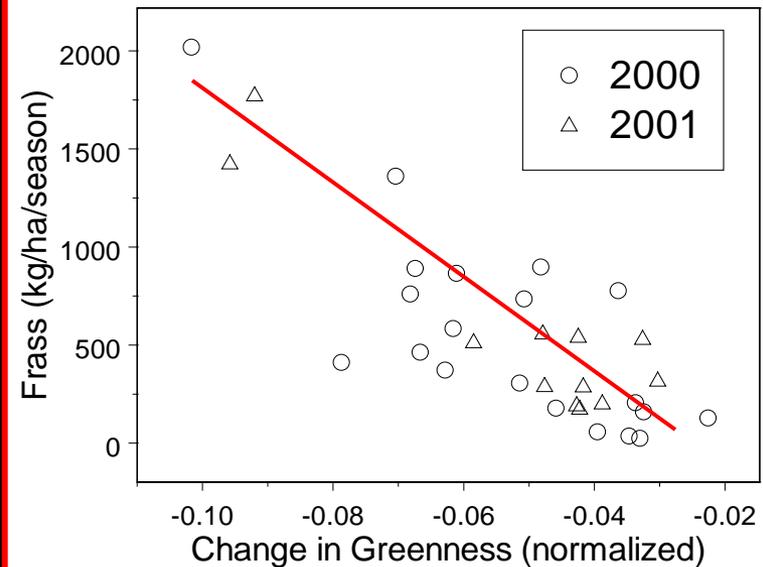
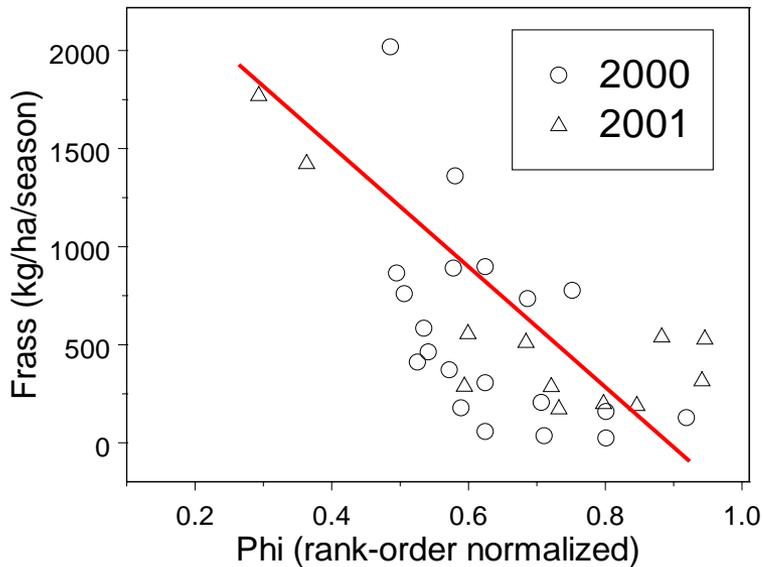


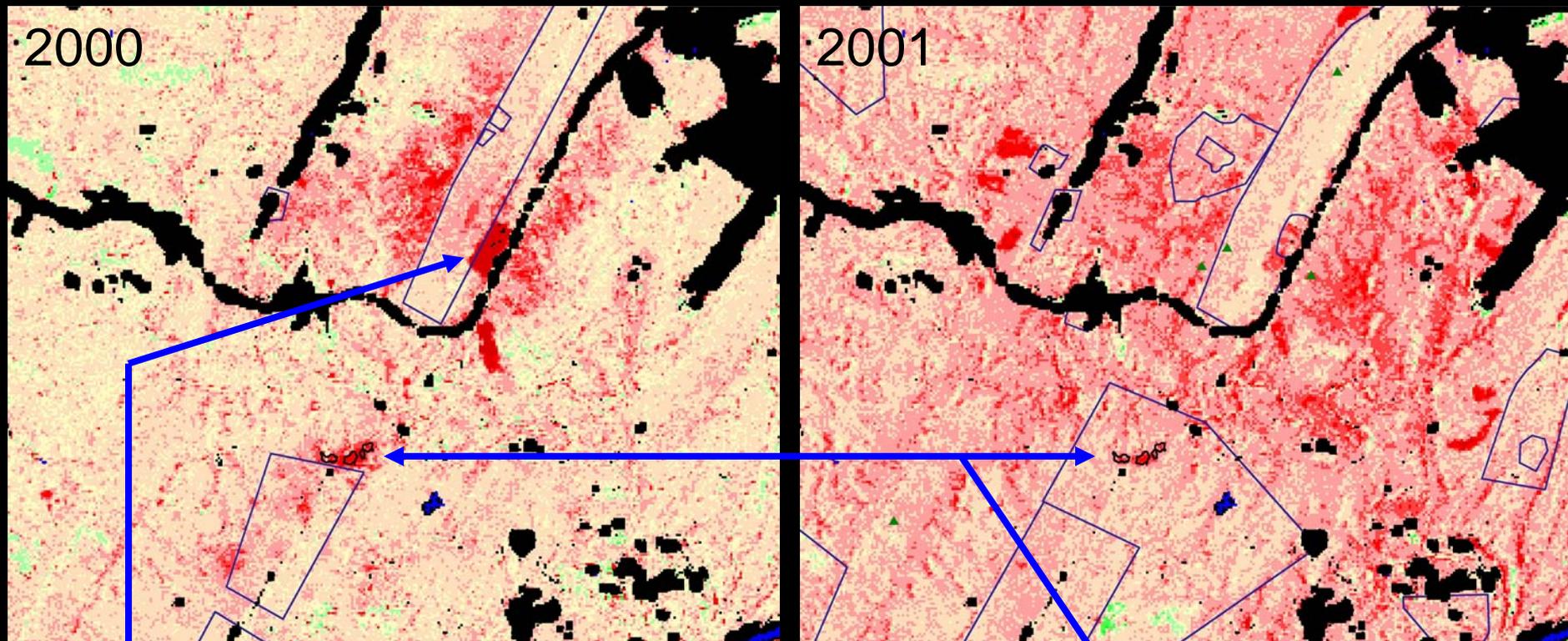


Relationships between frass fall and remote sensing variables:

Strongest relationship is with magnitude change, but....

Note: 2 years are plotted together.

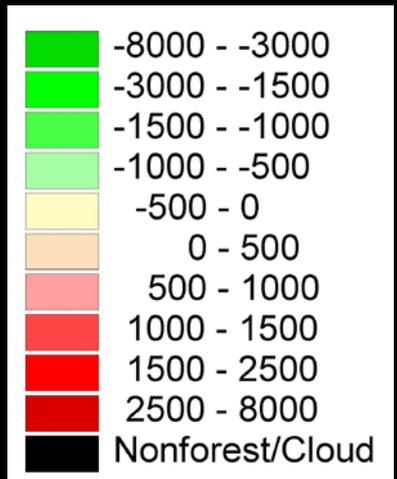




Clearcut: estimated loss of biomass
5000 – 7000 kg/ha.

Compare to estimates for region of
foliar biomass: 3500 – 6000 kg/ha.

Areas of forest mortality.



Results

- For 2001, the MDA estimated that 25,194 acres were defoliated in Allegany County.
- In contrast, we estimate the loss of foliar biomass in study area:
 - 381 kg/ha in 2000
 - 480 kg/ha in 2001
 - 109 kg/ha in 2002
- In 2001, this averages 15% foliar biomass, and even this amount leads to substantial increases in N export.
- Frass averages 3.1% N by weight, indicating that in 2001 approx. 15 kg/ha N is being input into the forest floor system *as a consequence of gypsy moth activity.*

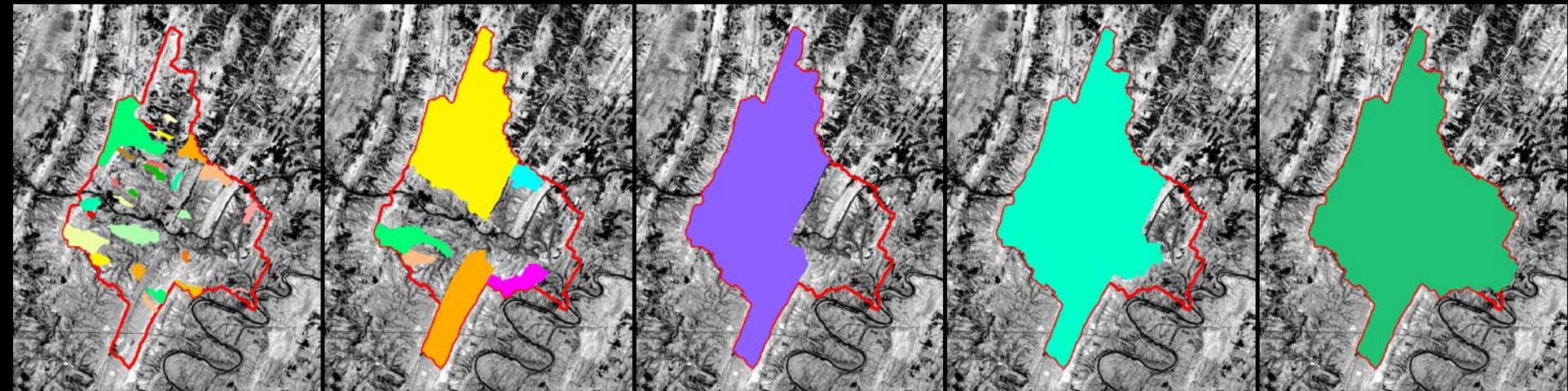
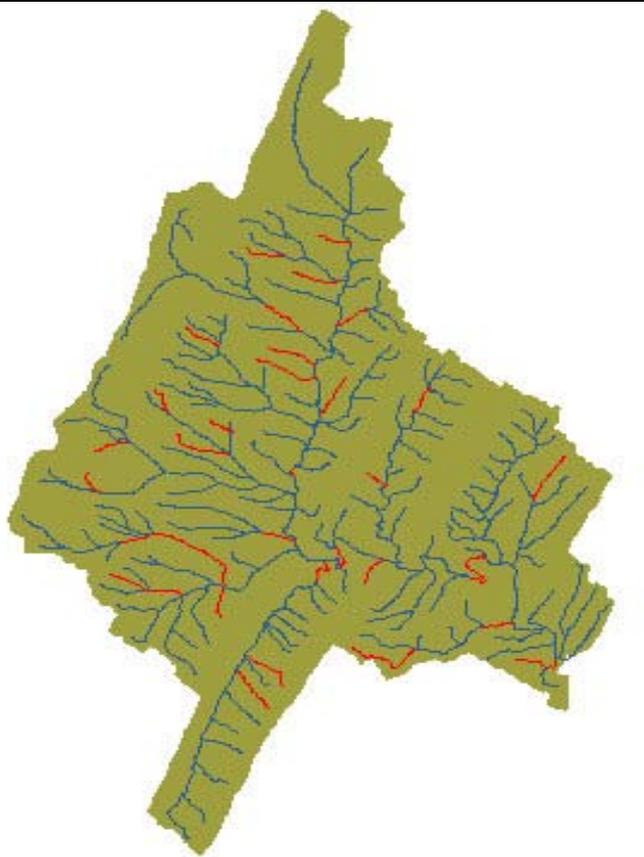


What now? Interdisciplinary Science Program

- **Hydrologic study**
 - 2 primary river basins
 - Savage River and Fifteenmile Creek
 - Water quality data sets ~5 yrs (some data to 1980s)
 - 4 Shenandoah NP basins (data to 1980)
- **Field ecology/ecosystem study**
 - 19 permanent plots each in SR and FC
 - Most first sampled in 1998 (pre-disturbance)
- **Remote sensing study**
 - Landsat data to 1980s
 - Hyperspectral data – spp. comp. & foliar N

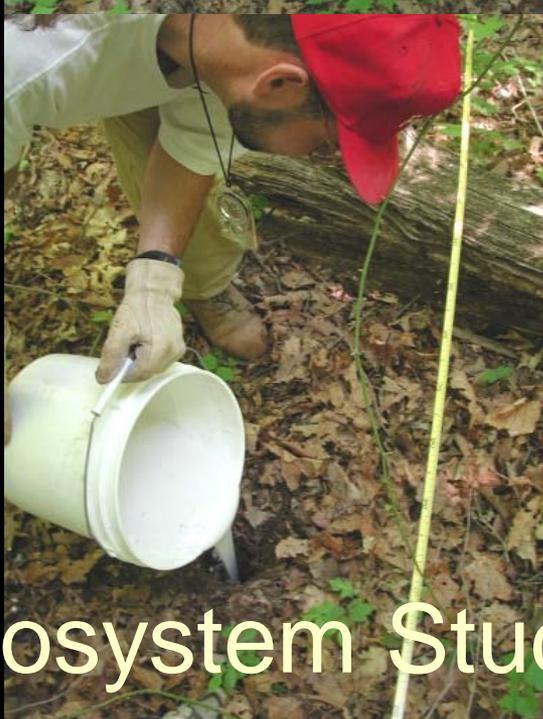
Intensive Stream Survey

- Random Sample Design (35-40 reaches per river basin)
- Sampled quarterly at base flow
- Defined subwatersheds range in:
 - Size: 22 -15,877 hectares
 - Cover: 43-100% forest, 0-44% cleared
 - Disturbance history
 - Ice, wind, logging, HWA
- TDN, NO₃-N, DON





Lysimeters



Ecosystem Study

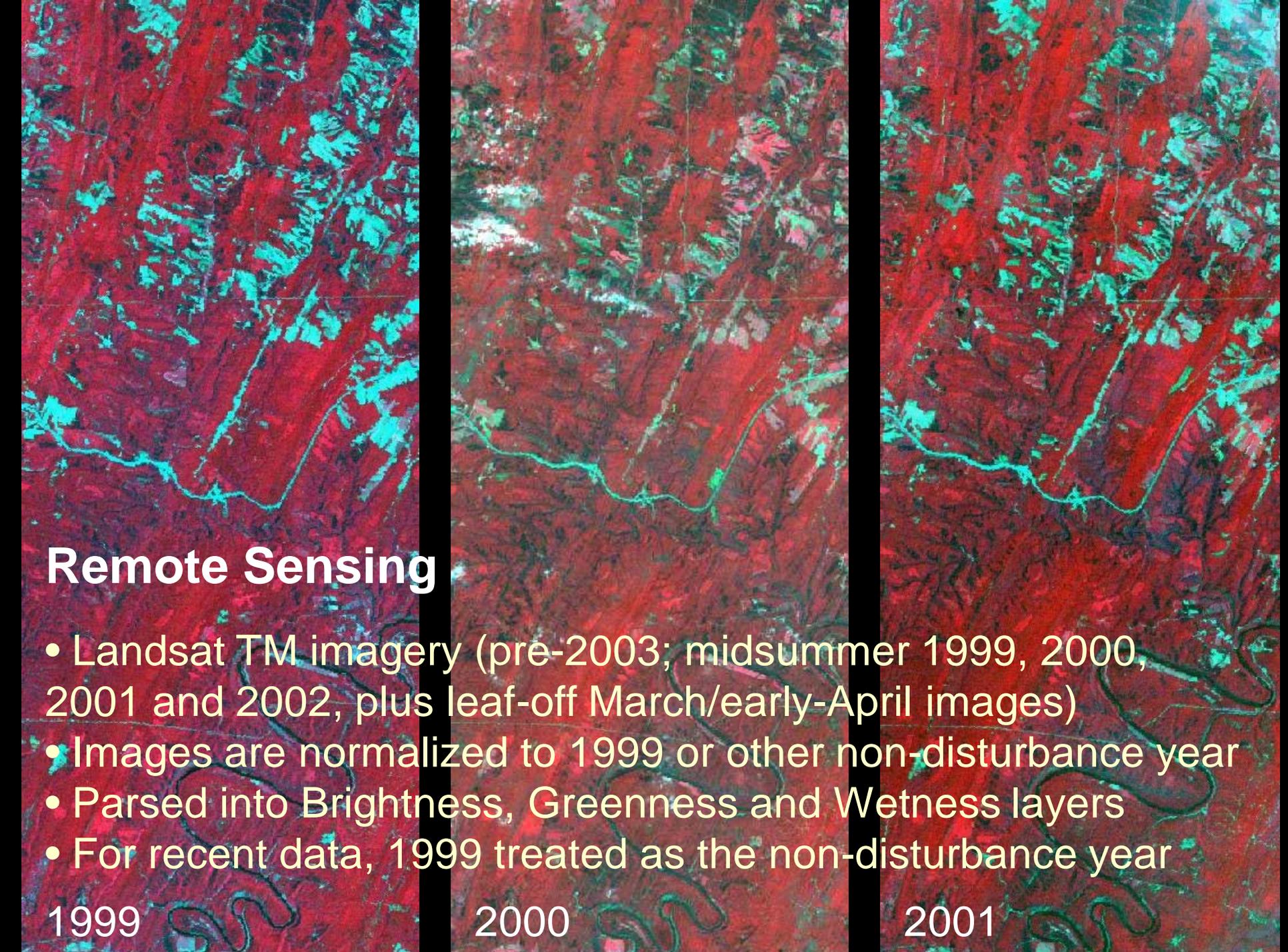


CWD, tree heights, mortality



Early Data

- **Tree heights**
 - Ice storm damaged forests
 - up to 10m forest height sheared off in ice-storm damaged areas
- **Coarse woody debris**
 - All forests
 - 0.4 – 60 Mg ha⁻¹ across all plots
 - A wide range....



Remote Sensing

- Landsat TM imagery (pre-2003; midsummer 1999, 2000, 2001 and 2002, plus leaf-off March/early-April images)
- Images are normalized to 1999 or other non-disturbance year
- Parsed into Brightness, Greenness and Wetness layers
- For recent data, 1999 treated as the non-disturbance year

1999

2000

2001

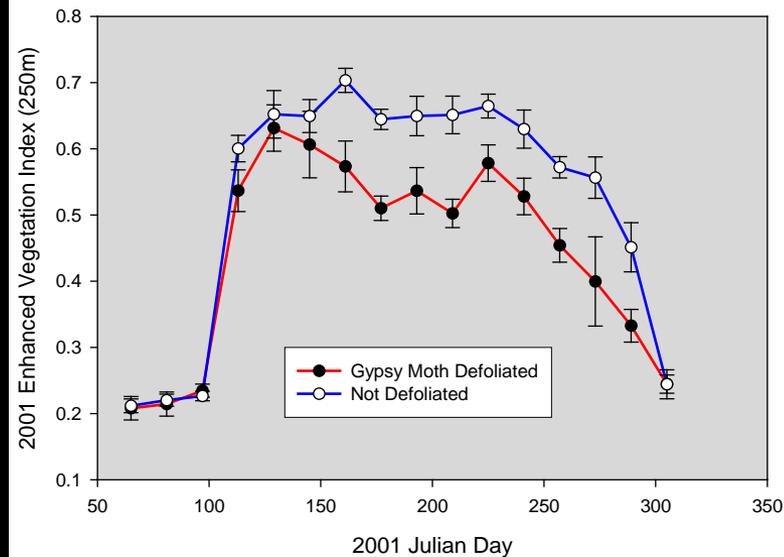
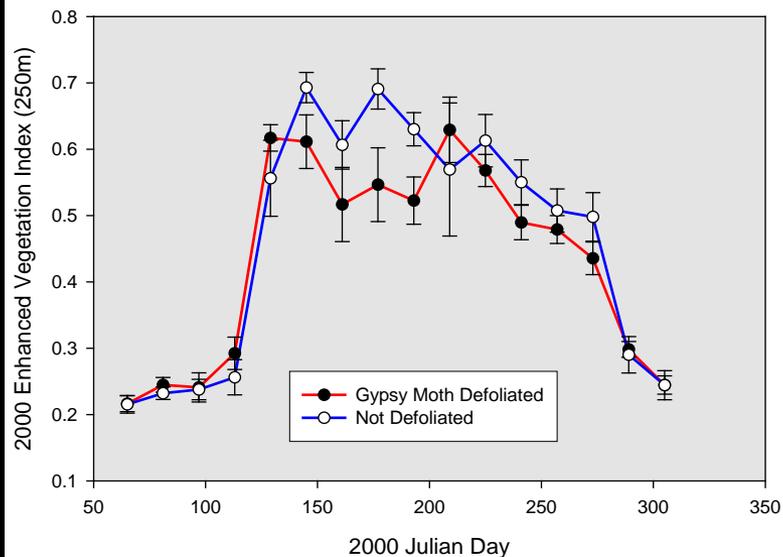
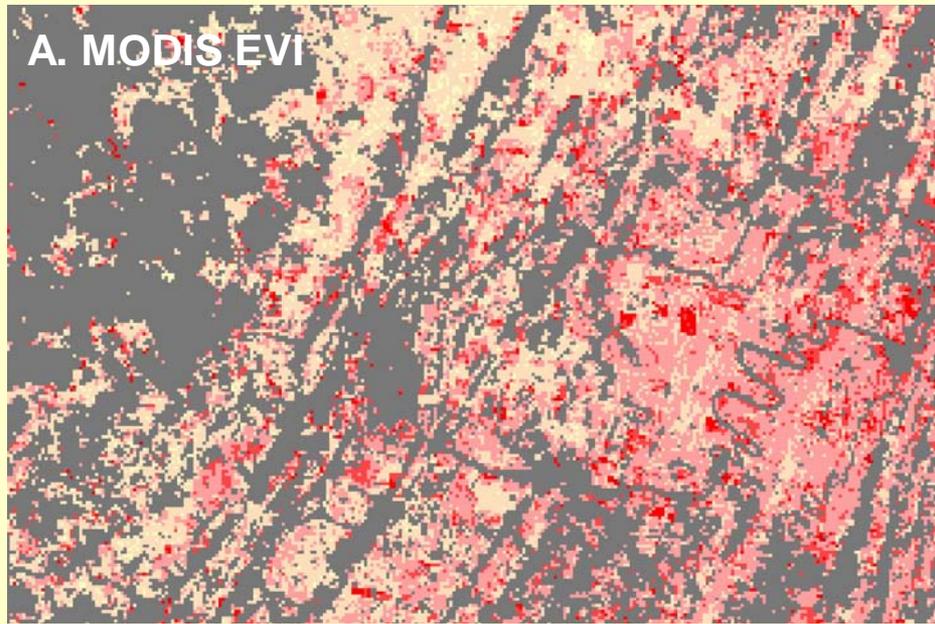
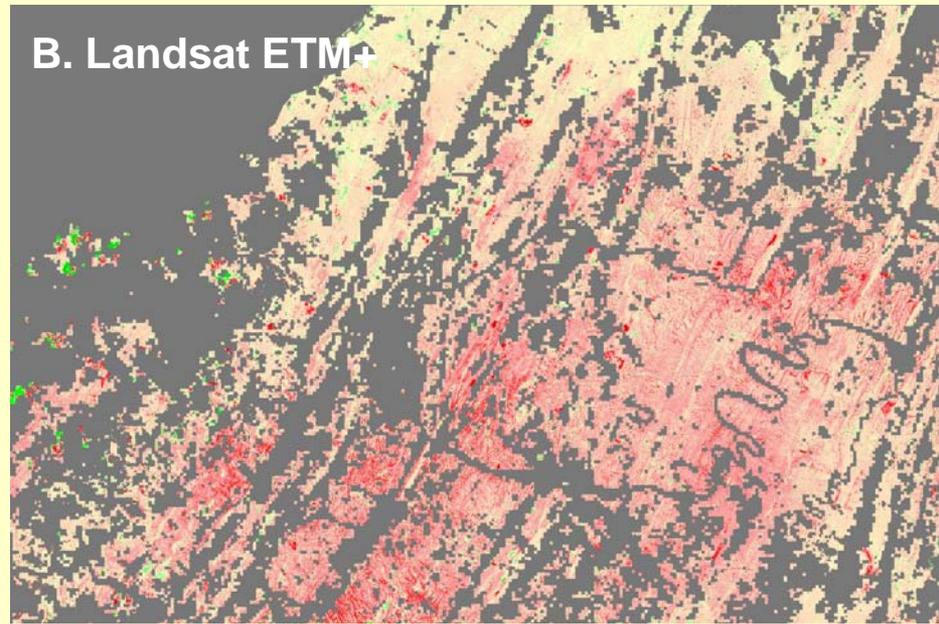


Figure 4. MODIS seasonal profiles of 250m EVI for defoliated and undisturbed areas in 2000 (left) and 2001 (right). Bars indicate 95% confidence intervals. Note the apparent refoilation in late summer of both years.

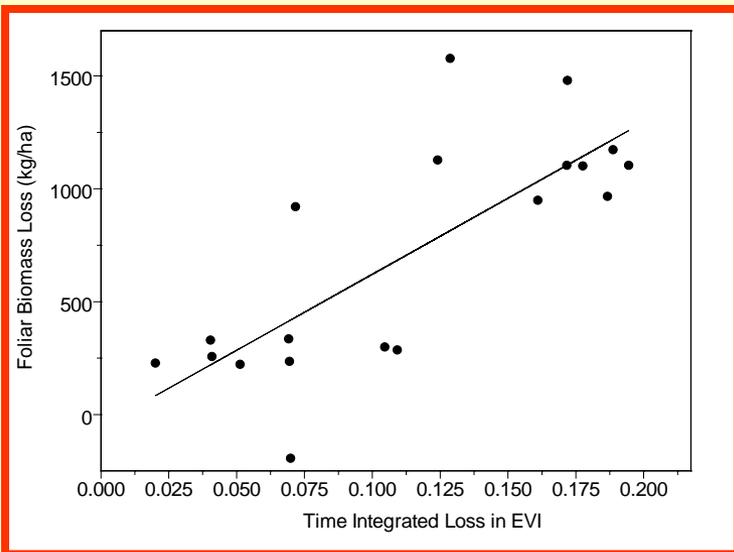
A. MODIS EVI



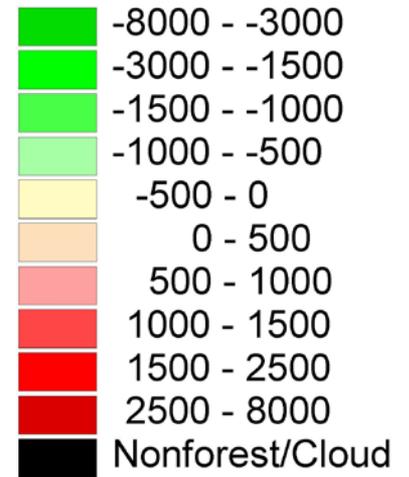
B. Landsat ETM+



Map of 2001 foliar biomass loss from MODIS and Landsat ETM+ (same data as prev. for slightly larger area). Map is based on relationship shown below; units are biomass lost kg/ha/yr. Black areas represent clouds or MODIS pixels that are < 80% forest. Logged areas were not distinguished from defoliated areas on these maps.



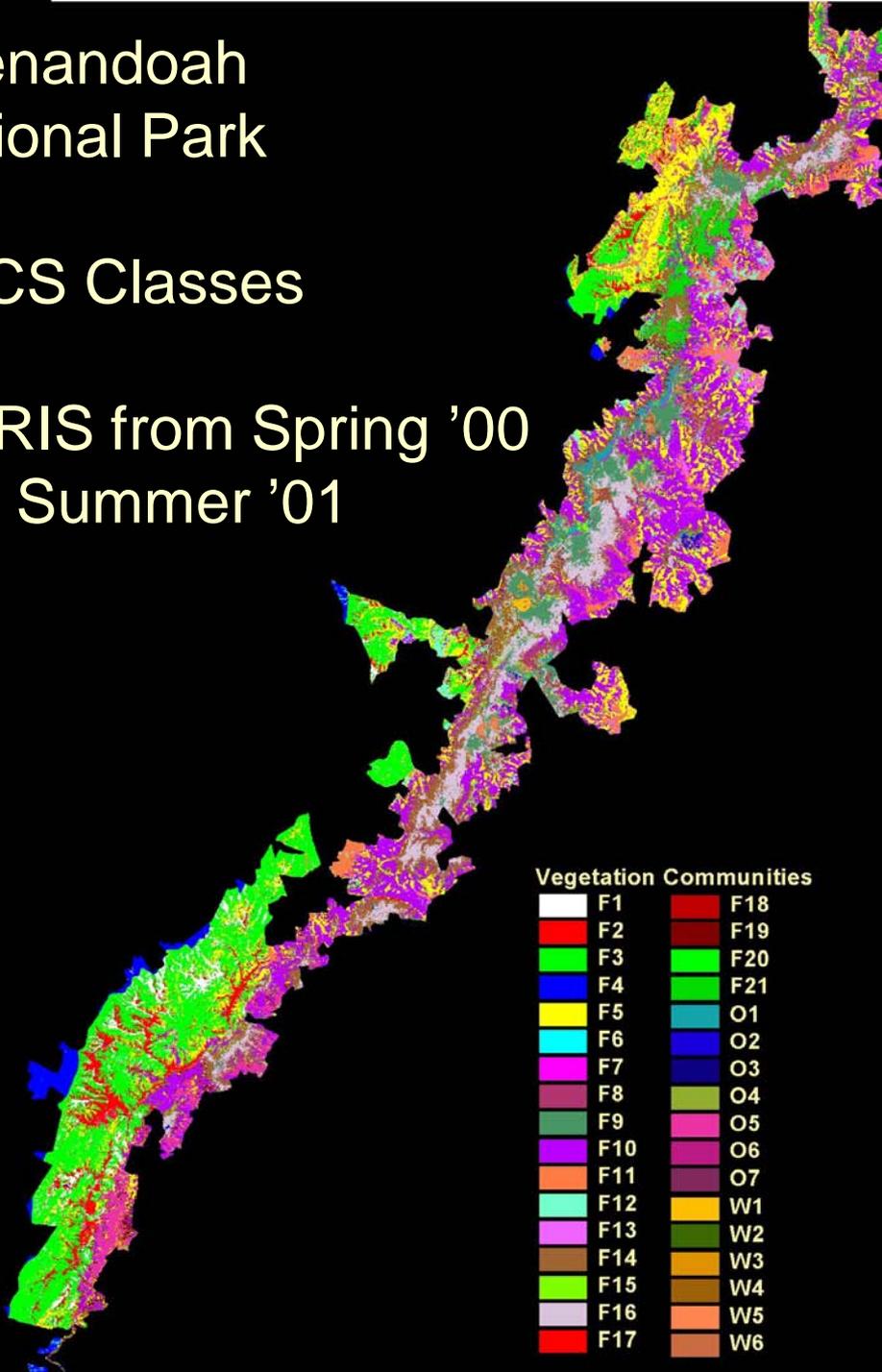
Preliminary prediction of 2001 foliar biomass loss (as derived from Landsat ETM+ analysis) as a function of time integrated average loss in growing season 250m EVI. Model $R^2 = 0.5956$ ($p = 0.0001$) and mean absolute error (MAE) = 238 kg/ha/yr.



Shenandoah National Park

NVCS Classes

AVIRIS from Spring '00 and Summer '01



Vegetation Communities

White	F1	Red	F18
Red	F2	Dark Red	F19
Green	F3	Bright Green	F20
Blue	F4	Light Green	F21
Yellow	F5	Light Blue	O1
Cyan	F6	Dark Blue	O2
Magenta	F7	Dark Blue	O3
Brown	F8	Dark Blue	O4
Grey	F9	Light Green	O5
Purple	F10	Pink	O6
Orange	F11	Purple	O7
Light Cyan	F12	Yellow	W1
Pink	F13	Dark Green	W2
Brown	F14	Orange	W3
Light Green	F15	Dark Green	W4
Light Purple	F16	Light Green	W5
Red	F17	Light Green	W6

- 296 plots
- Classification by VA Natural Heritage Program
- Compared AVIRIS (2 dates), Hyperion, Multi-date Landsat
- also used topo vbls
- LDA, Evaluate through cross-validation
- NatureServe now acq. additional validation

- Spr AVIRIS 83% 97%
- Sum AVIRIS 82% 95%
- Hyperion 90% 93%
- Landsat 57% 76%

Area of images not overlapping

BLUE = WHOLE MAP

GREEN = COMMON AREA all maps

Next Steps

- **Hydrologic study**
 - Continuous sampling
 - Lab analysis and interpretation
- **Field ecology/ecosystem study**
 - Establish plots in Shenandoah
 - Annual measurements of mortality
 - Quarterly measurements of lysimeters
 - Assess disturbance as it happens.....
- **Remote sensing study**
 - Continue to build dist. histories to the 1980s
 - Map species composition (SR only) and foliar nutrients (if new AVIRIS available)



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