# Monitoring, Modeling, & Managing Forests Through Time Using Landsat

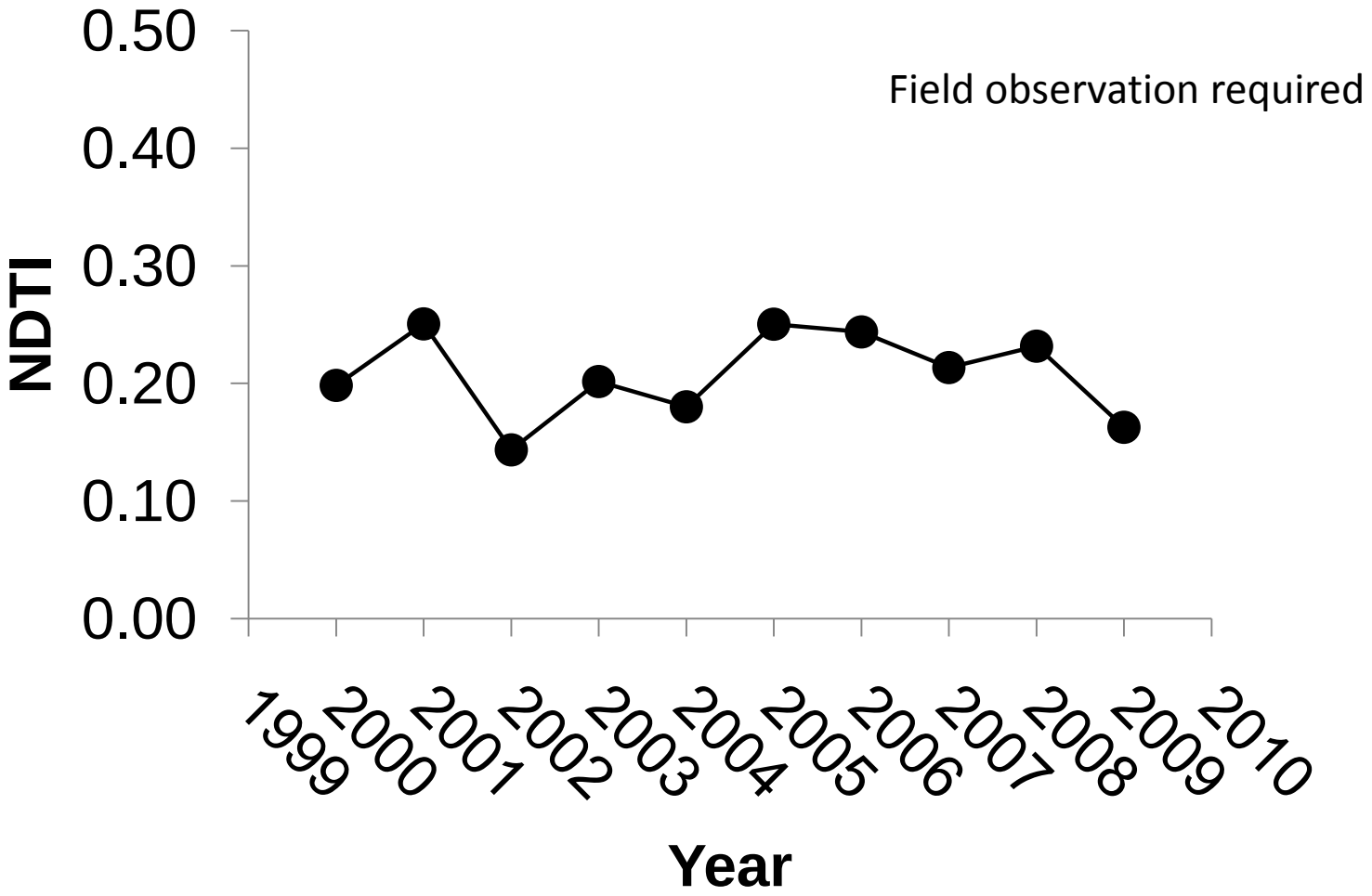
Christine E. Blinn, Susmita Sen, Nilam Kayastha, Baojuan Zheng, Carl Zipper, Valerie A. Thomas, James B. Campbell, John O. Browder, Thomas R. Fox, Randolph H. Wynne

# Topics

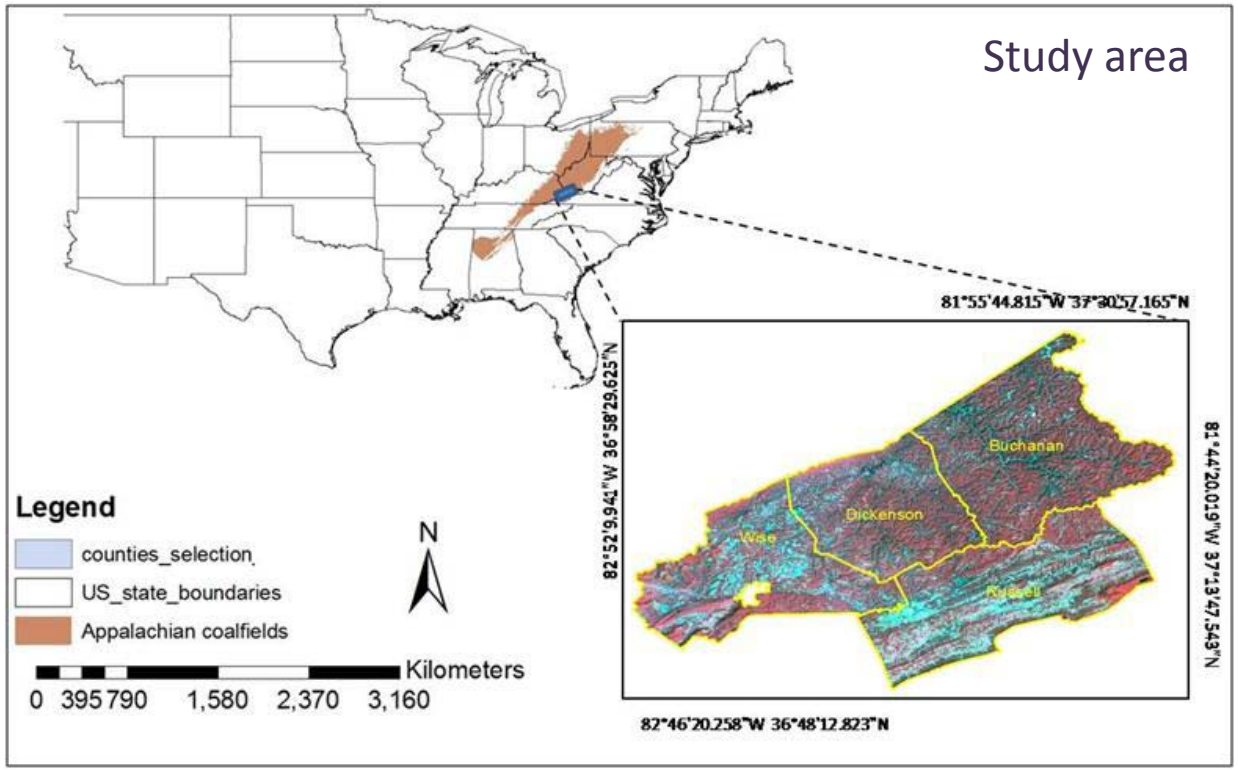
- Mining disturbance and recovery
- Longitudinal study of household drivers of tropical deforestation
- Industrial forestry applications
- NEP modeling for carbon management
- Ecosystem services

# Zheng et al. Crop Residues

## Ag. Field 2



# Methodology




## Image data

23 Landsat Images (Path 18, Row34)

| Image date | Sensor type |
|---|---|
| 9/17/1984 | TM |
| 9/20/1985 | TM |
| 6/19/1986 | TM |
| 6/6/1987 | TM |
| 6/8/1988 | TM |
| 6/11/1989 | TM |
| 6/30/1990 | TM |
| 9/21/1991 | TM |
| 6/6/1993 | TM |
| 8/28/1994 | TM |
| 8/31/1995 | TM |
| 9/5/1997 | TM |
| 5/19/1998 | TM |
| 9/3/1999 | TM |
| 6/9/2000 | TM |
| 8/15/2001 | TM |
| 5/22/2002 | ETM+ |
| 6/2/2003 | TM |
| 9/24/2004 | TM |
| 9/11/2005 | TM |
| 7/12/2006 | TM |
| 9/17/2007 | TM |
| 9/3/2008 | TM |

## Ancillary data

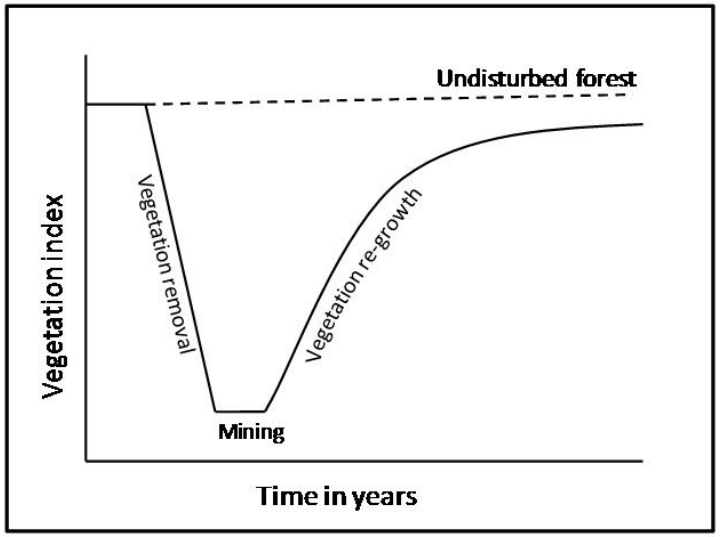
- Aerial photos {DOQQ (1994-1998), NAIP (2003, 2005, 2008)}
- Transportation GIS layer from Virginia Department of Transportation (VDOT)
- Urban layer from NLCD, 1992 and 2001

Pre-mining forest

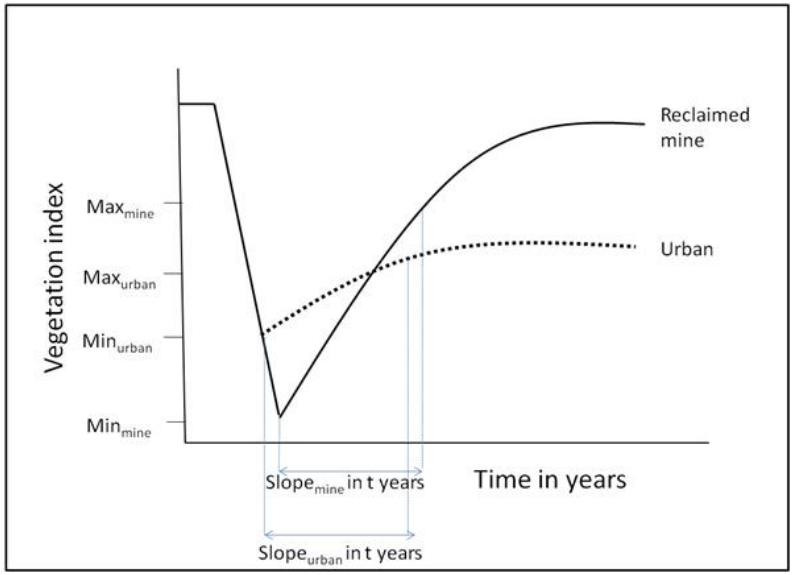
Mining

Post-mining vegetation

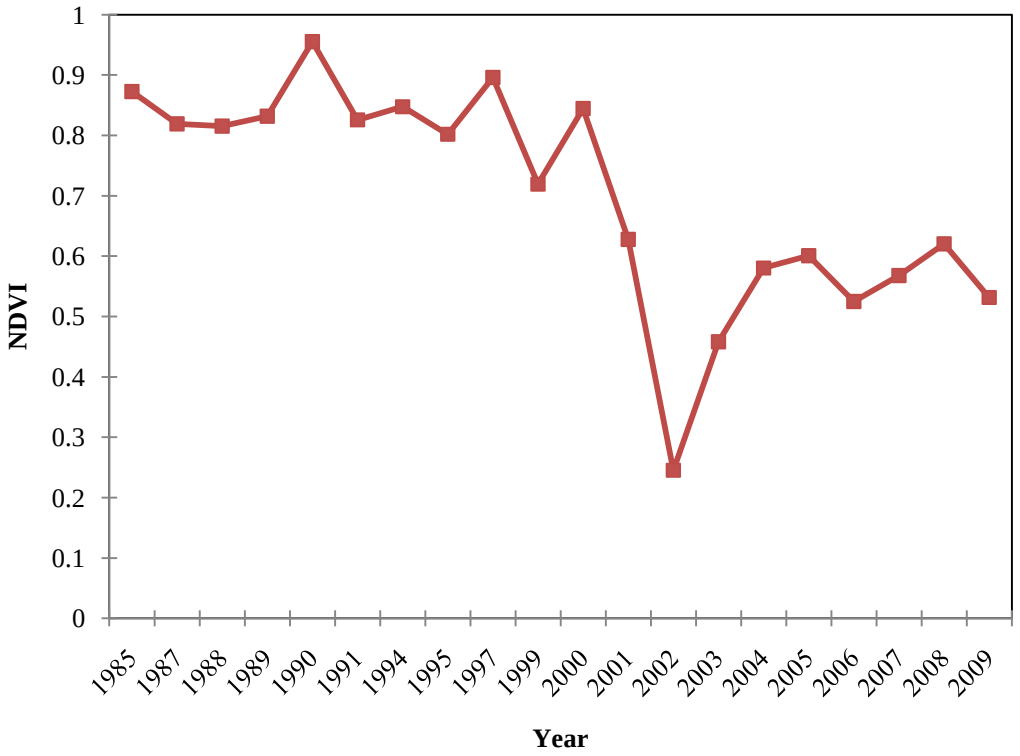
Mining trajectory



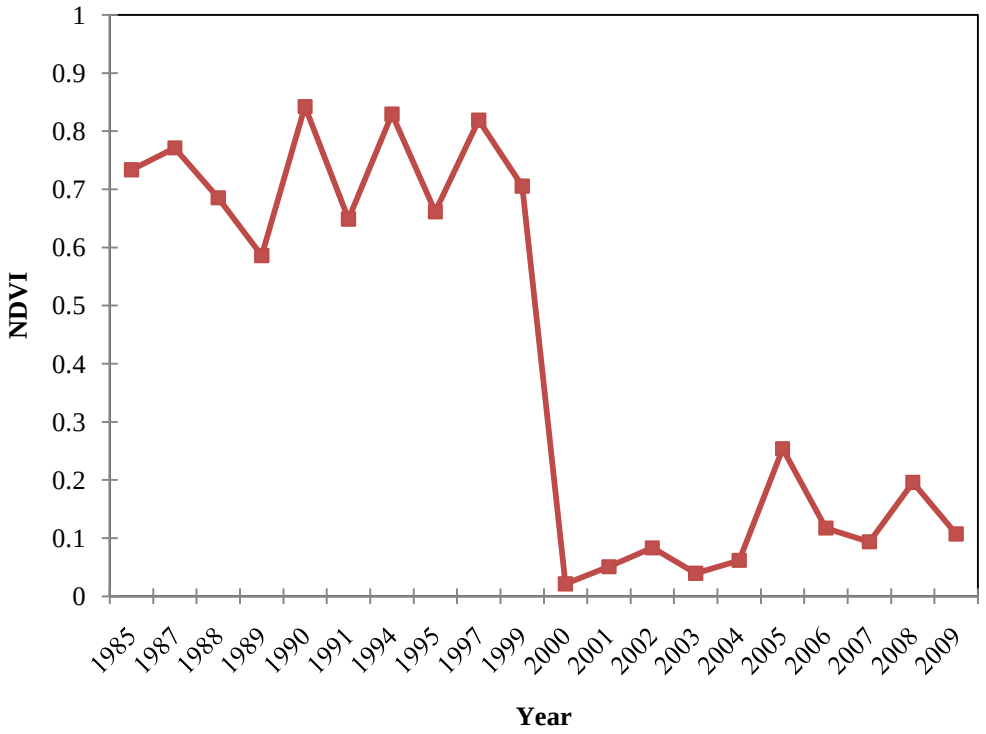

Differences in mining and non-mining disturbance trajectories

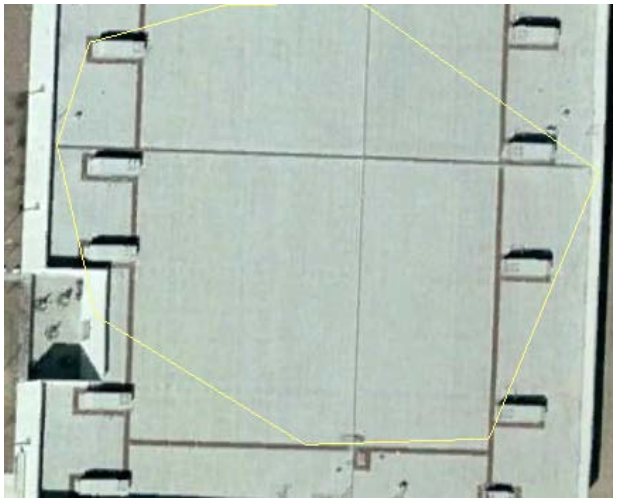


**Trajectory for an wetland area changed to suburban development**



**Trajectory for an wetland area changed to urban development**



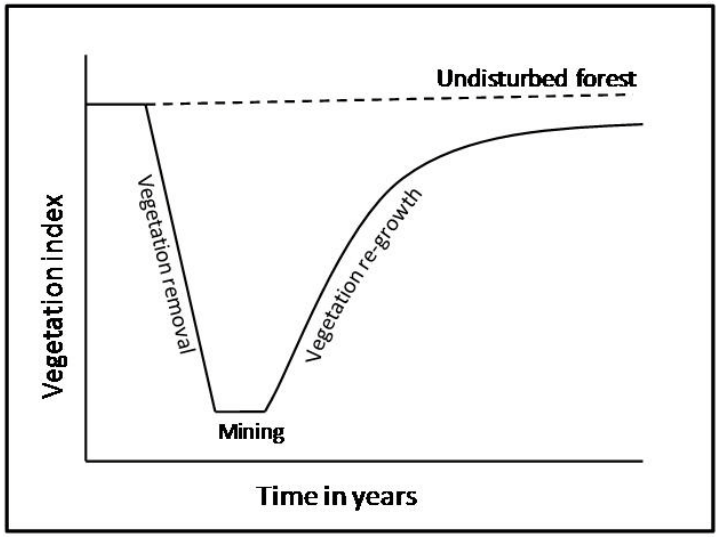



Pre-mining forest

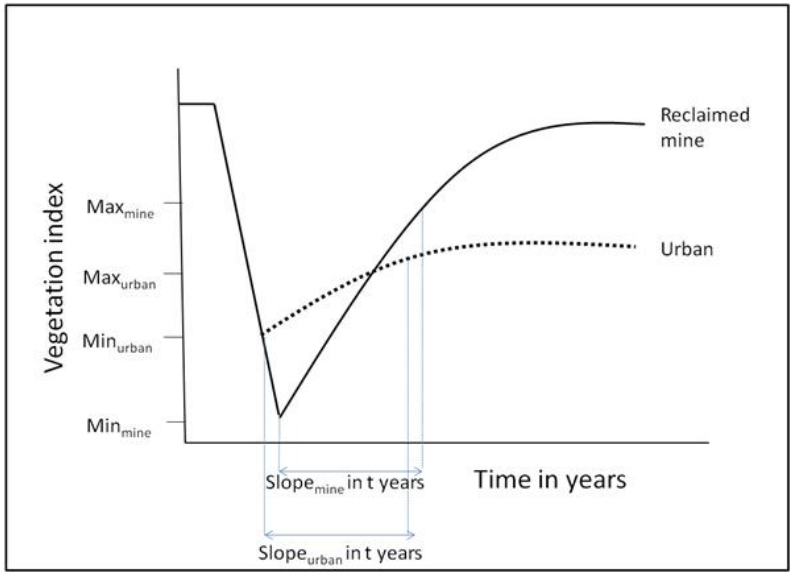
Mining

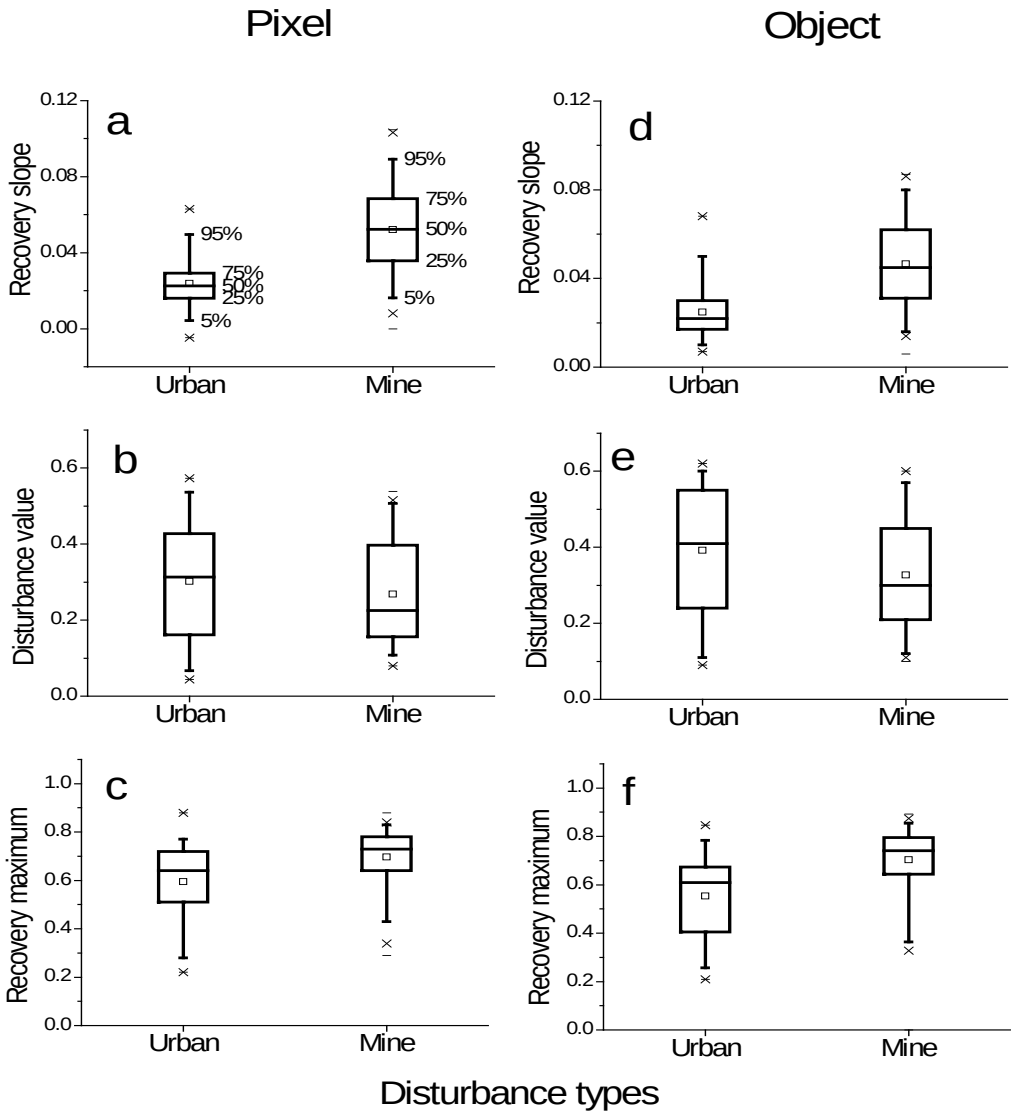
Post-mining vegetation

Mining trajectory




Differences in mining and non-mining disturbance trajectories

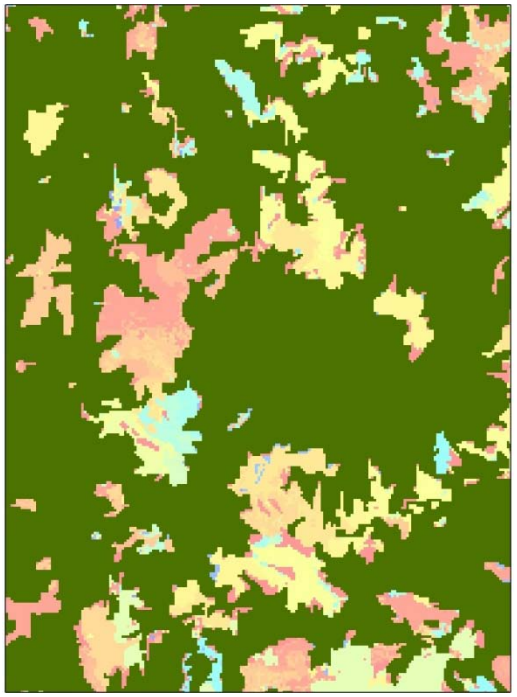


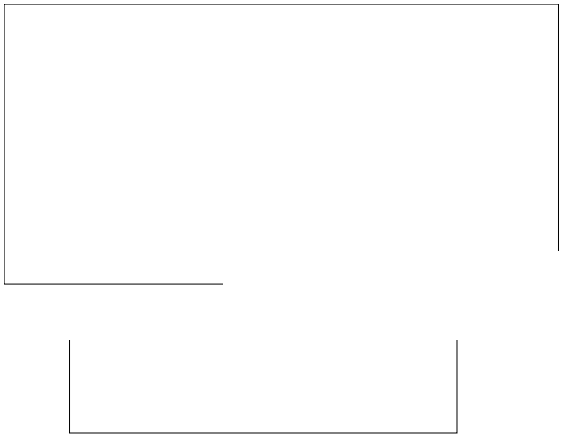



Comparison of parameter values of mine and urban categories, computed from NDVI training data for pixels (a-c) and objects (d-f). Box plots represent the 25$^{th}$ and 75$^{th}$ percentiles, and medians; the whiskers range from 5$^{th}$ to the 95$^{th}$ percentile, while the small open boxes represent means.

# Results-contd.

Disturbance year map of reclaimed mines



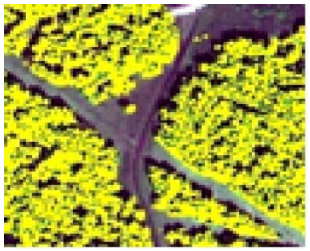


Mine vs. non-mine classification accuracies

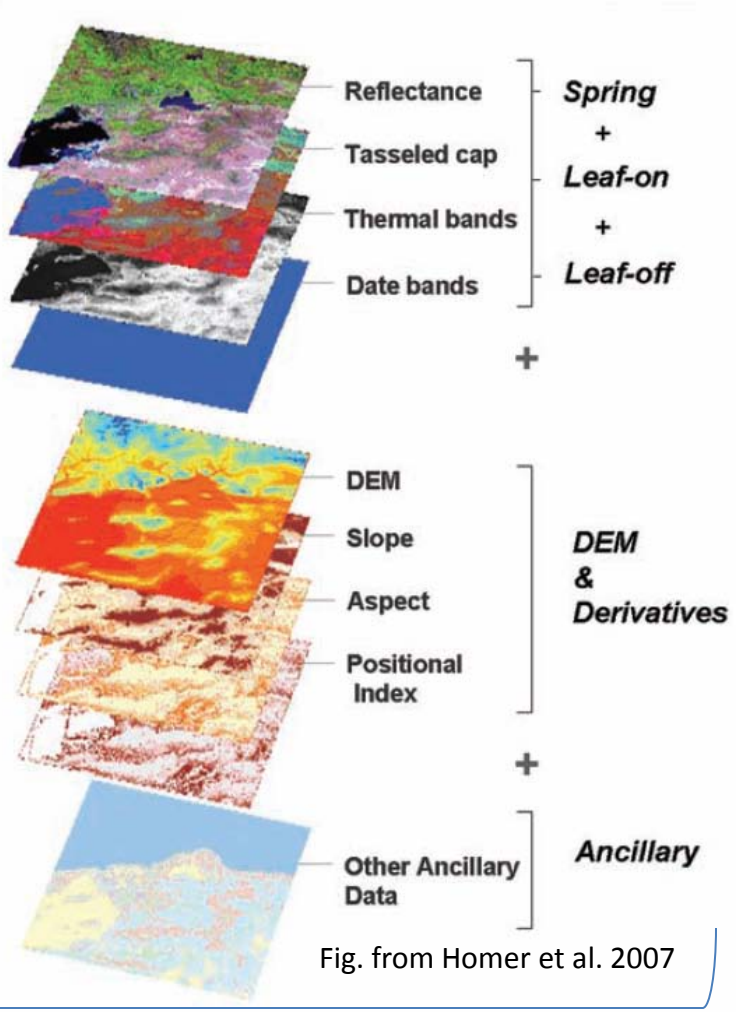
| | PIXEL | OBJECT |
|---|---|---|
| NDVI | 87.25% | 87.90% |
| TC G/B | 86.27% | 89.05% |
| BAND 3 INVERSE | 77.62% | 80.39% |

$$Accuracy\,\% = \frac{correctly\ classified\ (mine + non - mine)}{Total\ number\ of\ validation\ points}\ X\ 100$$

# 2001 General Modelling Approach



=

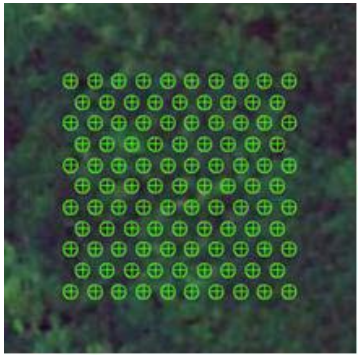



Response developed by classifying Tree crown cover on high resolution Imagery for 3-4, 1-4 $km^2$ sampling chips per Landsat scene.

Fig. from Homer et al. 2007

Model developed using regression tree (random forest) algorithm

# 2011 General Modelling Approach



=

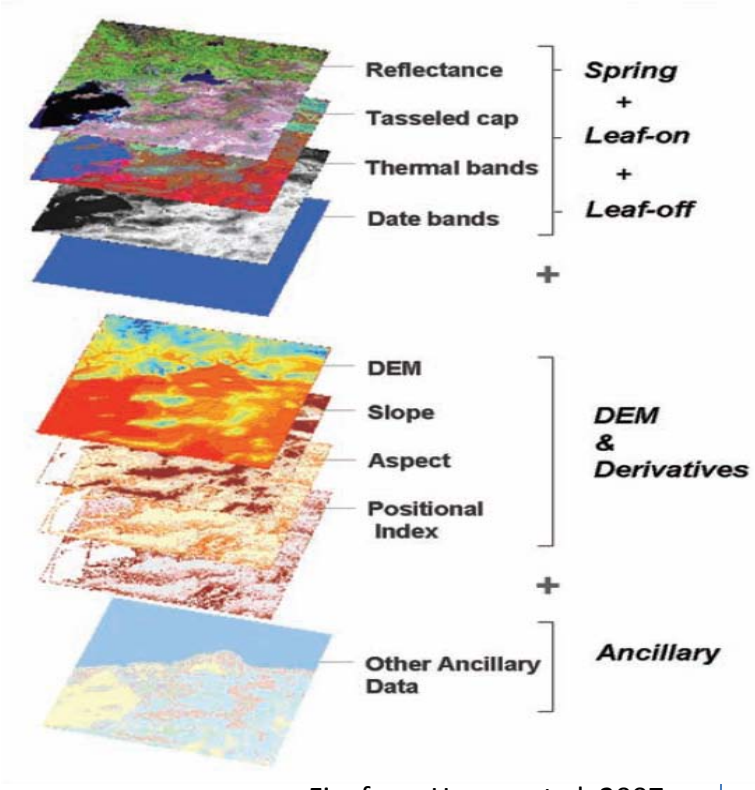


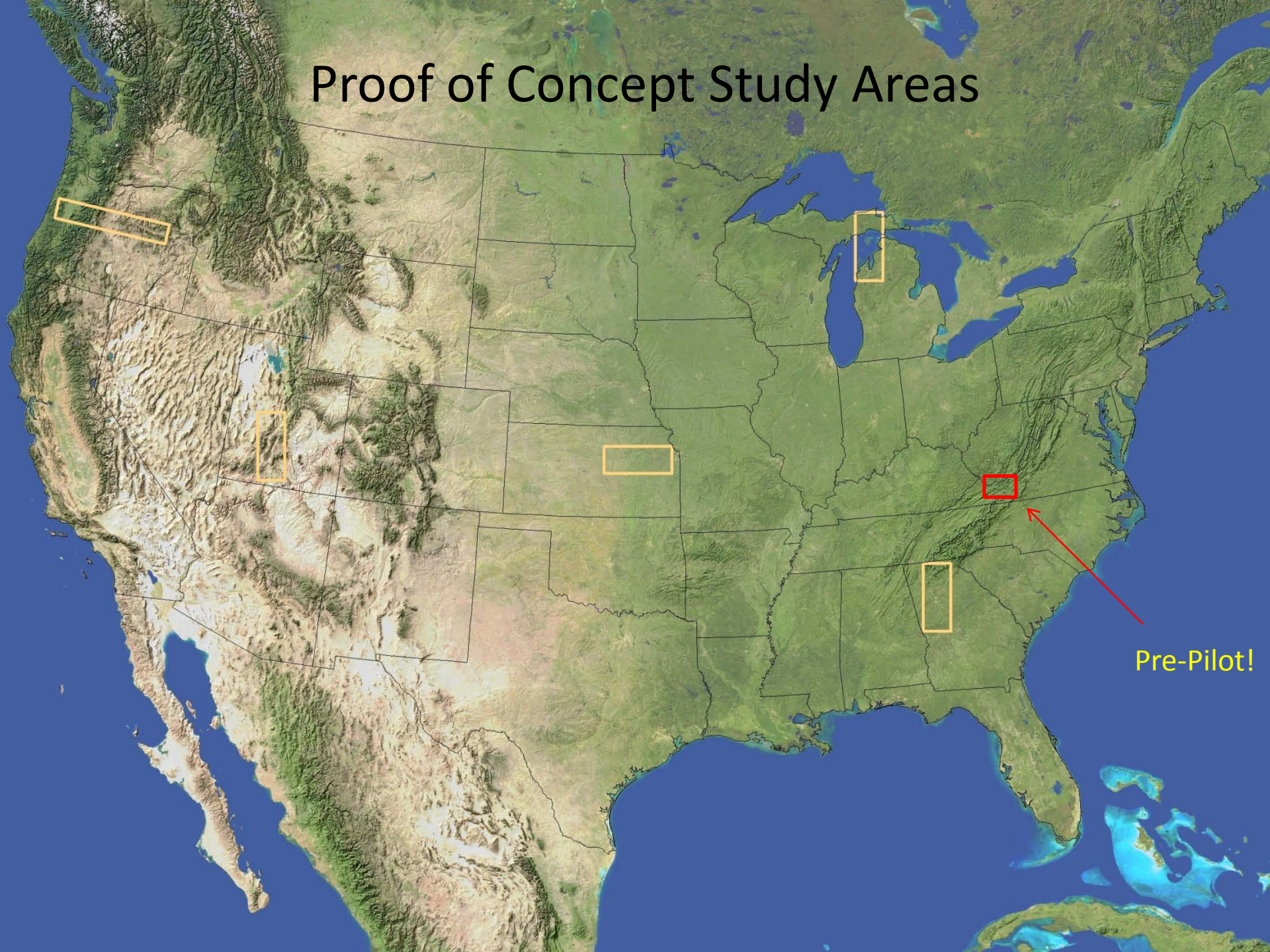

Fig. from Homer et al. 2007

Response developed by photo Interpreting Tree crown cover on NAIP Imagery for ~4160 8100m$^2$ sampling chips per Landsat scene.

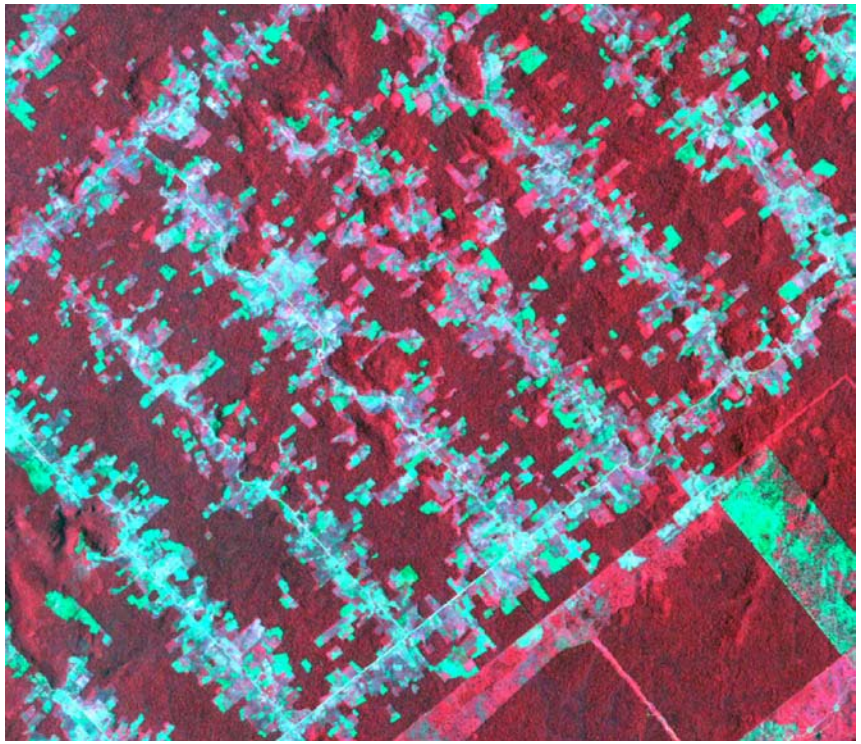
Example modelling techniques

- Random forest algorithm
- K nearest neighbor imputation
- Support vector machines

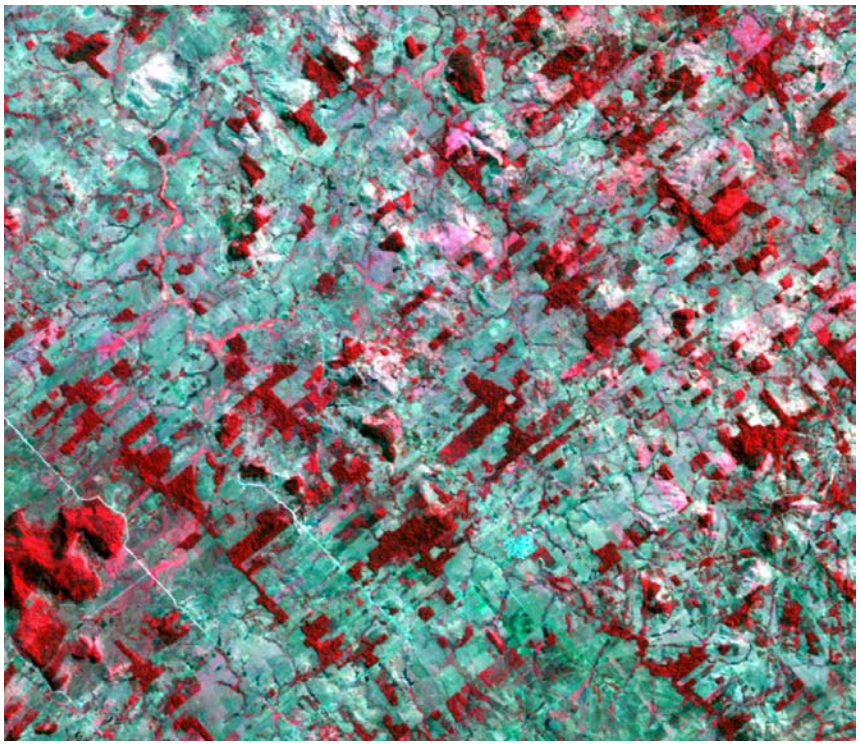
# Proof of Concept Study Areas



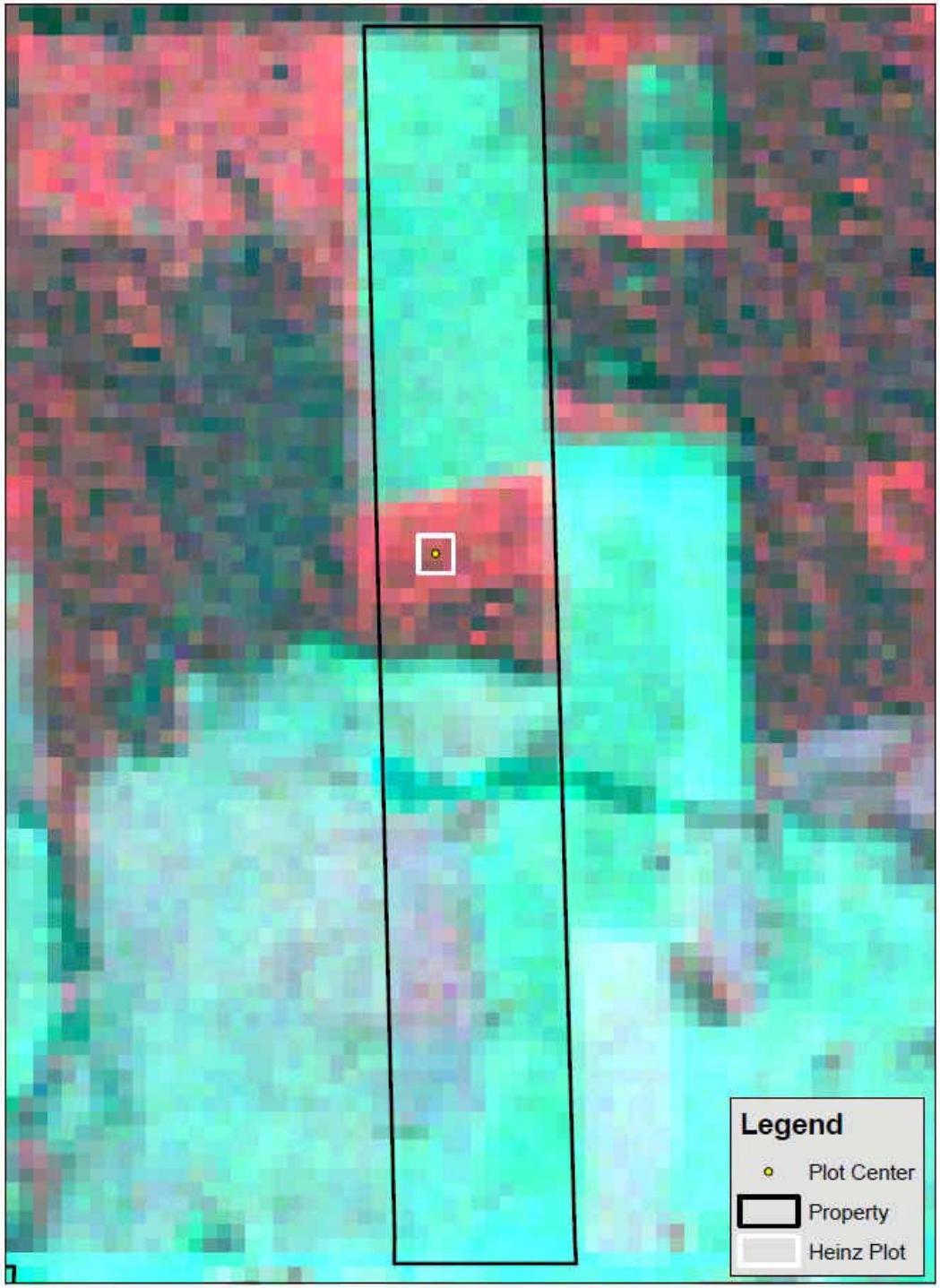
# Change in Forest Cover in the Brazilian Amazon



October 13, 1986



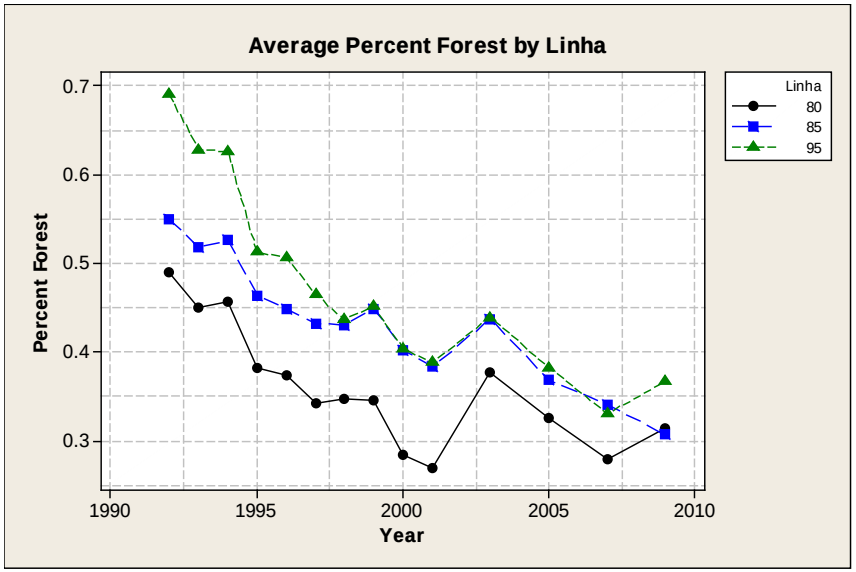
August 6, 2008

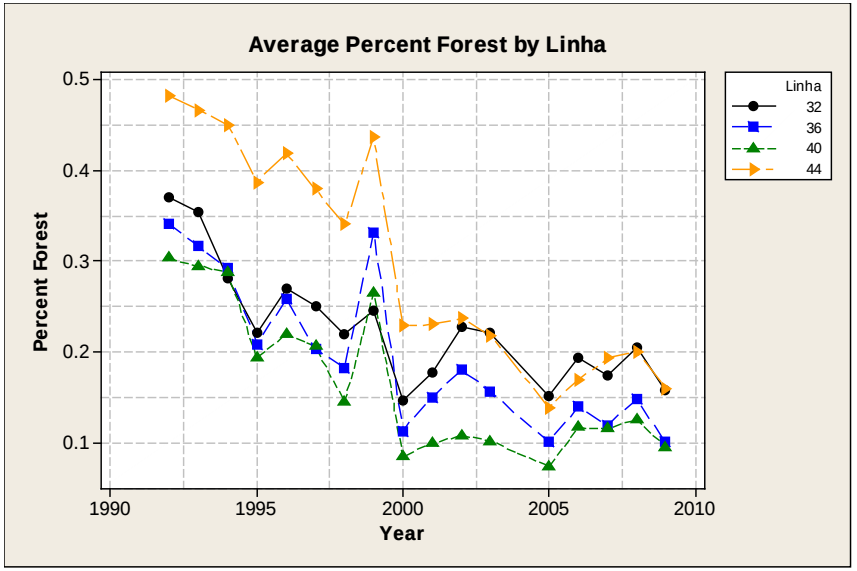



Conversion of the Brazilian Amazon forest to pasture

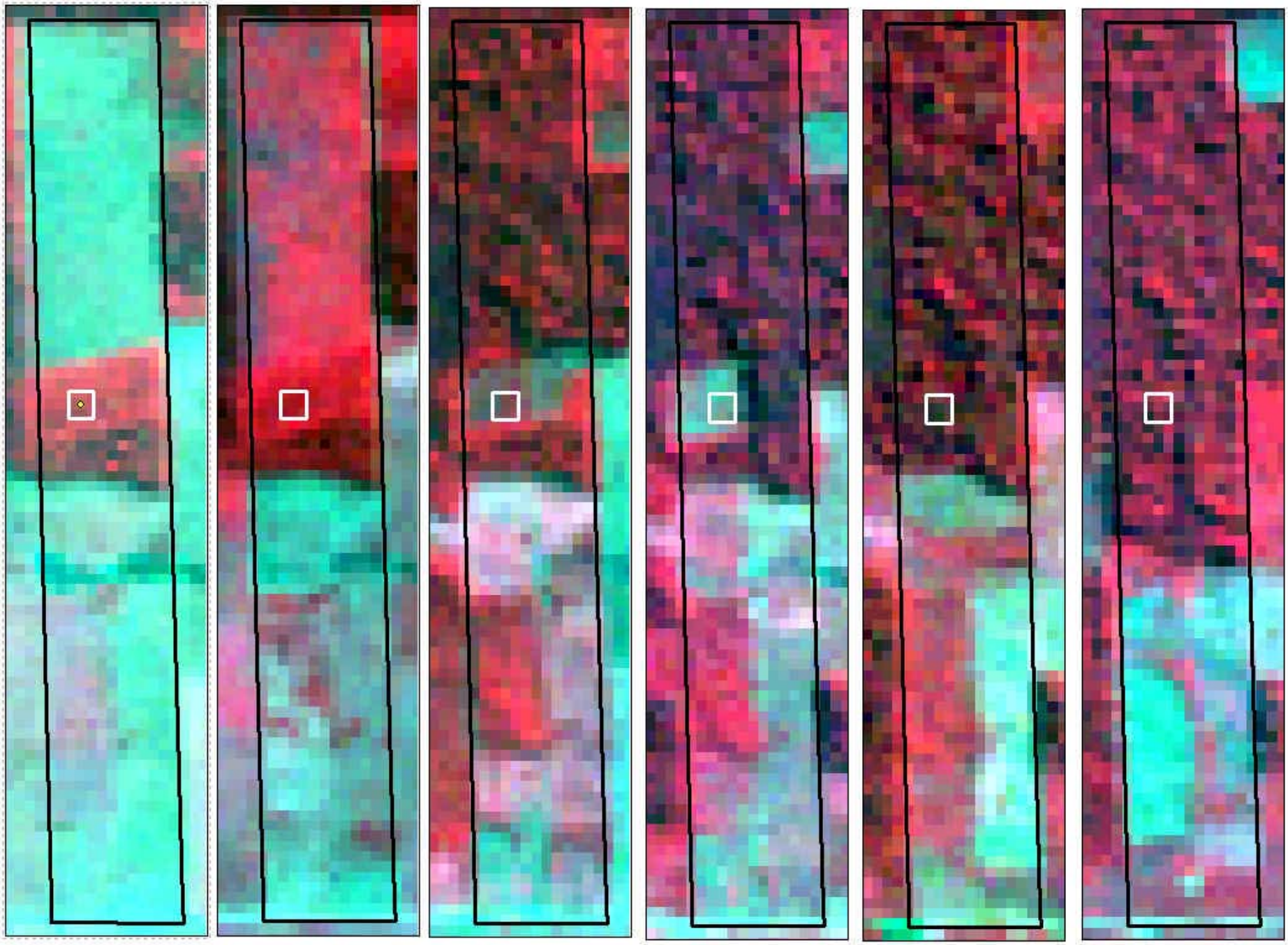
- Revisiting landowners this year for the third time since the early 90's who participated in a study sponsored by the Heinz Foundation to determine the socio-economic influences on their land use decisions
- Agroforestry plots were installed on a subset of the landowners' properties

# Change in Percent Forest Cover

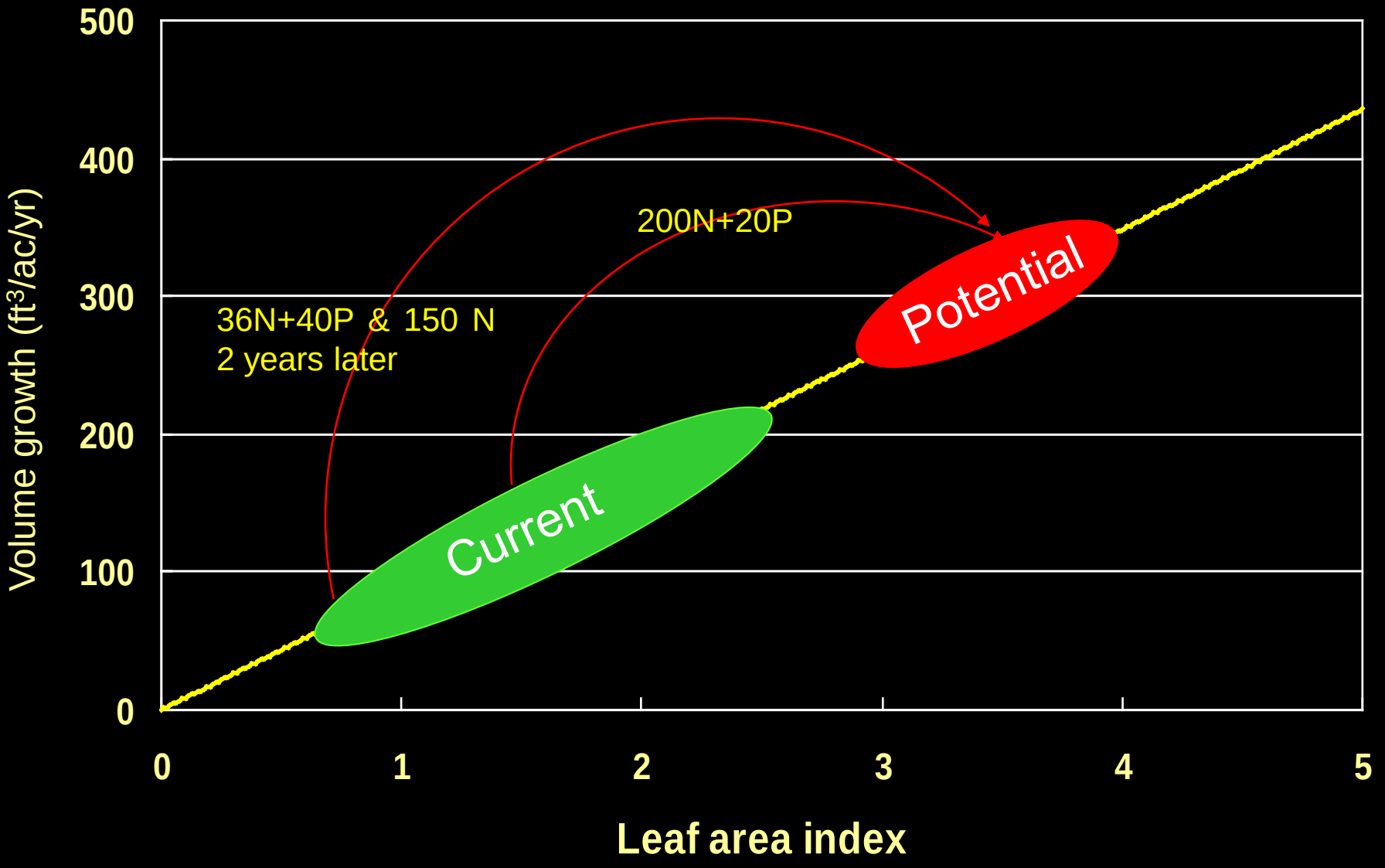



Rough estimates of the average percent forest on a landowner's property compared across several rows of properties and two study areas.


June 2, 2005
May 20, 2003
June 28, 2000
June 9, 1996
June 22, 1992
July 16, 1986

# Leaves Grow Trees



# Productivity Assessment– all unthinned stands > age 5

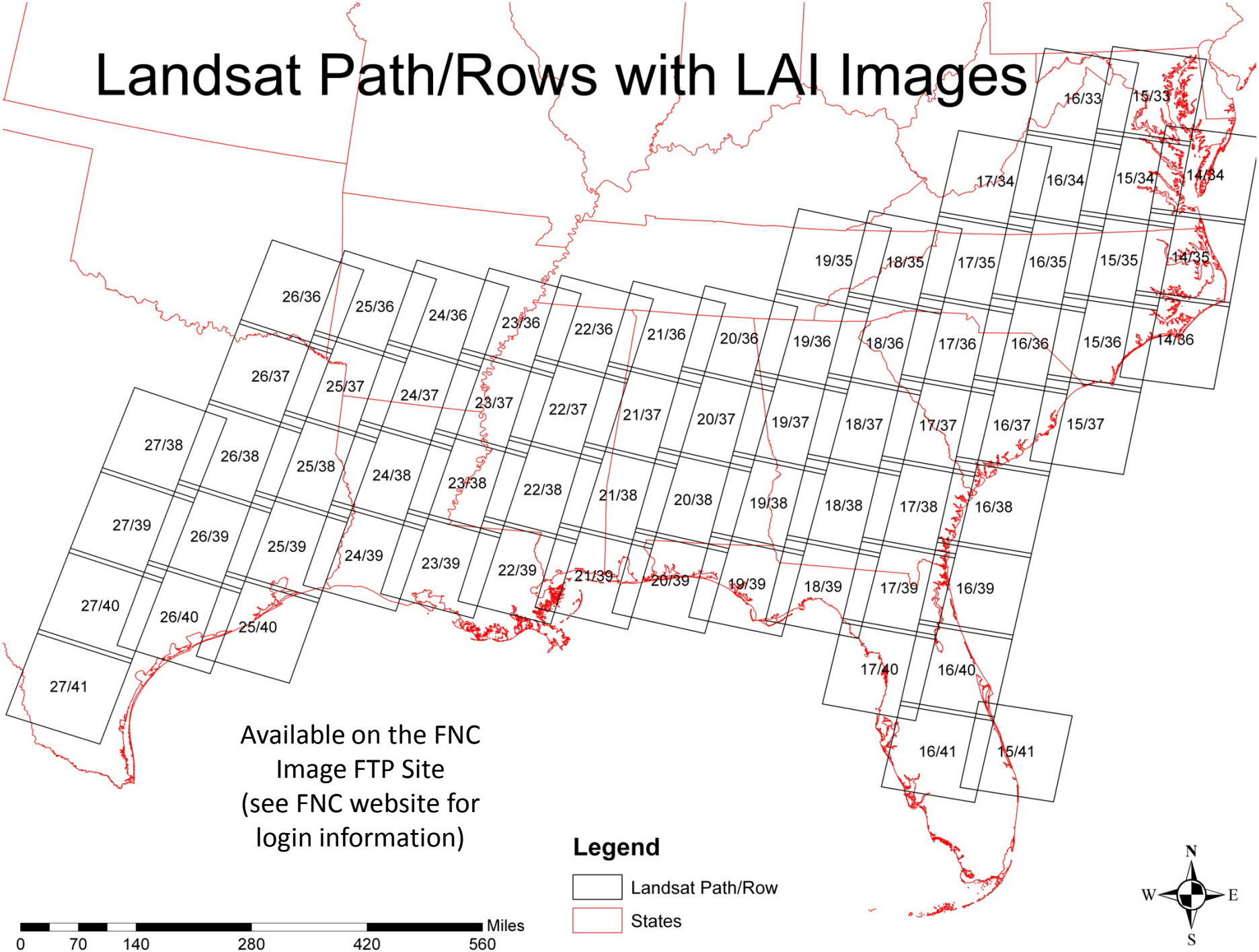
1,009 acres with peak LAI > 3.0
1,130 acres < 1.0
5,420 acres <1.5

We need to look at these and diagnose the problem

With LAI values, the Data Warehouse provides ability to query and report

| Standkey | Stand Acres | Calc Ac | Mean 0804 | Stand Age | Thin Year | Fert Year | Site Index 25 |
|---|---|---|---|---|---|---|---|
| 11037E0023 | 148 | 27.4 | 3.68 | 5 | 0 | 2004 | 64 |
| 11014B0018 | 116.2 | 39.4 | 3.34 | 6 | 0 | 0 | 60 |
| 23098 0008 | 106.9 | 50.1 | 3.28 | 10 | 0 | 0 | 59 |
| 11025A0002 | 116.5 | 66.4 | 3.2 | 5 | 0 | 2004 | 64 |
| 11026 0003 | 215.7 | 23.1 | 3.19 | 5 | 0 | 2004 | 58 |
| 11041 0009 | 66 | 64.5 | 3.18 | 6 | 0 | 0 | 56 |
| [illegible] | 106.9 | 56.8 | 3.16 | 10 | 0 | 0 | 59 |
| [illegible] | 74.8 | 42.7 | 3.15 | 8 | 0 | 0 | 69 |
| [illegible] | 275.8 | 20.7 | 3.15 | 8 | 0 | 0 | 53 |
| 11018A0014 | 318.2 | 34 | 3.13 | 5 | 0 | 0 | 59 |
| 11135 0002 | 30.1 | 27.6 | 3.11 | 24 | 0 | 0 | 59 |
| 11013A0003 | 283.6 | 32.2 | 3.09 | 6 | 0 | 0 | 52 |
| 11013A0010 | 32.3 | 20.4 | 3.07 | 11 | 0 | 0 | 62 |
| 11145 0001 | 107.4 | 65.4 | 3.07 | 7 | 0 | 0 | 67 |
| 11144A0009 | 54 | 37.6 | 3.05 | 9 | 0 | 0 | 54 |
| 11018A0014 | 318.2 | 50.7 | 3.04 | 5 | 0 | 0 | 59 |
| 11018A0014 | 318.2 | 64.2 | 3.04 | 5 | 0 | 0 | 59 |
| 11014B0018 | 116.2 | 76.8 | 3.01 | 6 | 0 | 0 | 60 |
| 11018A0014 | 318.2 | 67 | 3.01 | 5 | 0 | 0 | 59 |
| 11108 0005 | 73.8 | 73.8 | 3.01 | 14 | 0 | 0 | 54 |
| 12026A0004 | 115.7 | 22.7 | 3.01 | 21 | 0 | 2001 | 59 |
| 12066 0015 | 50.5 | 24.8 | 3.01 | 13 | 0 | 0 | 62 |

# Landsat Path/Rows with LAI Images




Available on the FNC Image FTP Site (see FNC website for login information)

**Legend**

- Landsat Path/Row
- States

Miles

0 70 140 280 420 560

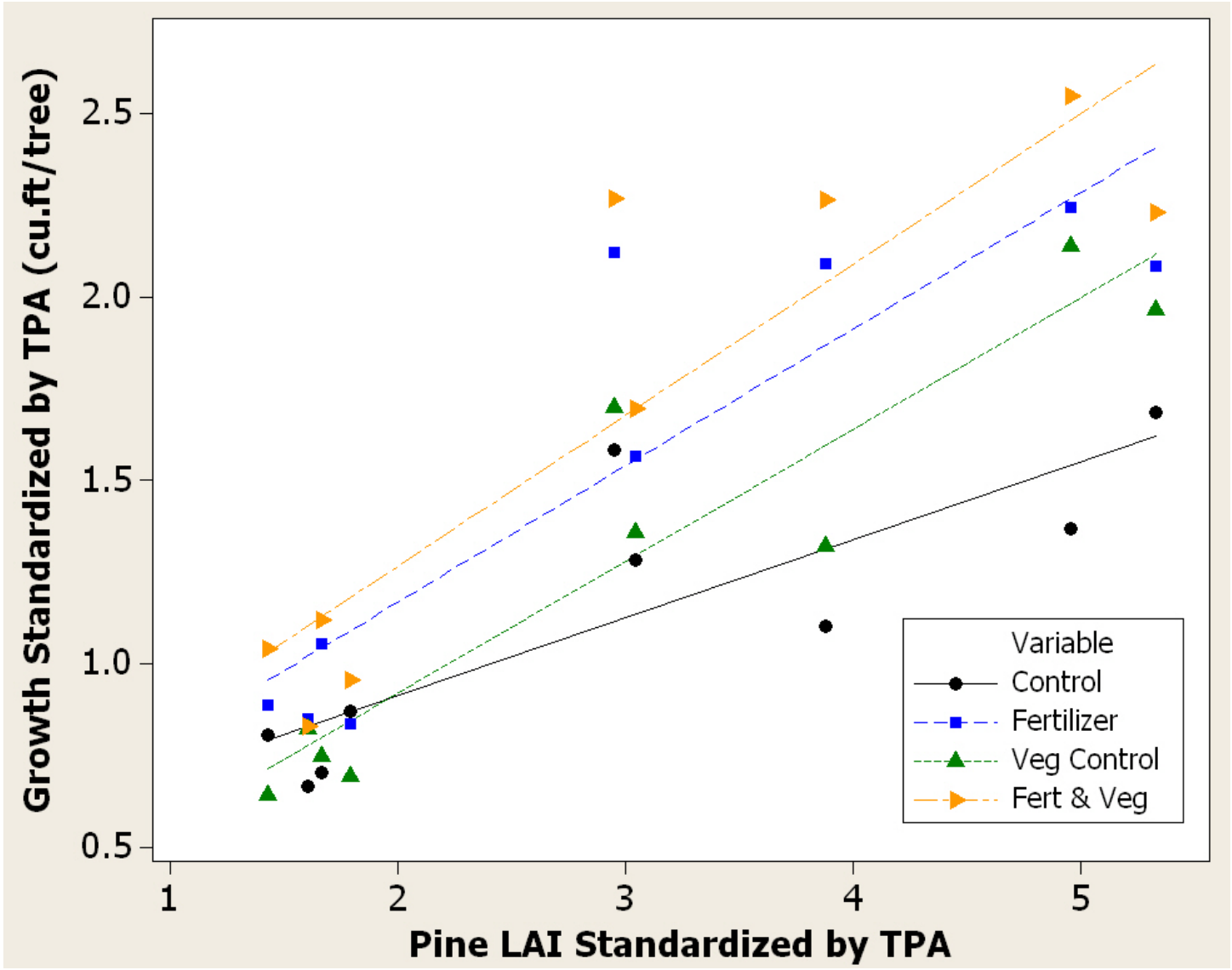
N W E S

Peduzzi et al.
*SJ Appl For*

| ***LOBLOLLY*** | **Total Summer LAI ($m^2m^{-2}$)** | **Overstory Summer LAI ($m^2m^{-2}$)** | **Overstory Winter LAI ($m^2m^{-2}$)** | **SR Summer** | **SR Winter** |
|---|---|---|---|---|---|
| **Basal Area ($m^2ha^{-1}$)** | 0.308 | 0.332 | 0.414 | 0.245 | 0.331 |
| **Site Index (m)** | 0.047 | **0.522** | 0.354 | **0.44** | **0.508** |
| **Height (m)** | **0.455** | 0.267 | 0.375 | 0.28 | 0.184 |
| **Crown Length (m)** | 0.265 | -0.175 | 0.012 | 0.213 | -0.03 |

| ***SLASH*** | **Total Summer LAI ($m^2m^{-2}$)** | **Overstory Summer LAI ($m^2m^{-2}$)** | **Overstory Winter LAI ($m^2m^{-2}$)** | **SR Summer** | **SR Winter** |
|---|---|---|---|---|---|
| **Basal Area ($m^2ha^{-1}$)** | 0.347 | 0.181 | 0.211 | 0.350 | **0.626** |
| **Site Index (m)** | 0.177 | -0.055 | -0.014 | **0.461** | **0.735** |
| **Height (m)** | -0.099 | 0.017 | -0.024 | **0.548** | **0.708** |
| **Crown Length (m)** | 0.364 | 0.388 | 0.343 | 0.127 | **0.486** |

# Standardized Pine LAI vs. Yr3-4 Growth Standardized




| Treatment | R-sq |
|---|---|
| Control | 68.5* |
| Fertilizer | 79.9* |
| Veg Control | 86.6* |
| Fert & Veg | 80.5* |

* Significant Regression

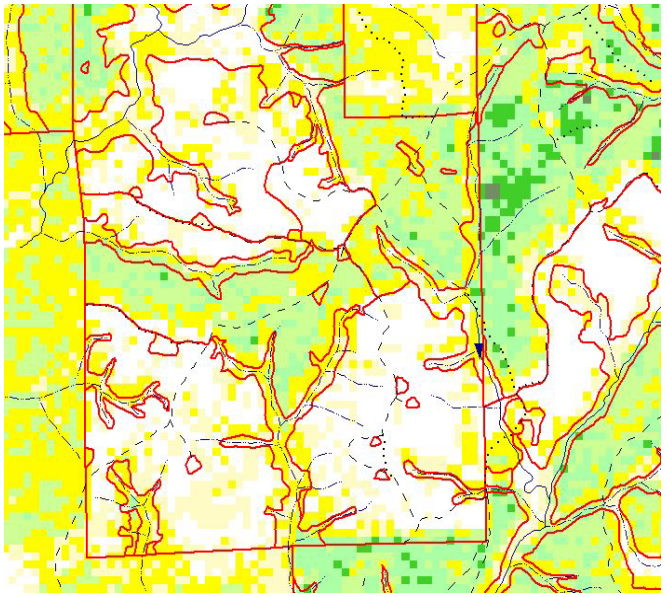
Pine LAI Std. = (Mean LAI/TPA) * 1000

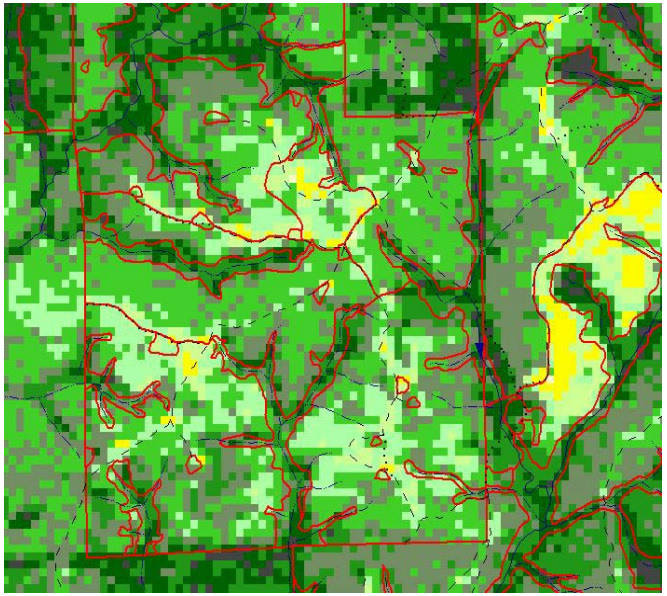
# Competition Control - Woody

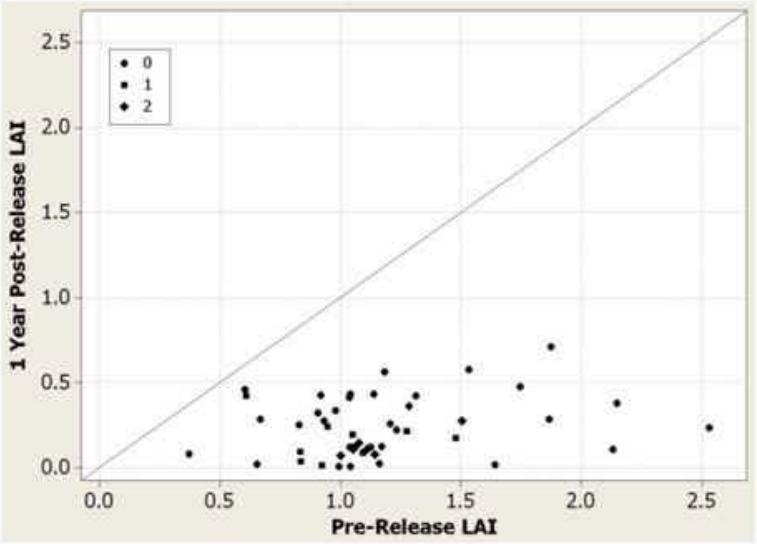
## 3 year-old plantations

Polygon > 20 acres

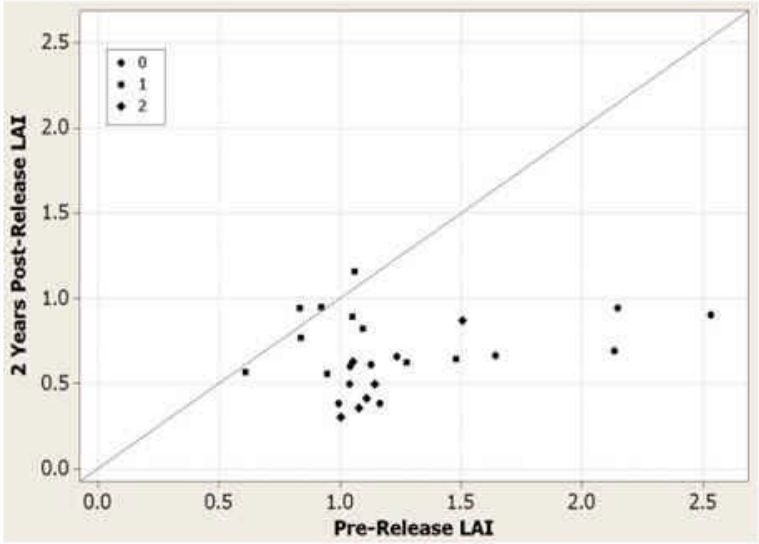
| Standkey | Stand Acres | Calc Ac | Mean 1203 | Mean 0404 | Difference |
|---|---|---|---|---|---|
| 11016 0008 | 183 | 23.8 | 0.47 | 2.03 | 1.56 |
| 11015C0024 | 107.9 | 23.8 | 0.5 | 1.84 | 1.34 |
| 32006A0001 | 292.5 | 40.6 | 0.51 | 1.42 | 0.91 |
| 32009C0003 | 59.3 | 31.9 | 0.58 | 1.45 | 0.87 |
| 32006A0001 | 292.5 | 114.9 | 0.54 | 1.36 | 0.82 |
| 11041 0013 | 74.3 | 30.9 | 0.48 | 1.29 | 0.81 |
| 11015C0024 | 107.9 | 47.2 | 0.47 | 1.16 | 0.69 |
| 11025B0013 | 85.1 | 22.8 | 0.53 | 1.22 | 0.69 |
| 32006A0001 | 292.5 | 33.5 | 0.52 | 1.19 | 0.67 |
| 32006A0001 | 292.5 | 75.6 | 0.51 | 1.15 | 0.64 |
| 11015D0020 | 114.7 | 44.8 | 0.47 | 1.1 | 0.63 |
| 11015D0020 | 114.7 | 35.8 | 0.5 | 1.11 | 0.61 |
| 11016 0005 | 211.9 | 125.8 | 0.47 | 1.05 | 0.58 |
| 11025D0008 | 39.3 | 39.3 | 0.55 | 1.12 | 0.57 |
| 32009B0002 | 87 | 65.5 | 0.5 | 1.07 | 0.57 |
| 11016 0005 | 211.9 | 86.1 | 0.49 | 1.02 | 0.53 |
| 32009C0003 | 59.3 | 25.4 | 0.55 | 1.05 | 0.5 |
| 31042B0006 | 88 | 50.4 | 0.53 | 1.03 | 0.5 |
| 32006C0003 | 60.6 | 47.5 | 0.52 | 0.99 | 0.47 |
| 32009D0004 | 44.1 | 25.8 | 0.56 | 1.02 | 0.46 |
| 32044B0001 | 109.3 | 24.9 | 0.5 | 0.92 | 0.42 |
| 11016 0008 | 183 | 136.4 | 0.5 | 0.92 | 0.42 |



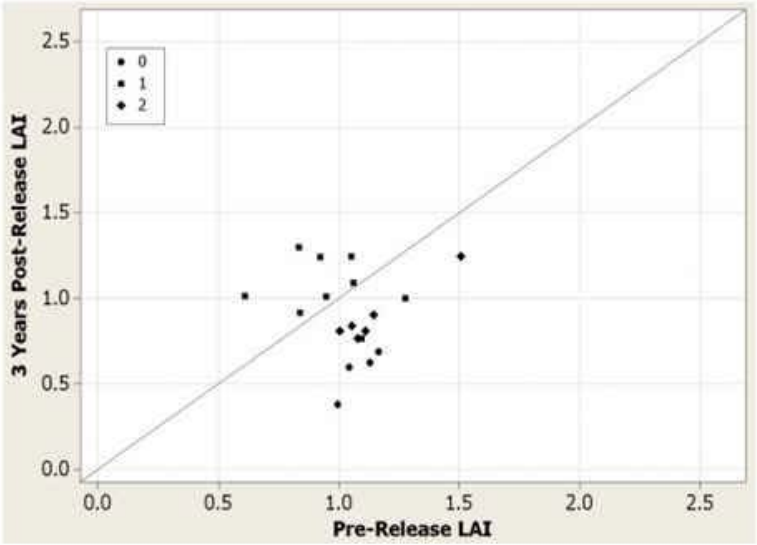




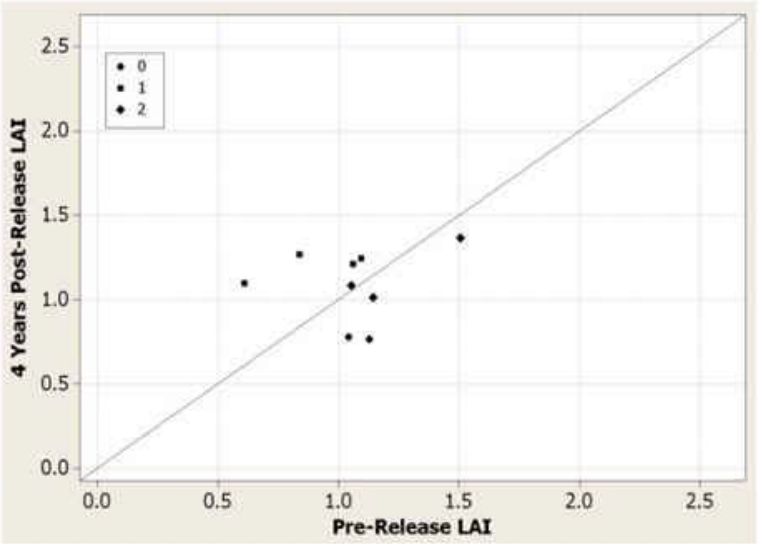

a) LAI pre-release versus 1 year post-release




b) LAI pre-release versus 2 years post-release




c) LAI pre-release versus 3 years post-release




d) LAI pre-release versus 4 years post-release

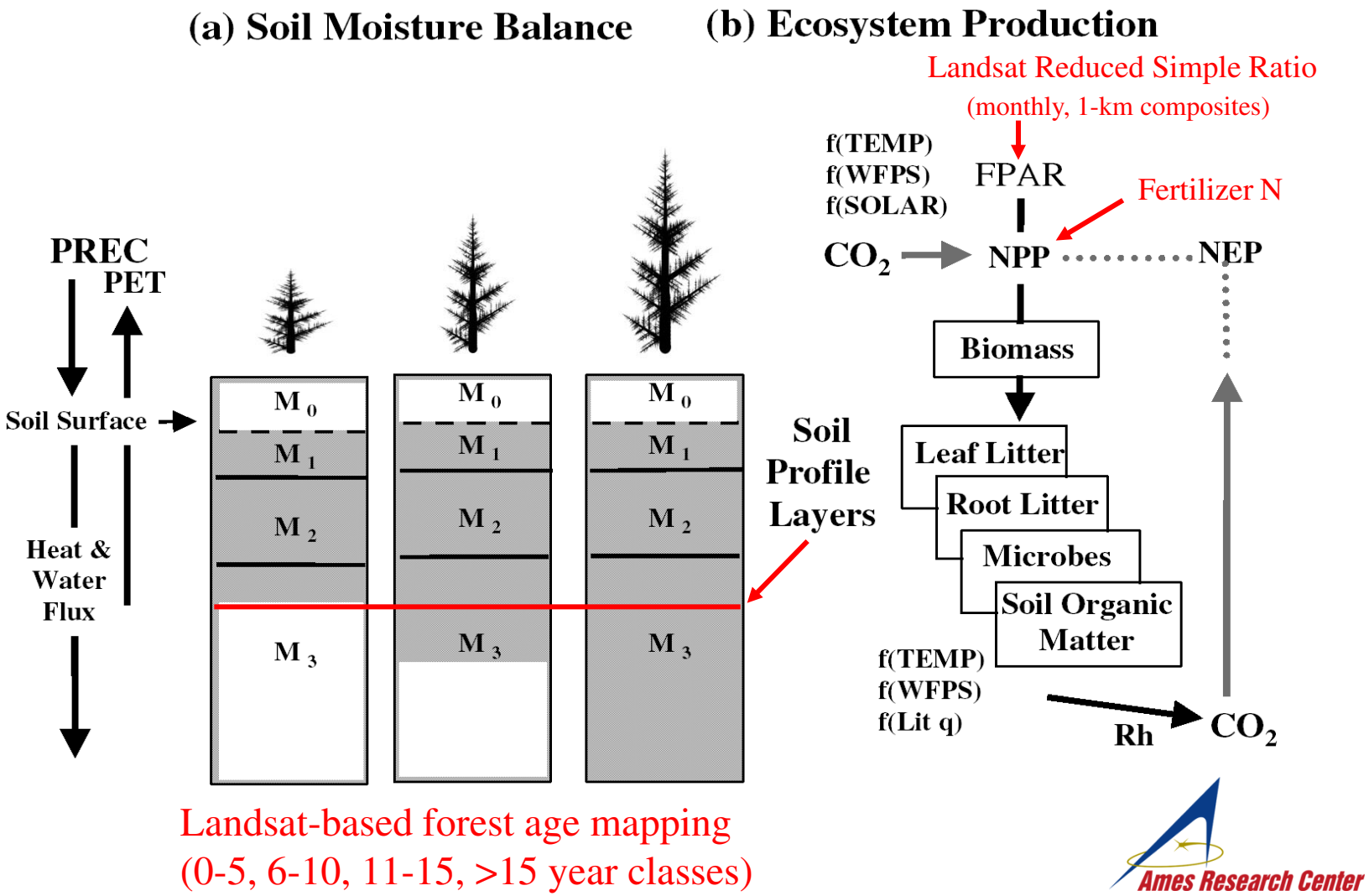
- Competing vegetation returns more rapidly in stands that are thinned.

Monitoring hardwood competition in pine stands before and after competing vegetation control

- stands are coded based on whether they were not thinned ‘0’ or thinned ‘1’ or ‘2’ years after release

# NASA-CASA Ecosystem Model (Potter et al. 2007)

## Modifications for Pine Growing Stands




Landsat-based forest age mapping
(0-5, 6-10, 11-15, >15 year classes)

Ames Research Center

Model

```
%LET Sand_mod=c*z**-d;
%LET Clay_mod=(a*(exp(-b*x)-exp(-a*x)))/(a-b);

%LET model = &Sand_mod * &Clay_mod;
```

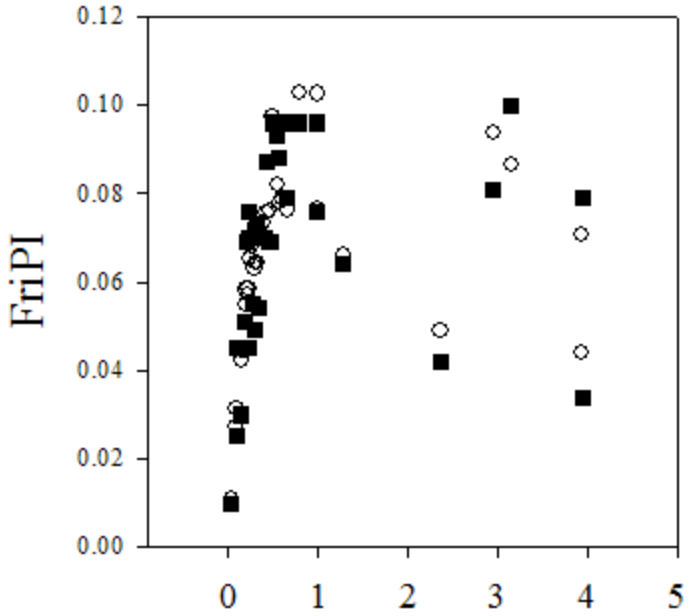
| Parameter | Estimate | Approx Std Error | Approximate 95% Confidence Limits | |
|---|---|---|---|---|
| a | 0.1844 | 0.0512 | 0.0799 | 0.2890 |
| b | 2.8604 | 0.5070 | 1.8251 | 3.8958 |
| c | 2.1140 | 0.6953 | 0.6939 | 3.5340 |
| d | 0.2452 | 0.0441 | 0.1551 | 0.3354 |

$r^2 = 0.83$

MSE = 0.0001

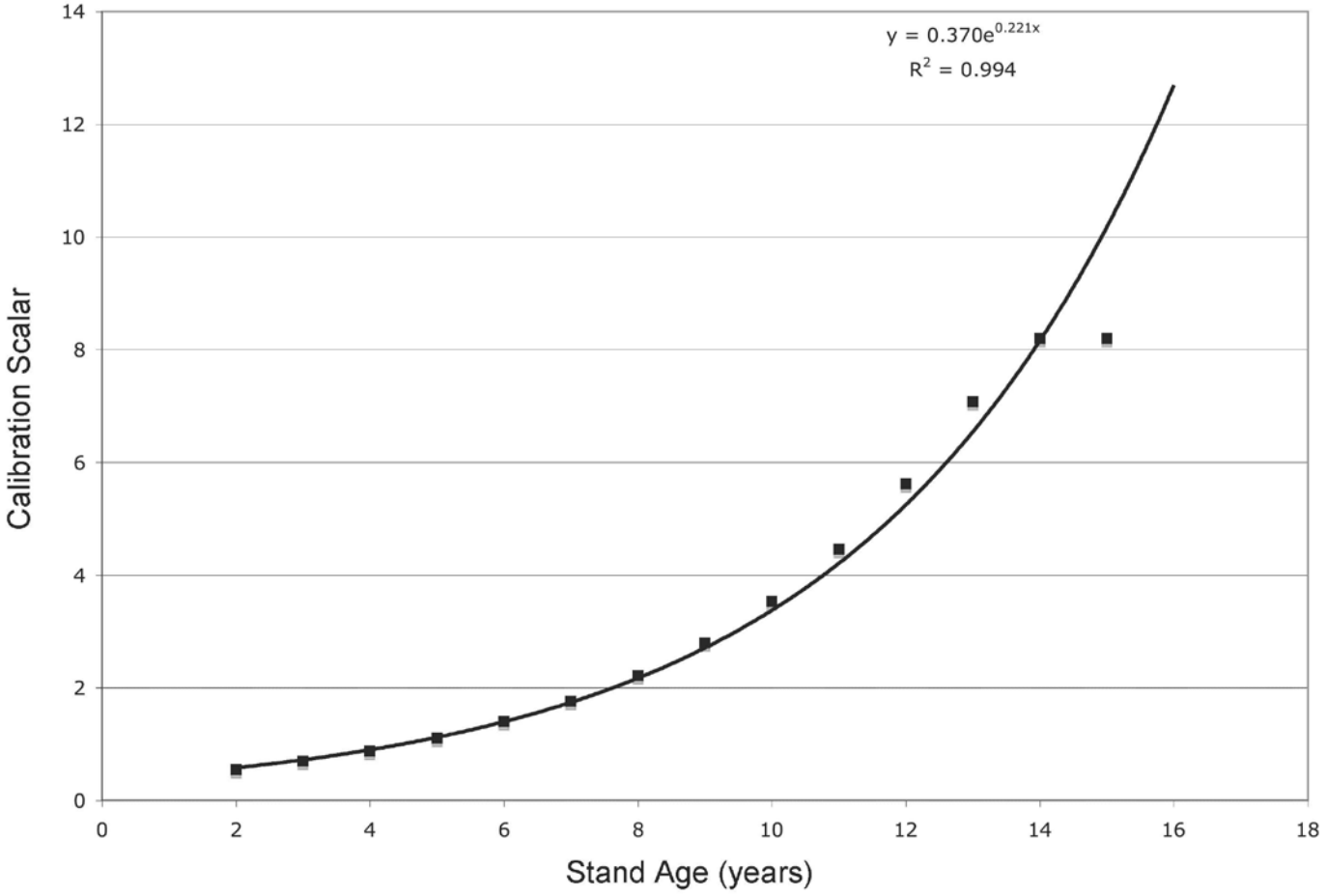
RMSE=0.01

FriPI - Control Plots
(no management intervention)

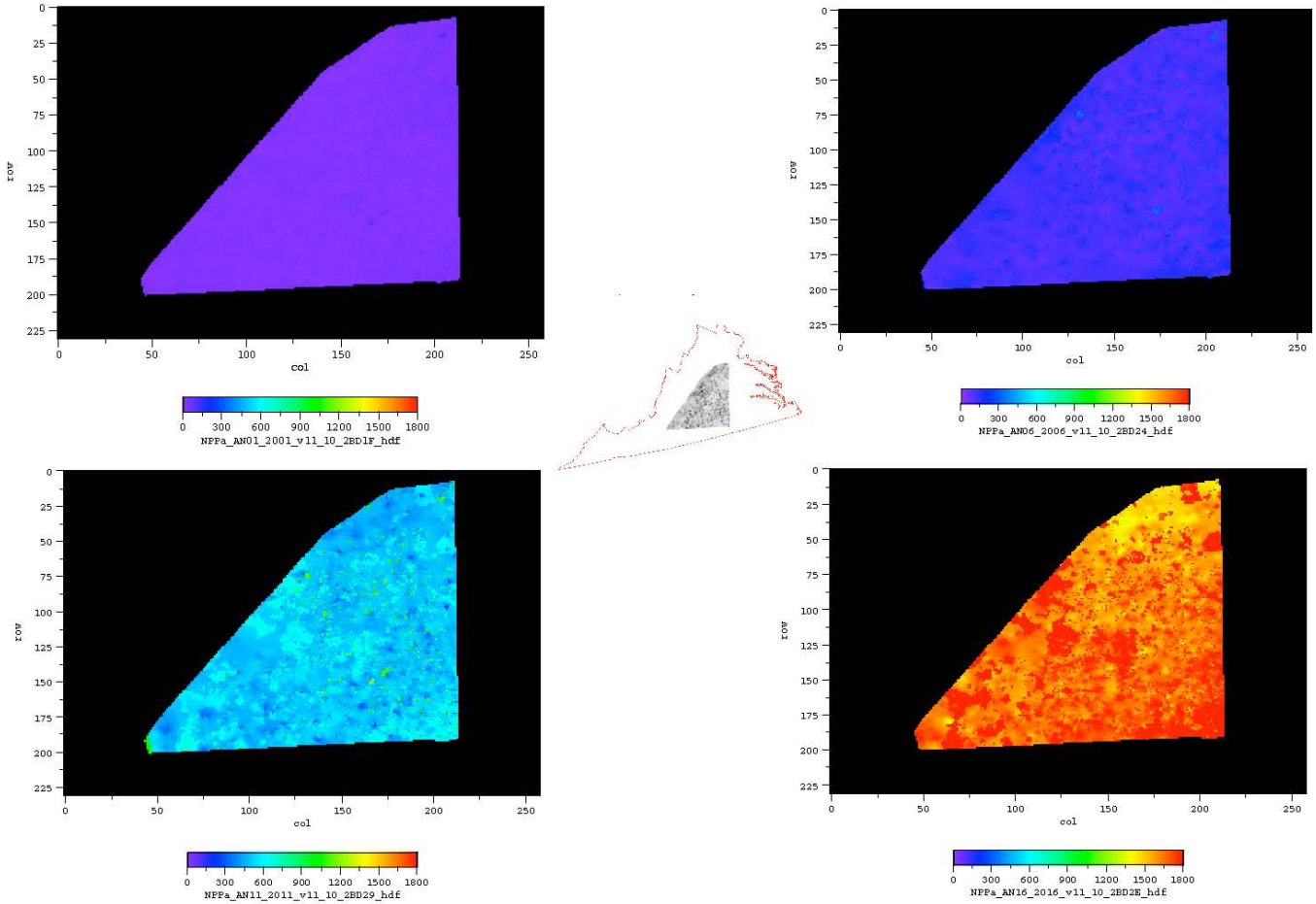


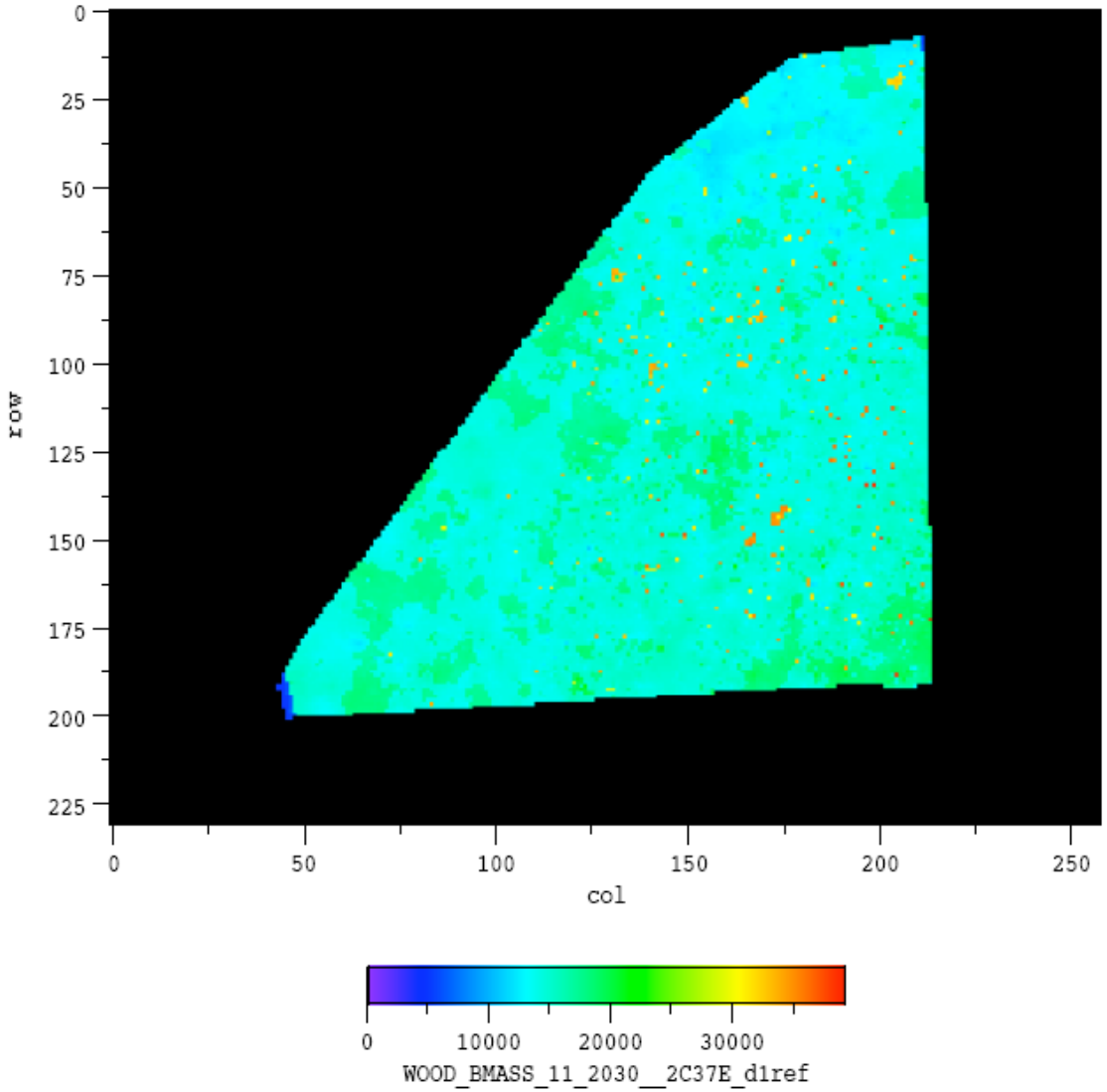

```
Real clay,sand
    Real b0,b1,b2,b3
    Data b0,b1,b2,b3 /0.1844,2.8604,2.114,0.2452/


clay=Clay1/100./DEPTH1
sand=Sand1/100./DEPTH1

    Hydro%SFRi=((b0*(exp(-b1*clay)-exp(-b0*clay))) /
            (b0-b1)  ) * (b2*(1./sand**b3))
```

Optimized calibration curve for NASA-CASA model annual NPP, based on regrowth rates of loblolly pine stands
across all age classes estimated from the IMP Virginia plot data.



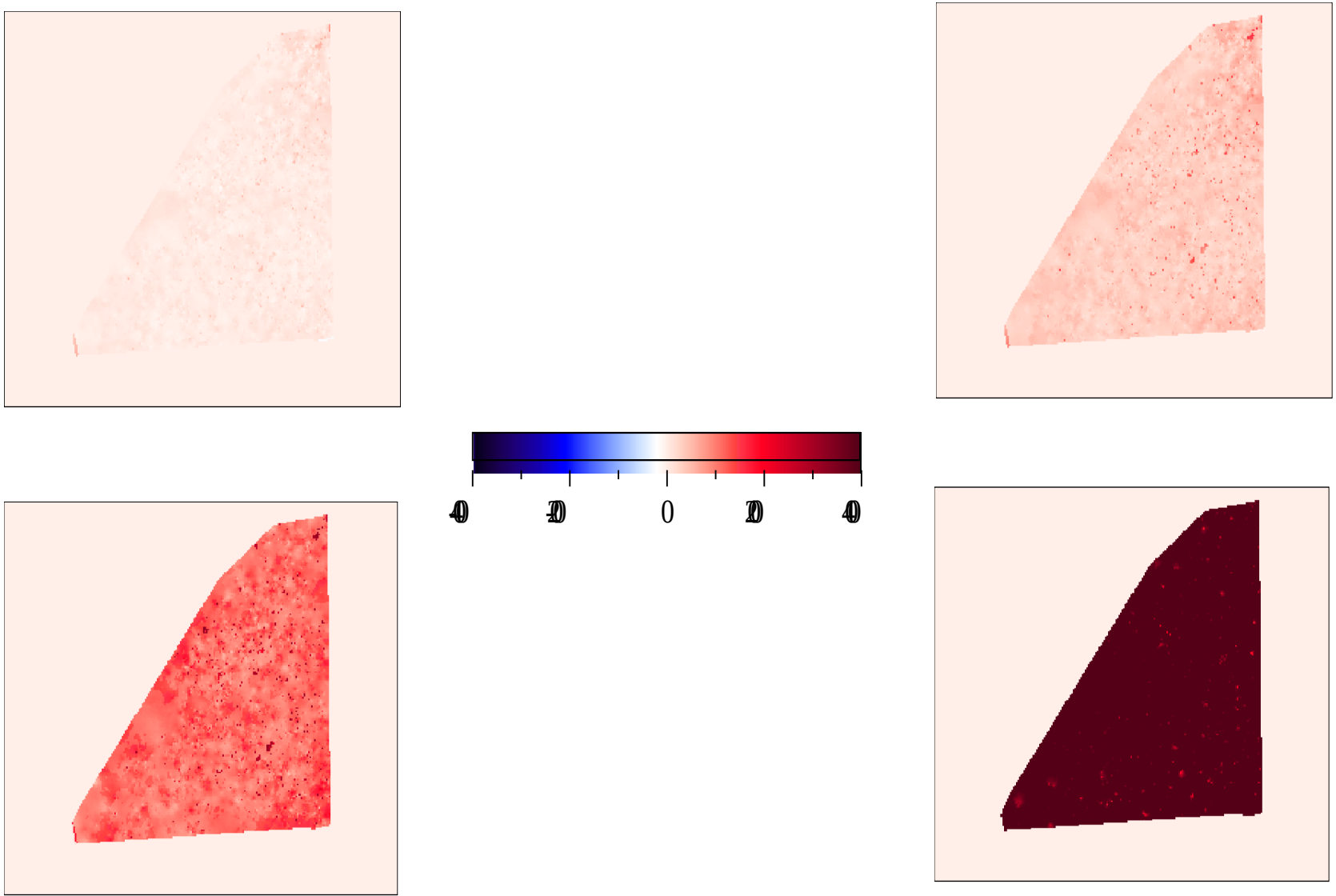
NASA-CASA model annual NPP for loblolly pine stands after 1 year (clockwise, starting from upper left panel), 5 years, 10 years and 15 years of regrowth across the Virginia region. Units are in g C m-2 yr-1






NASA-CASA model standing wood carbon in loblolly pine stands after 30 years of regrowth across the Virginia region. Units are in g C m-2 yr-1

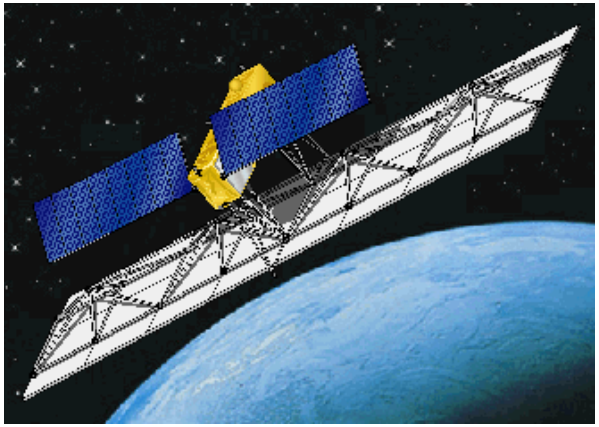
NASA-CASA model annual NEP for loblolly pine stands after 1 year (clockwise, starting from upper left panel), 5 years, 10 years and 15 years of regrowth across the Virginia region. Units are in g C $m^{-2}$ $yr^{-1}$



# Ecosystem Services

- Resources and processes supplied by natural ecosystems
- Include, but not limited to, water quality, biodiversity, carbon sequestration

# Summary

- Landsat now an essential tool for forest management – much more than just biomass/inventory
- Analysis of data through time – including interannual chronosequences – is now increasingly routine
- Landsat data can improve the precision and spatial specificity of models of net ecosystem production/exchange
- Web-based delivery of state-of-the-art decision support tools based on Landsat data now feasible

# Thanks!