

*Land-use change and terrestrial carbon storage  
in Western North Carolina, 1850-2030*

Ryan Kirk  
PhD Candidate

# Overview

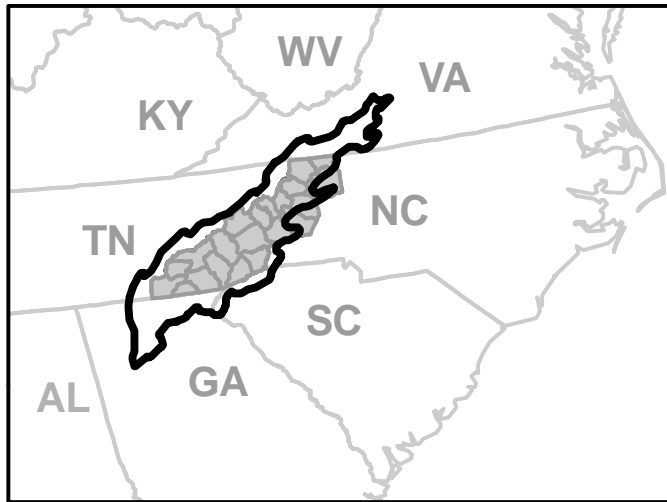
## Rationale:

- \* LUCC considered a major driver of global C budget
- \* Relative magnitude of LUCC influence on C uncertain
- \* LUCC history rarely known at landscape scale

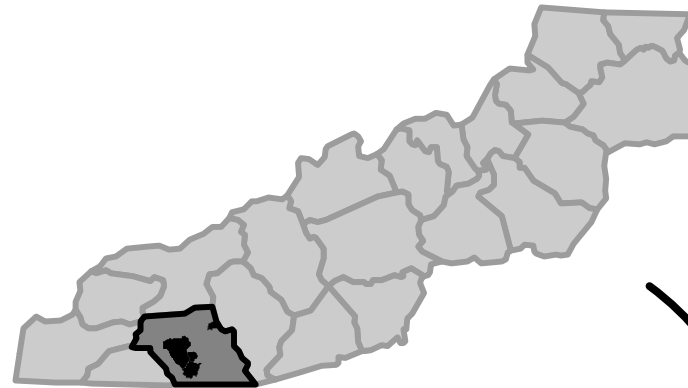
## Objectives:

- 1) Summarize narrative history of land use in the region
- 2) Quantify land use trajectories and rates of change
- 3) Reconstruct major land cover at decadal scale
- 4) Model C budget based on LUCC reconstruction

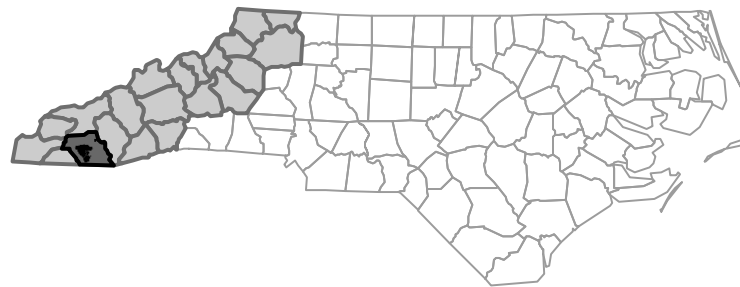
# Nested study areas



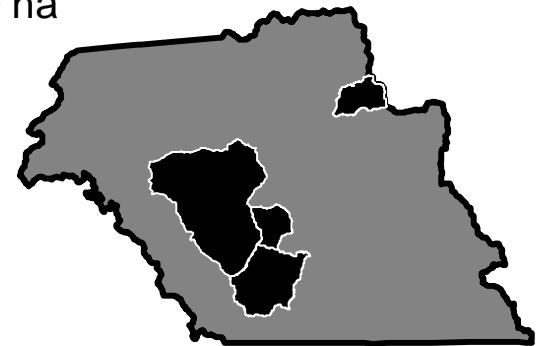
Southern Blue Ridge Province  
(Black Outline)



Meso-Scale (Dark Gray)  
Macon County, NC  
150,000 ha



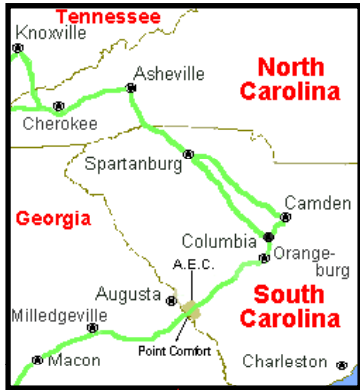
Macro-Scale (Light Gray)  
21 County Area, NC  
23,750 km<sup>2</sup>



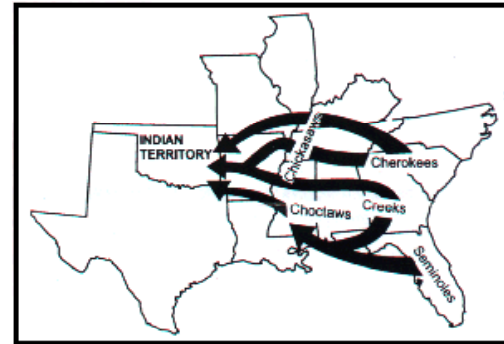
Micro-Scale (Black)  
4 Watersheds  
1000 - 15,000 ha

# Western North Carolina History

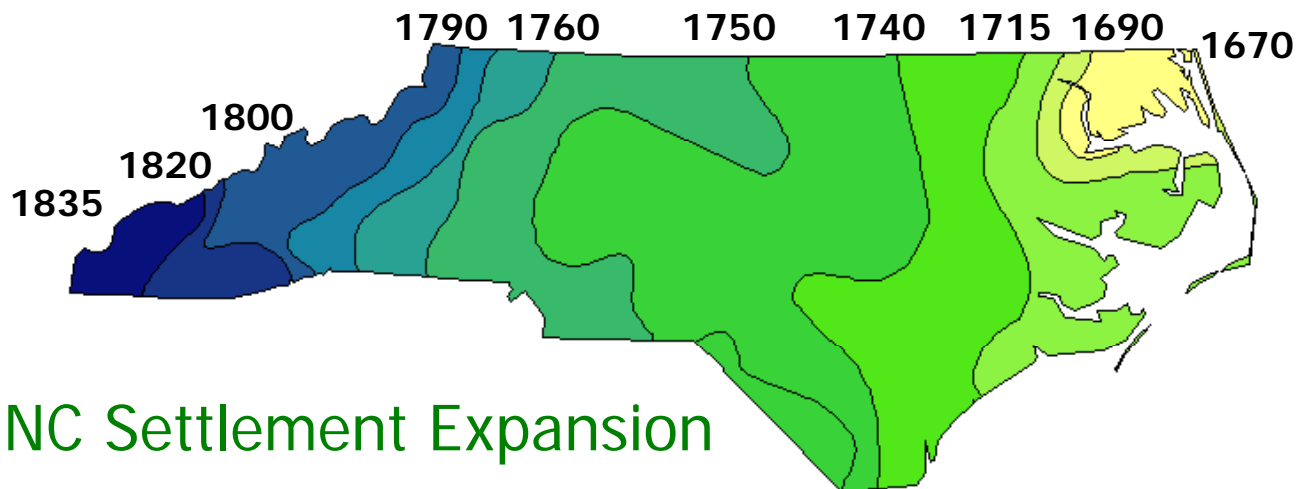
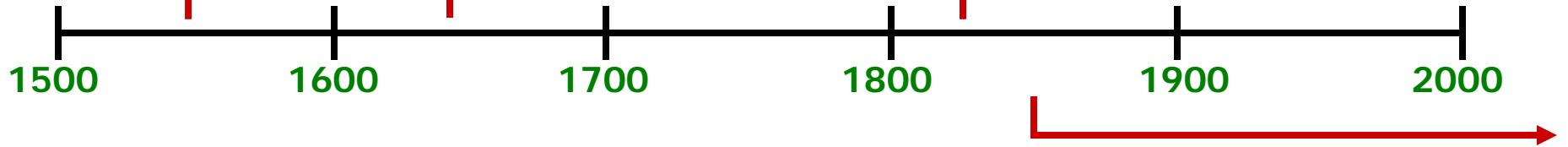
De Soto search for gold



"Trail of Tears" – Cherokee removal

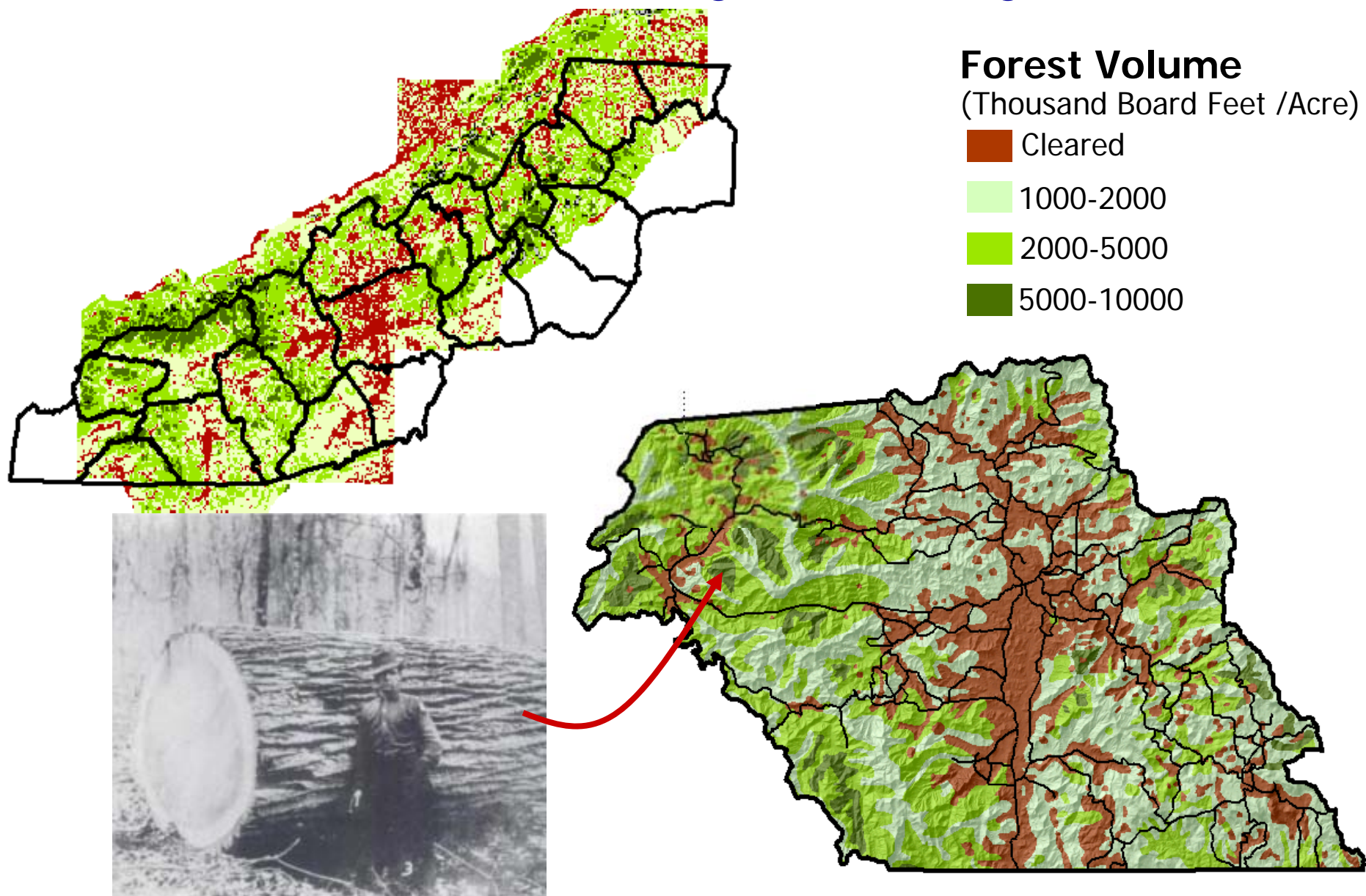


European Traders Established



NC Settlement Expansion

# 1904 Ashe/Ayers Survey



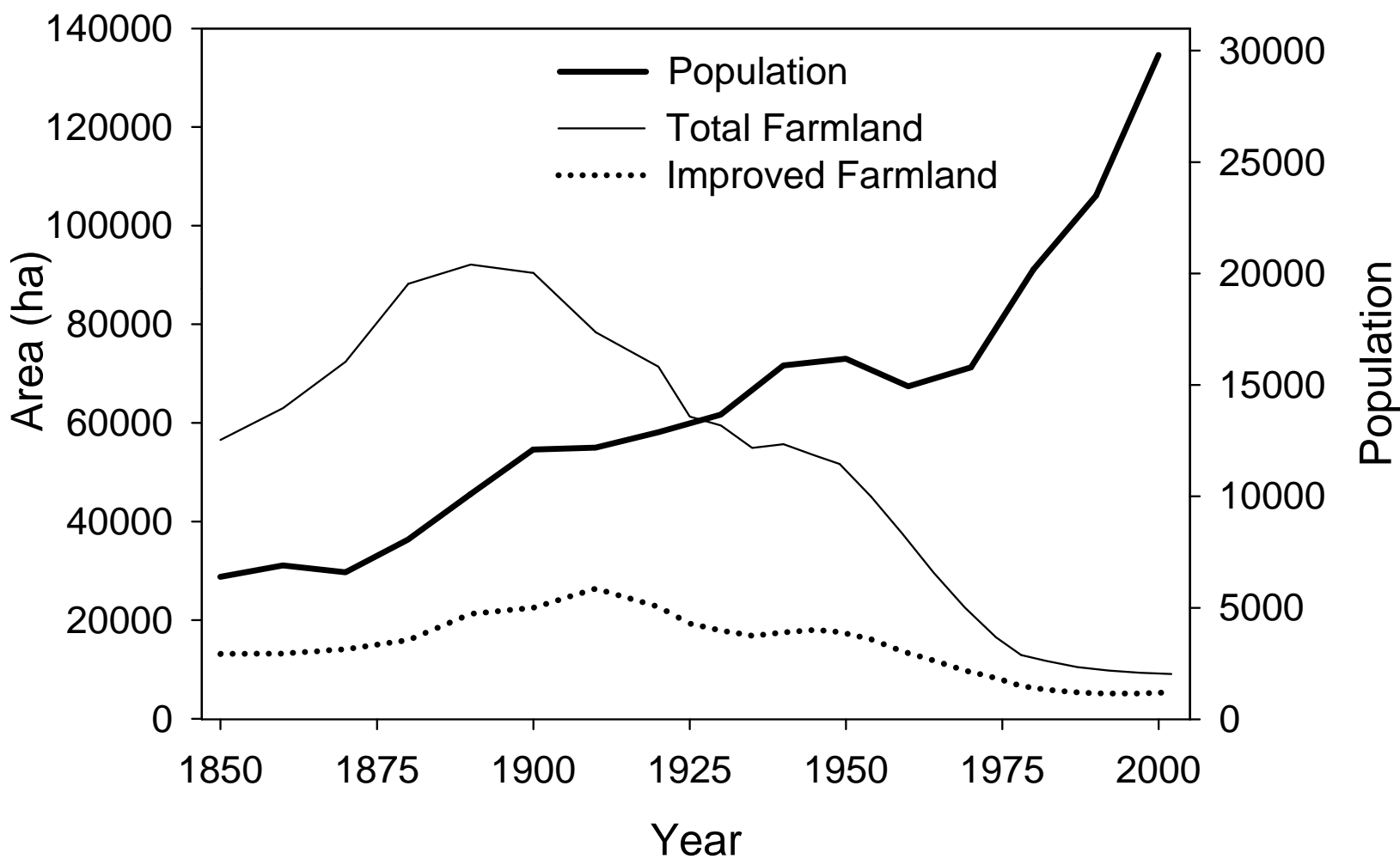
# Macon County Today



# Dissertation Chapters

- 1) Land use history, rates of change, and trajectories in Macon County, 1850-2030
- 2) Development trends in Macon County, 1900-2030
- 3) Decadal reconstruction of major land uses in the region, 1850-2000
- 4) Land-use change effects on aboveground woody biomass

# Census Data Collection





# Ch 1 Geospatial Database development

Buildings

Roads

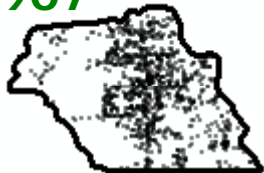
Land  
Cover

Terrain Variables

1865



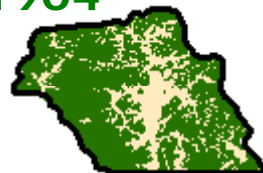
1907



1907



1904



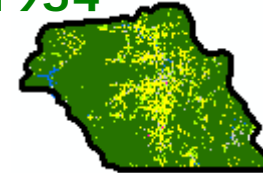
1929



1929



1954



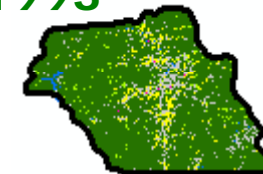
1954



1954



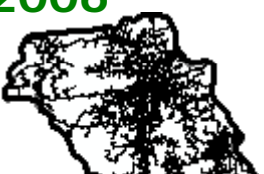
1993



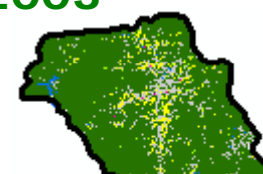
2006



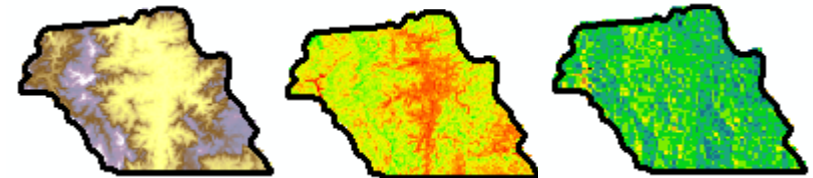
2006



2003



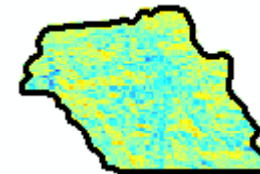
Elevation, Slope, Aspect



Terrain Shape (Cove → Ridge)



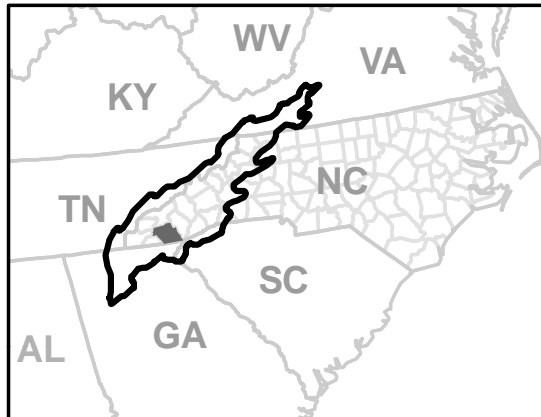
Relative Moisture Index



Eroded Soils, 1944

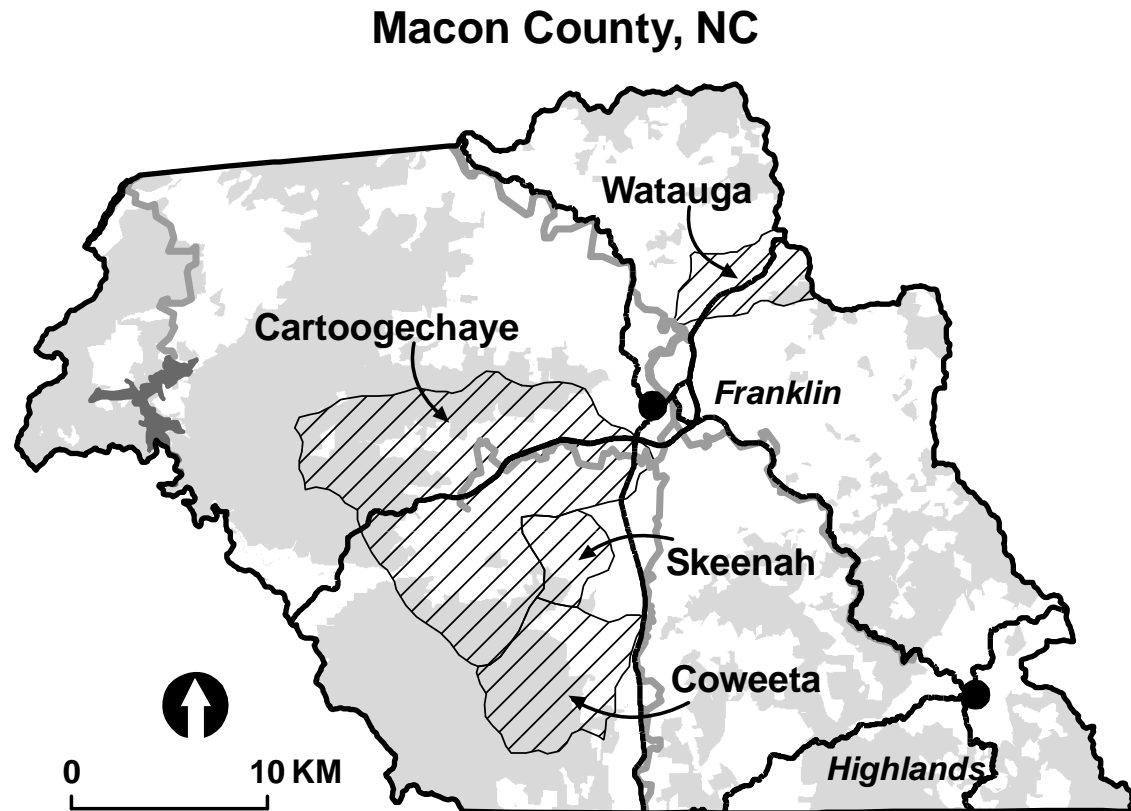


# Primary Watersheds

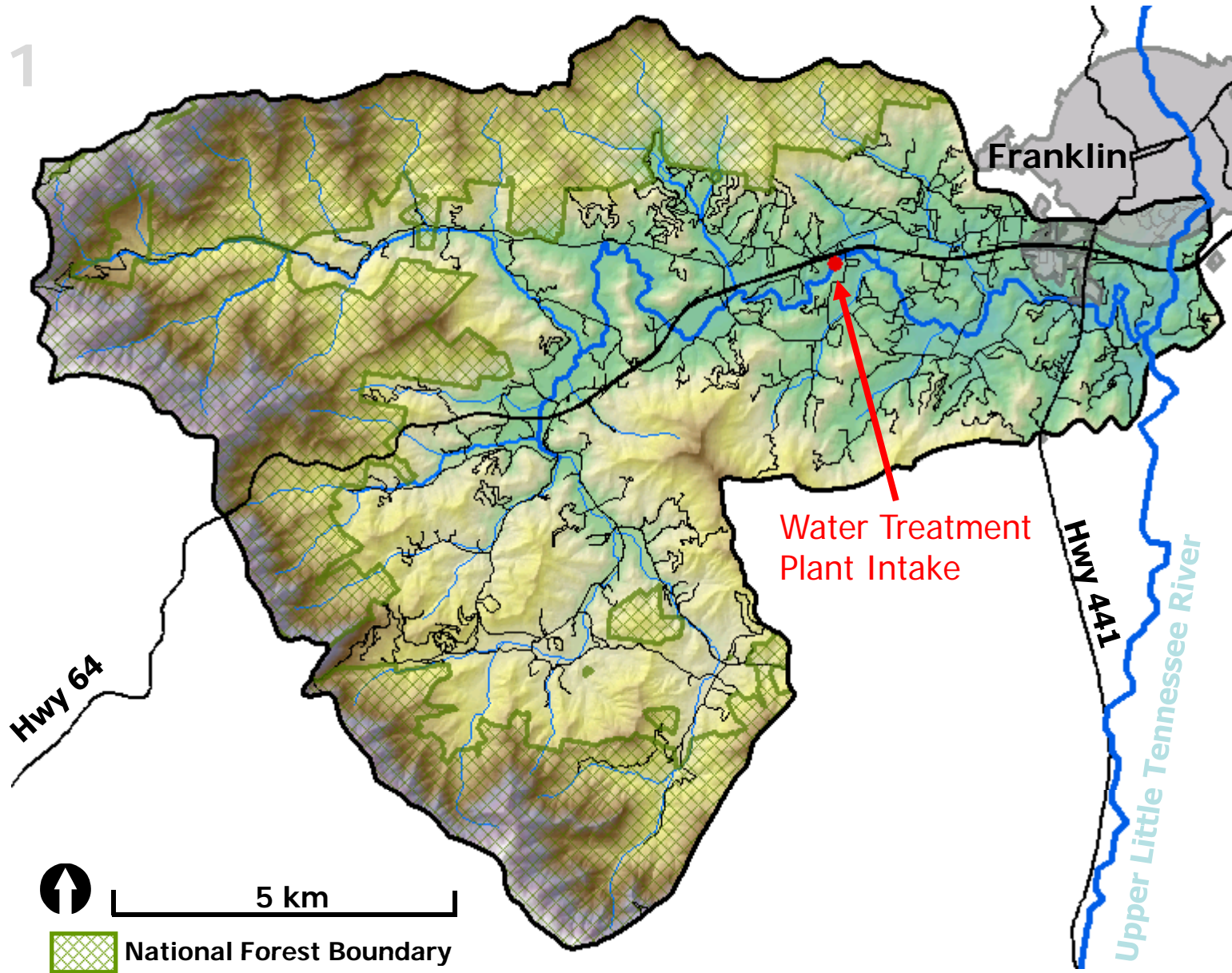


Southern Blue Ridge Province  
(Black Outline)

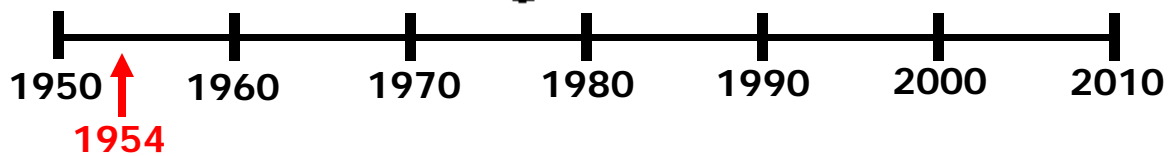
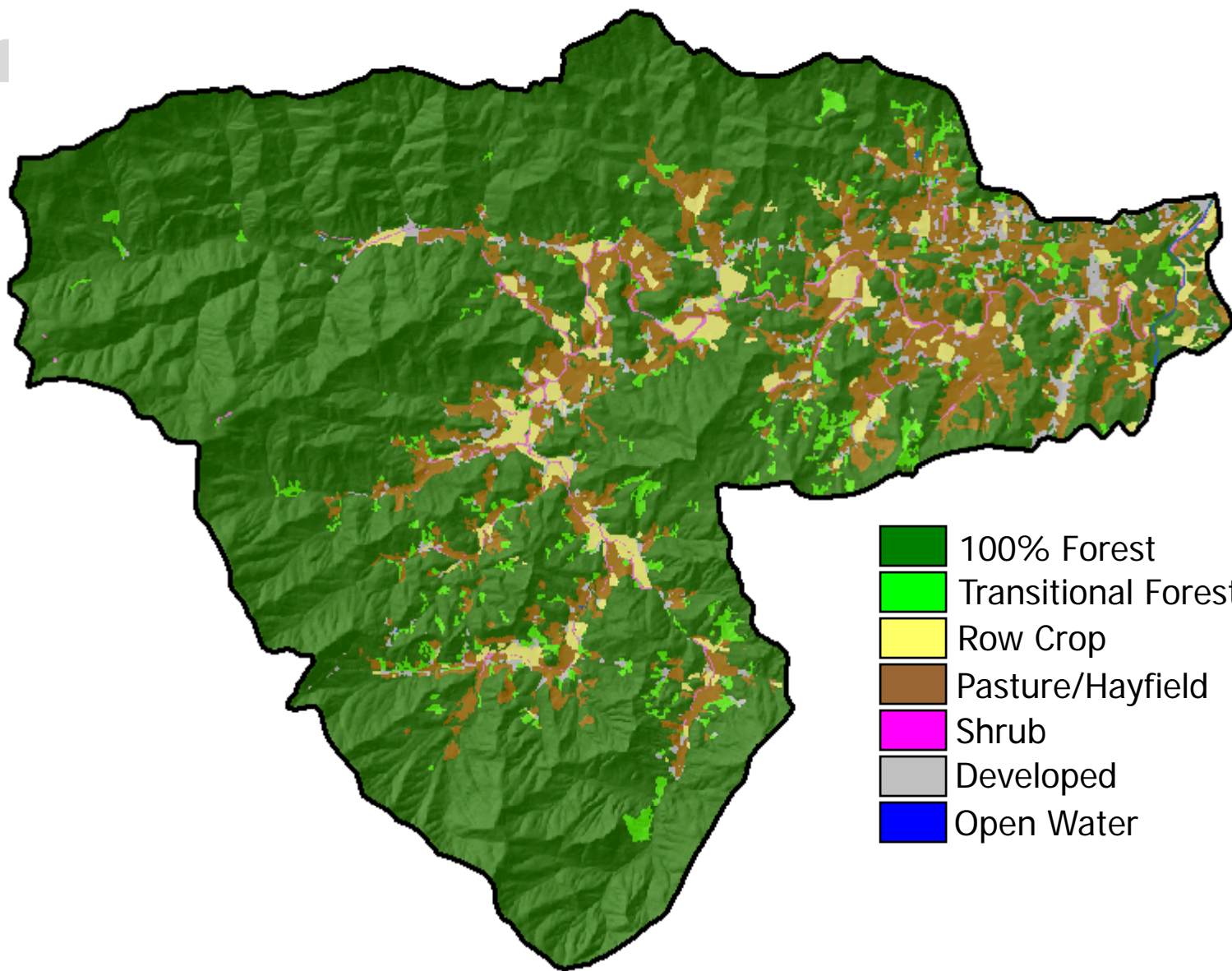
- Cities
- Primary Highways
- Rivers
- Lake Nantahala
- ▨ Study Watersheds
- Public Land



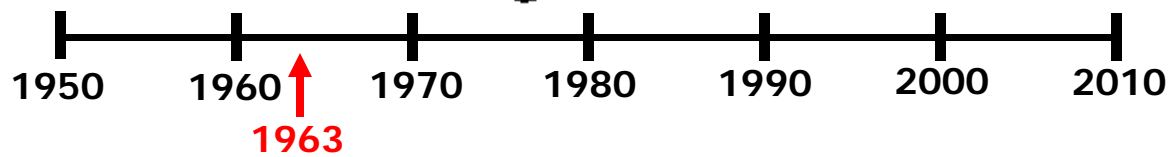
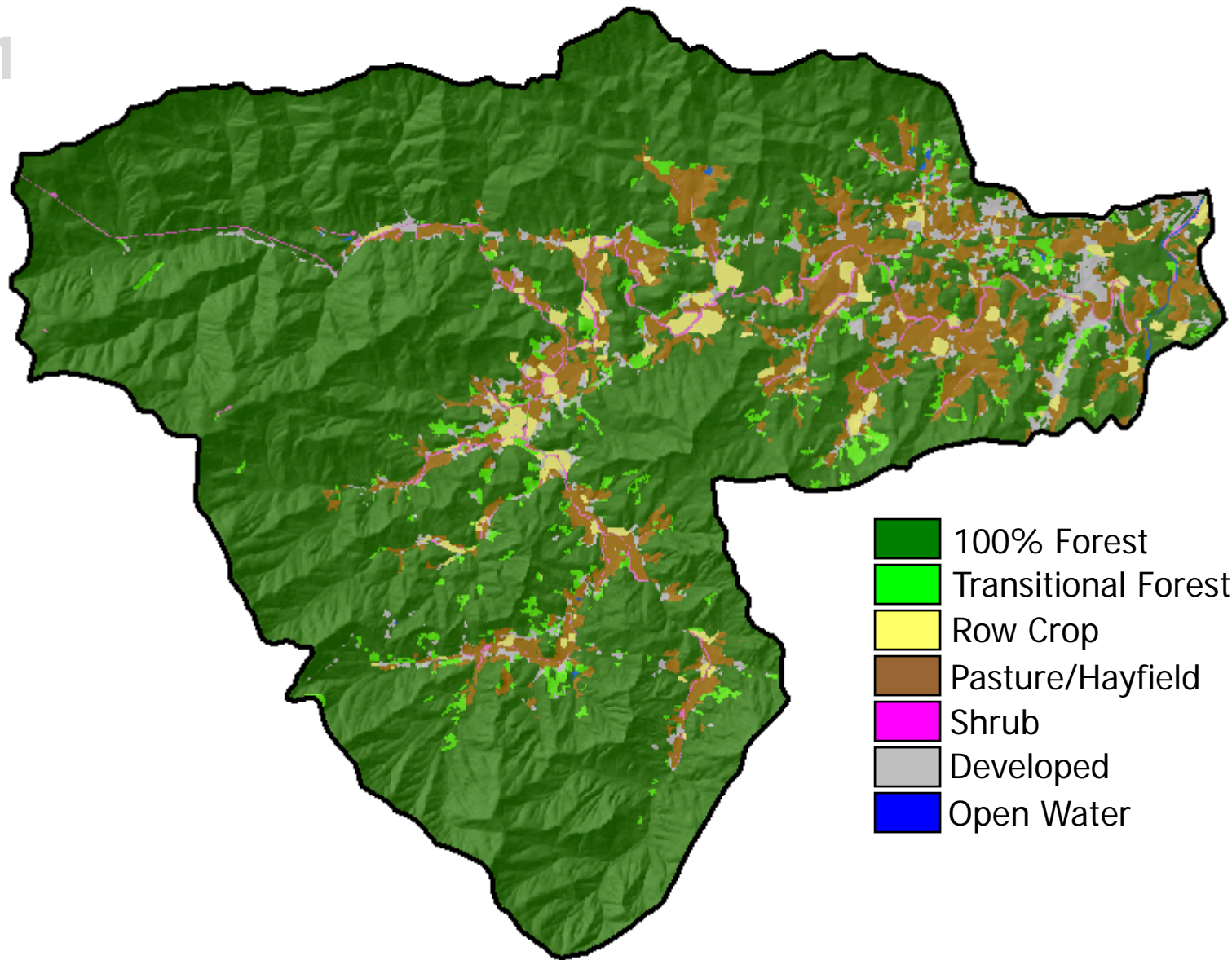
# Ch 1



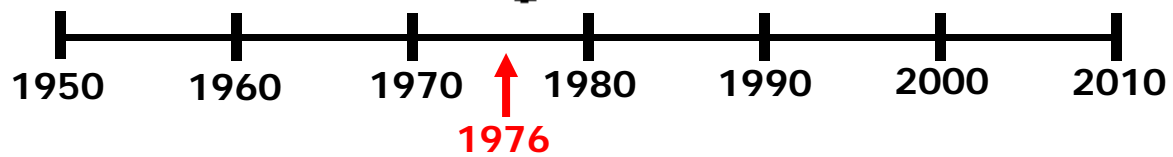
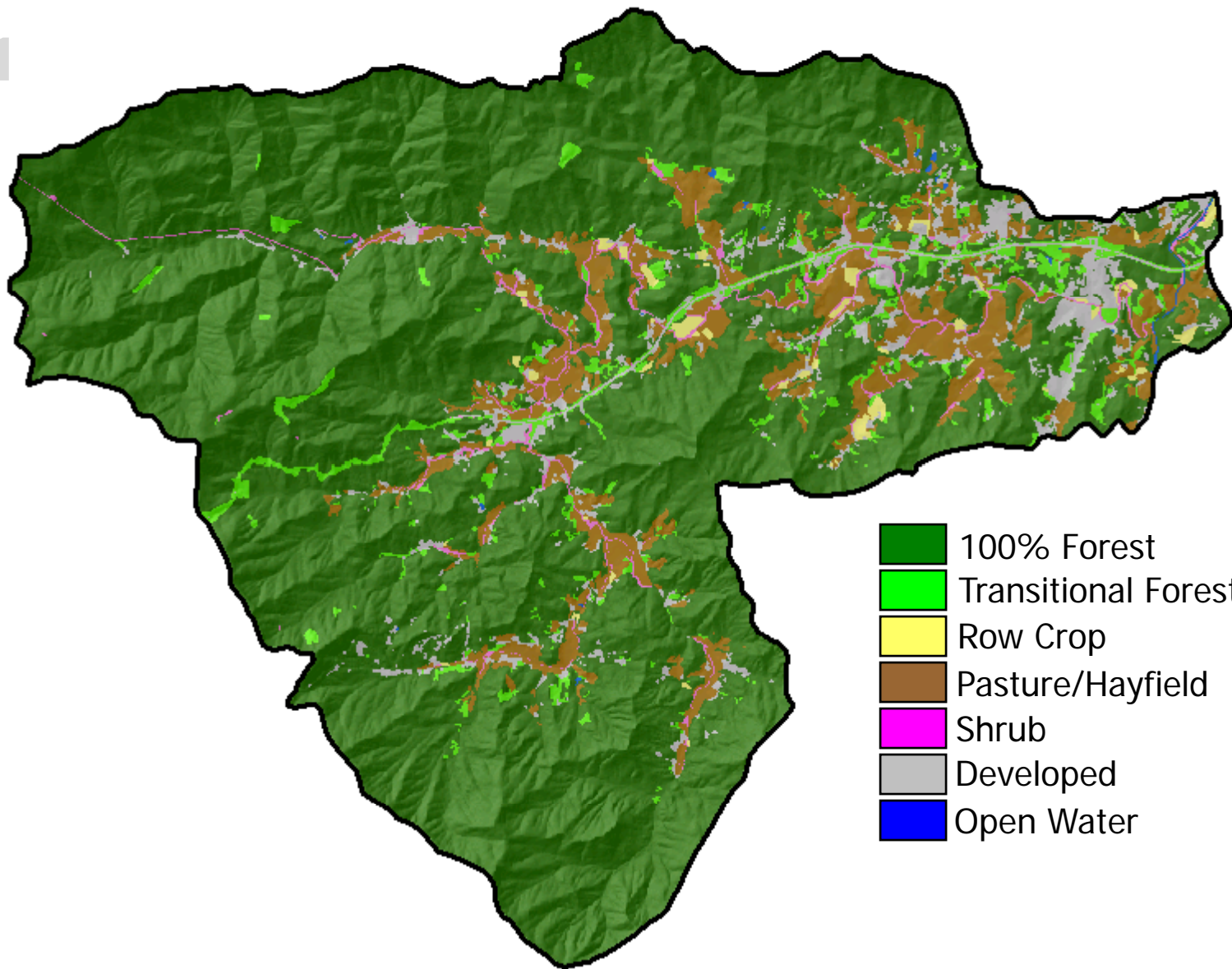
# Ch 1



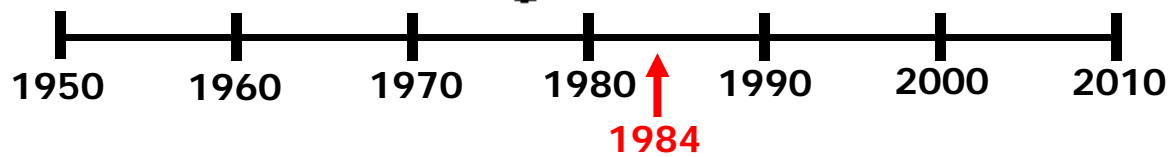
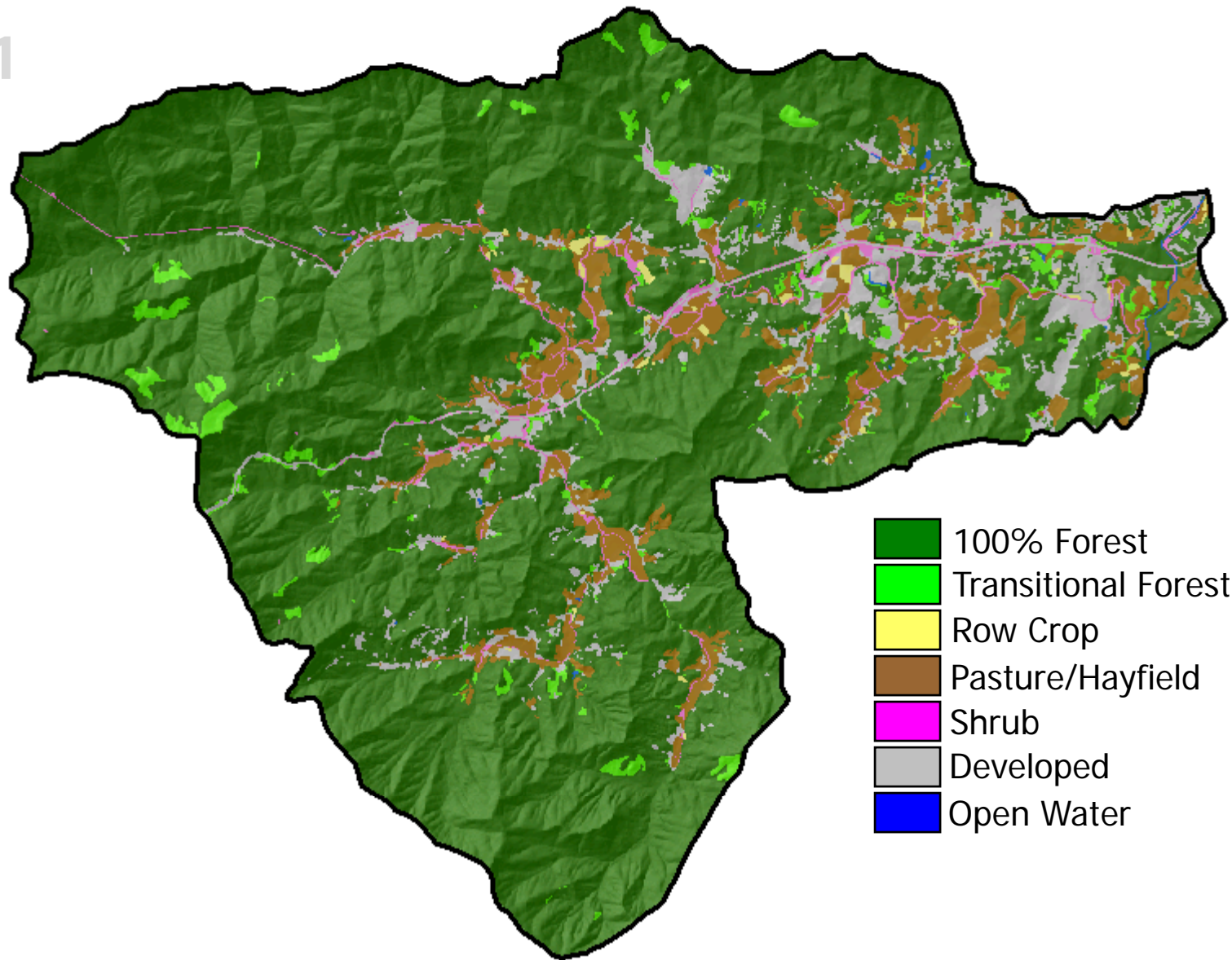
# Ch 1



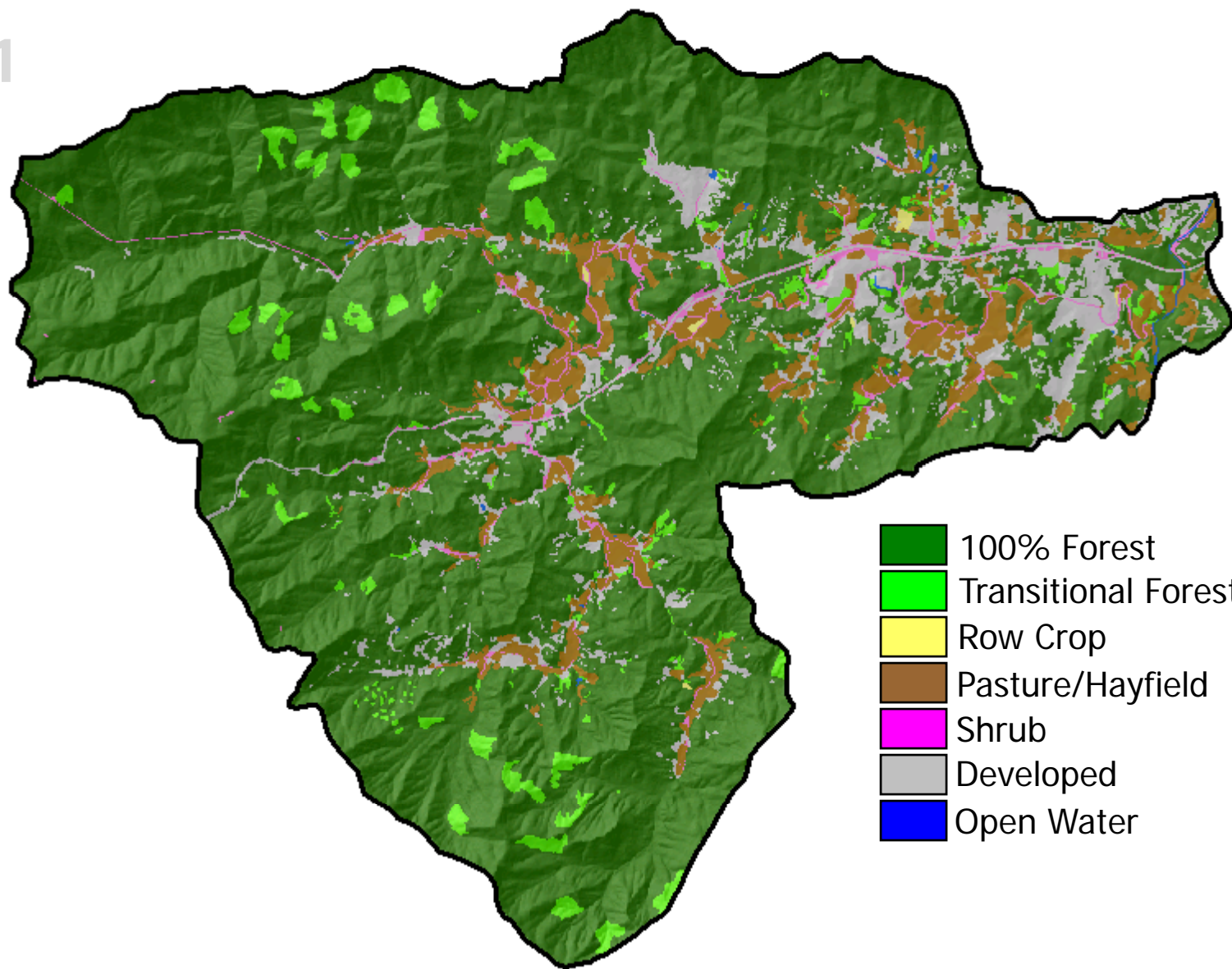
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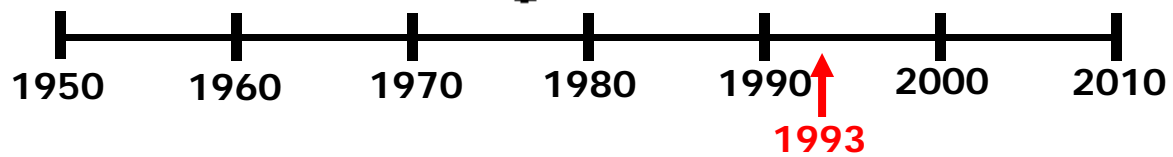
# Ch 1



# Ch 1

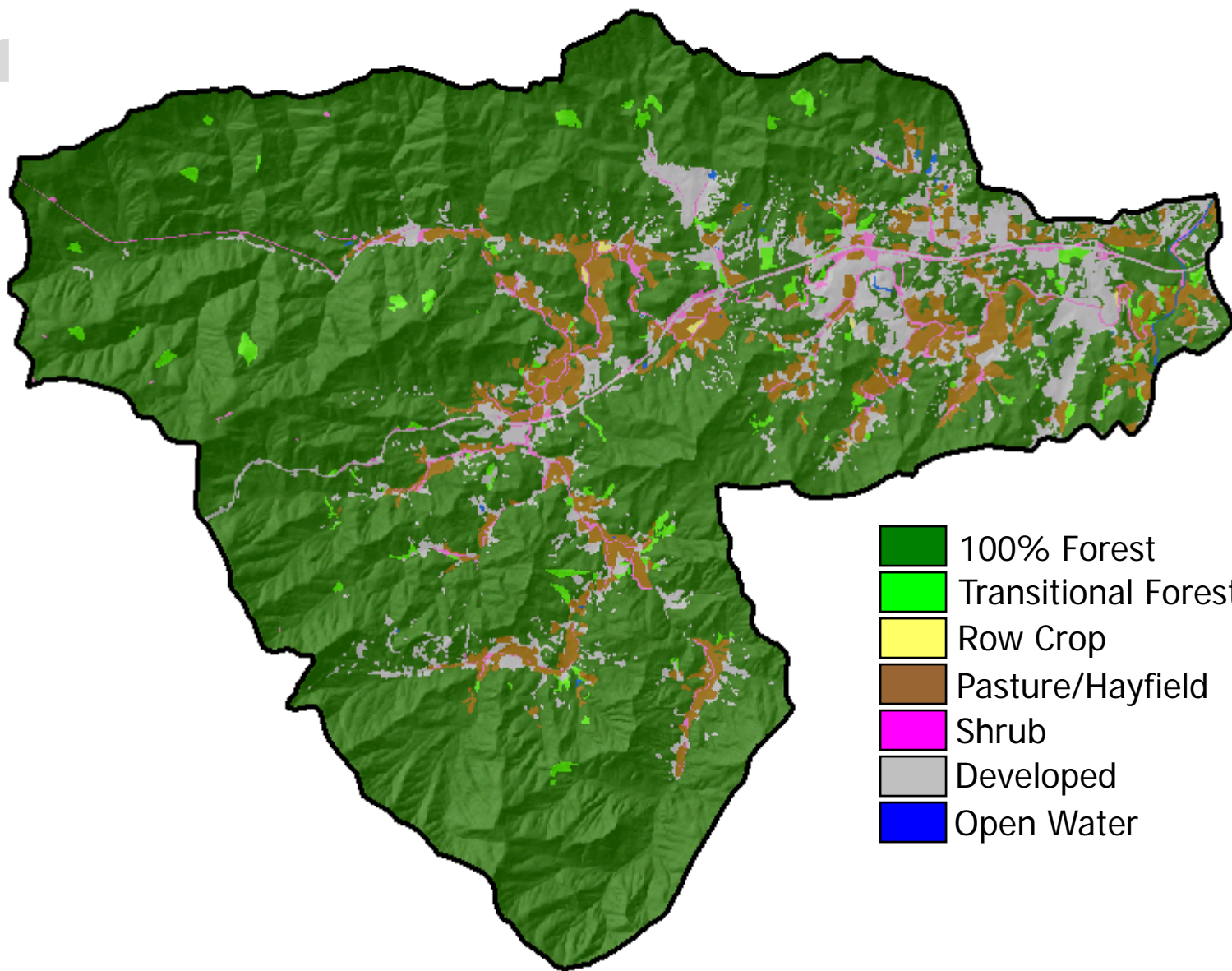


- 100% Forest
- Transitional Forest
- Row Crop
- Pasture/Hayfield
- Shrub
- Developed
- Open Water

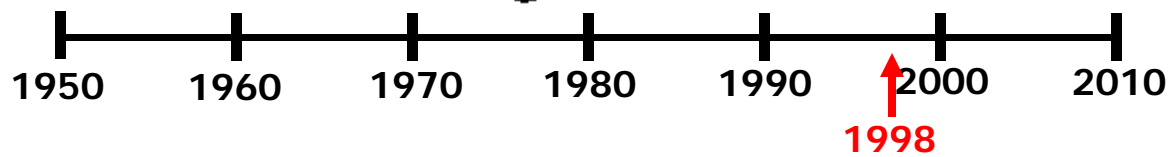




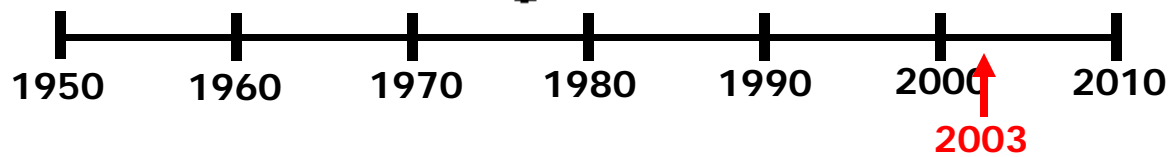
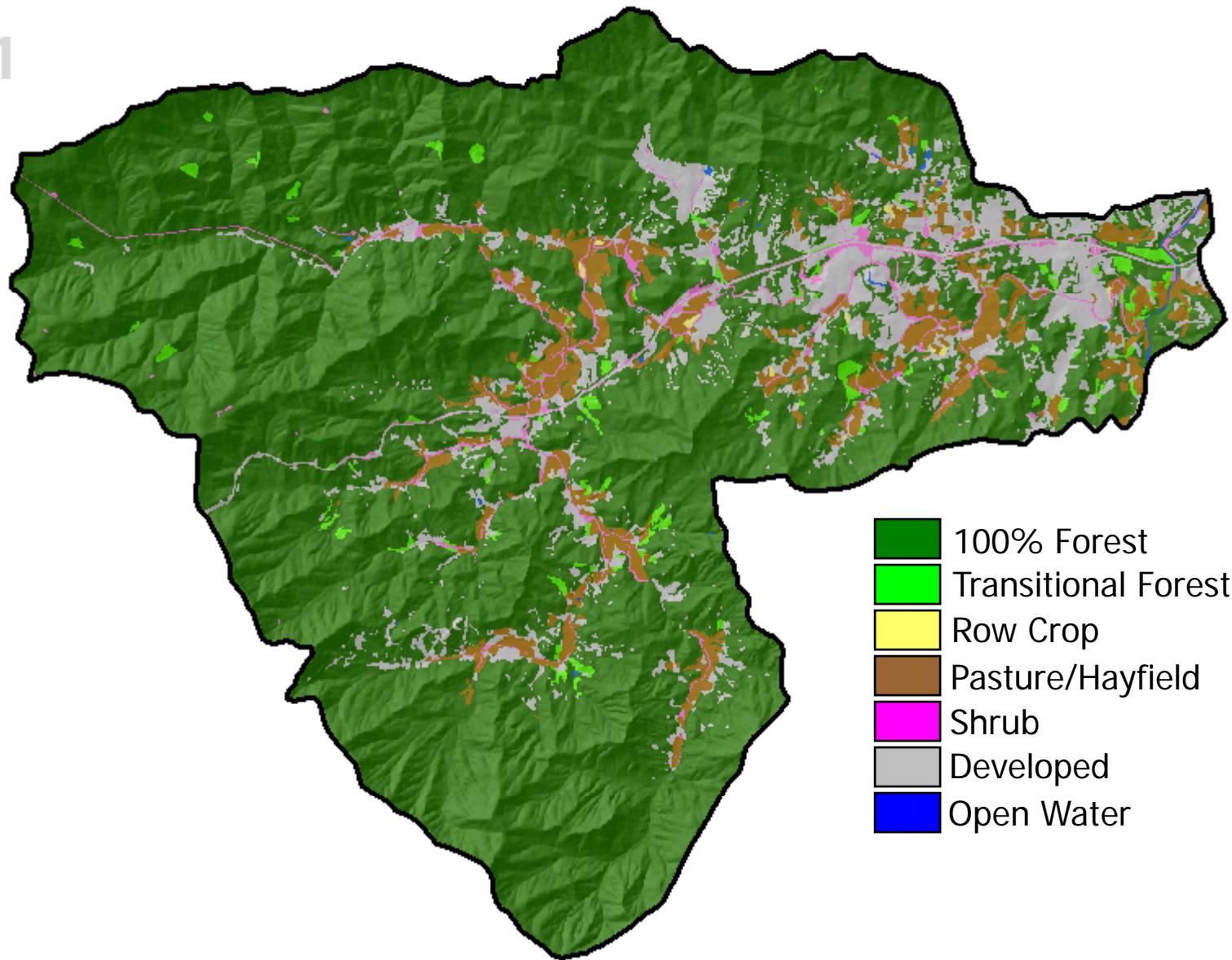
# Ch 1



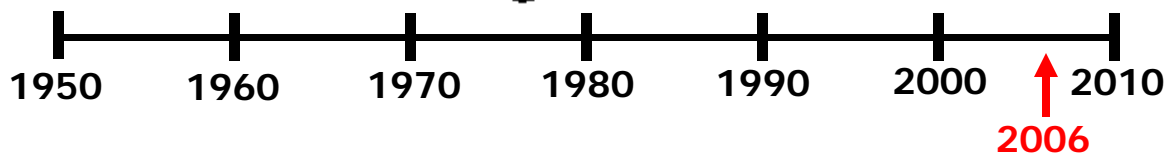
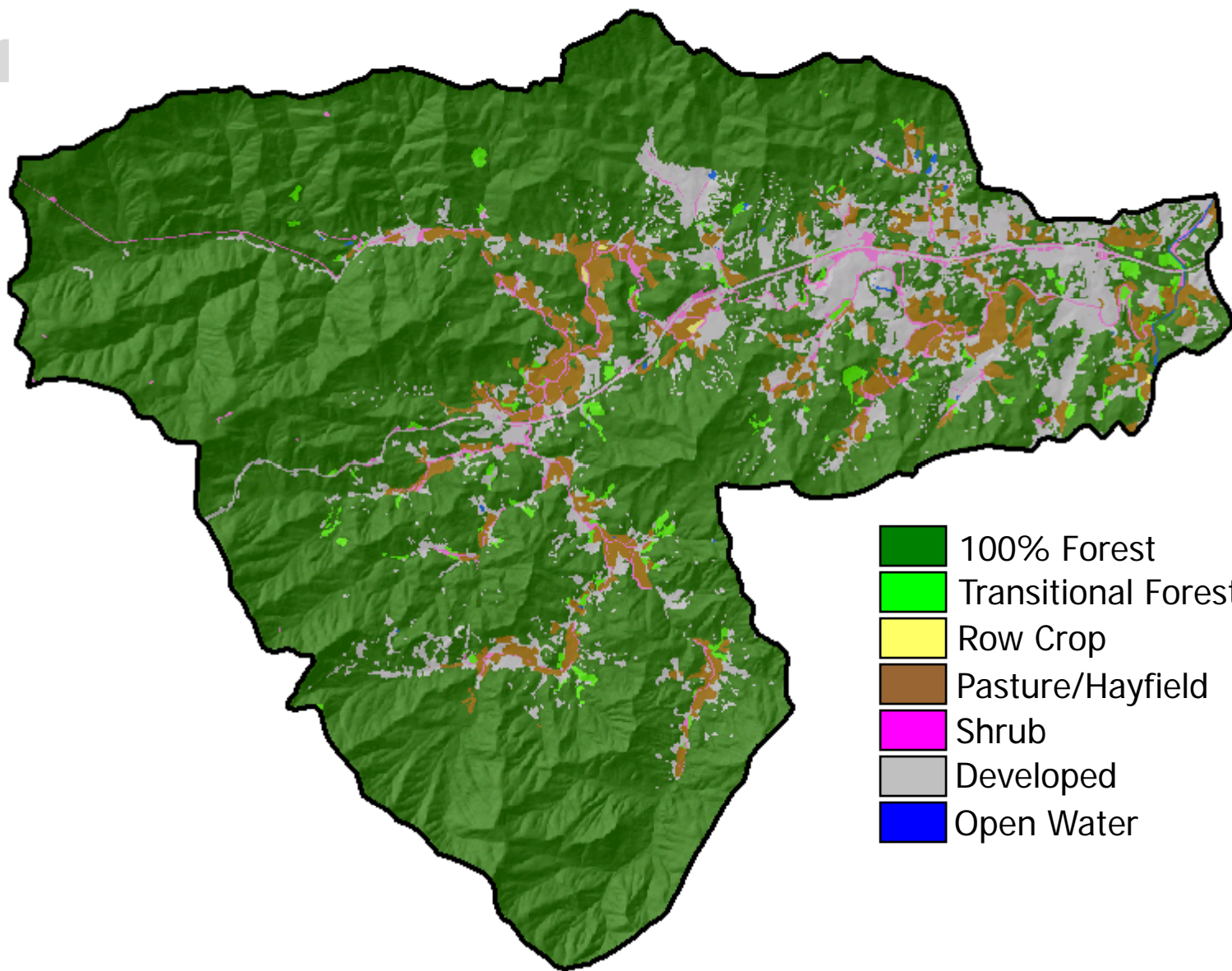
- 100% Forest
- Transitional Forest
- Row Crop
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# Ch 1



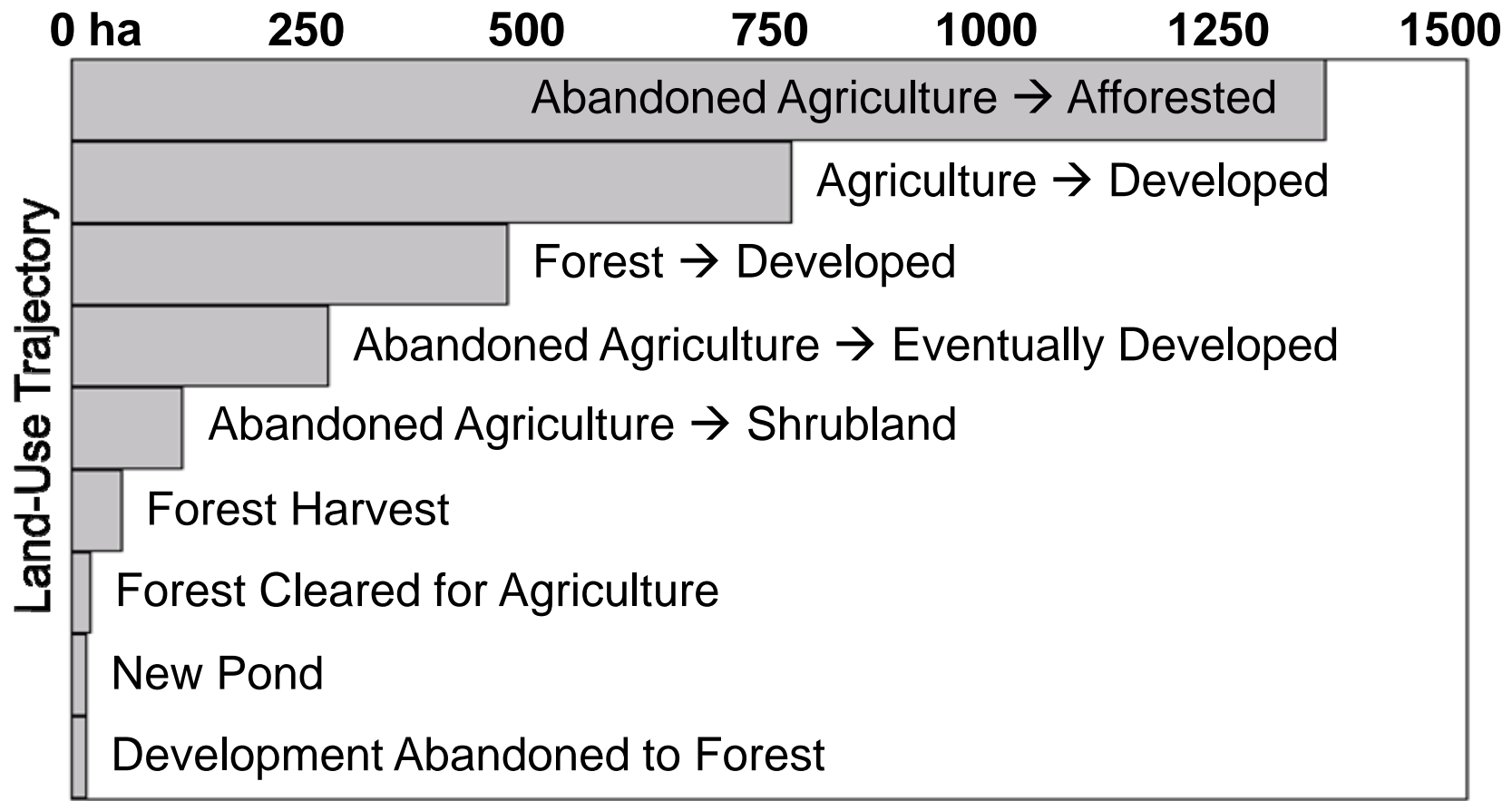
# Ch 1



# Ch 1

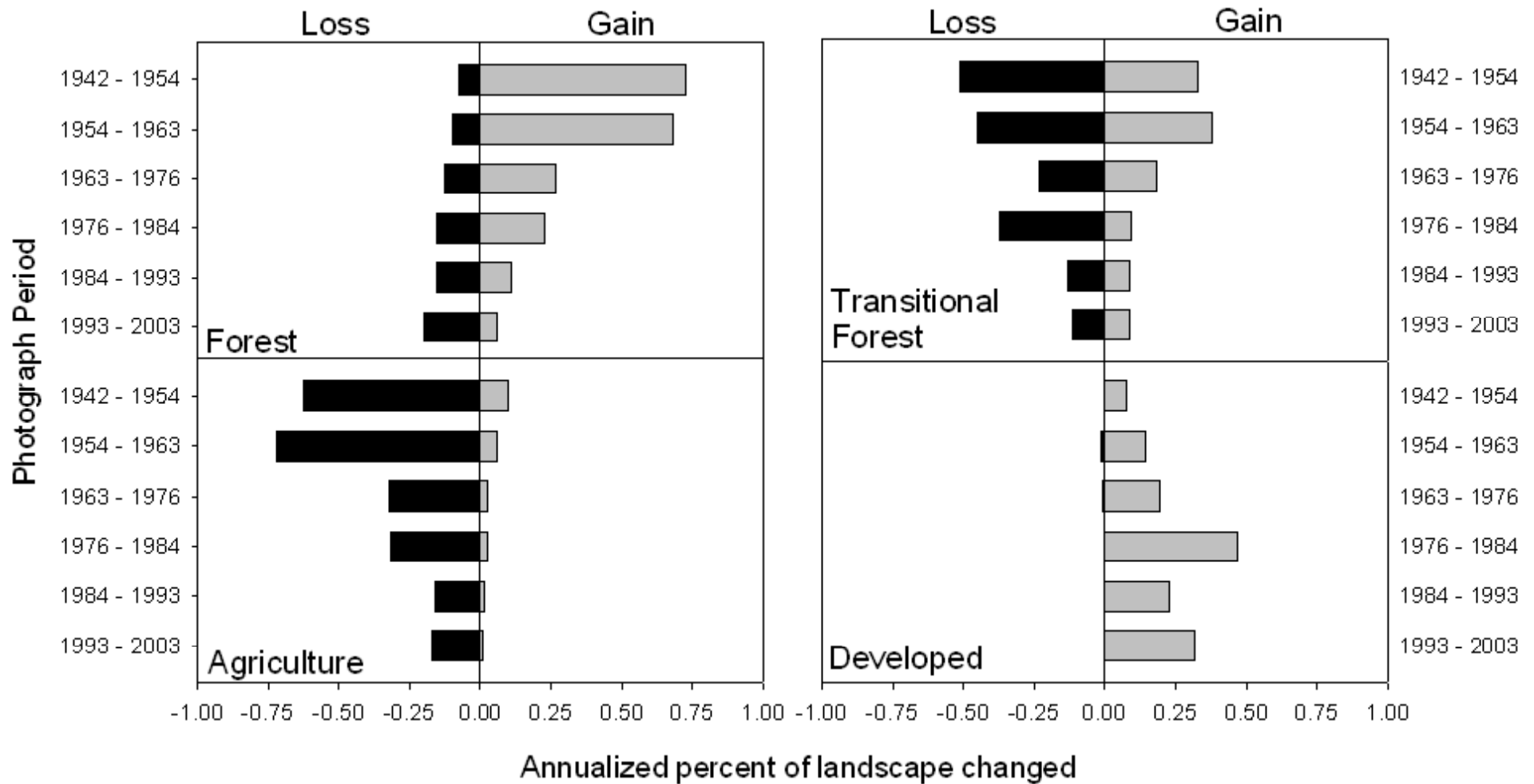
## Land Use Trajectories, 1954-2006

25% of 13,000 ha changed land use:



# Ch 1

# Rates of Change



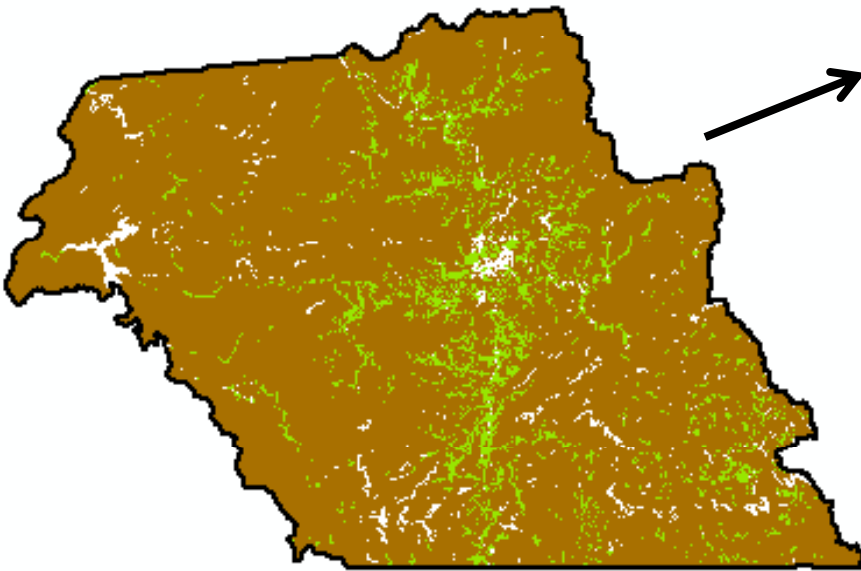
# Scaling up to the county

**Reconstruct decadal land cover using a hierarchical decision-rule model:**

- 1) Use spatial data sets where available
- 2) For remaining dates
  - a) identify quantity of change from census data
  - b) identify location of change using hierarchical approach
    - i) Use simple logic rules where defensible
    - ii) Use probability models in all other instances

# Ch 1 Probability model for agriculture

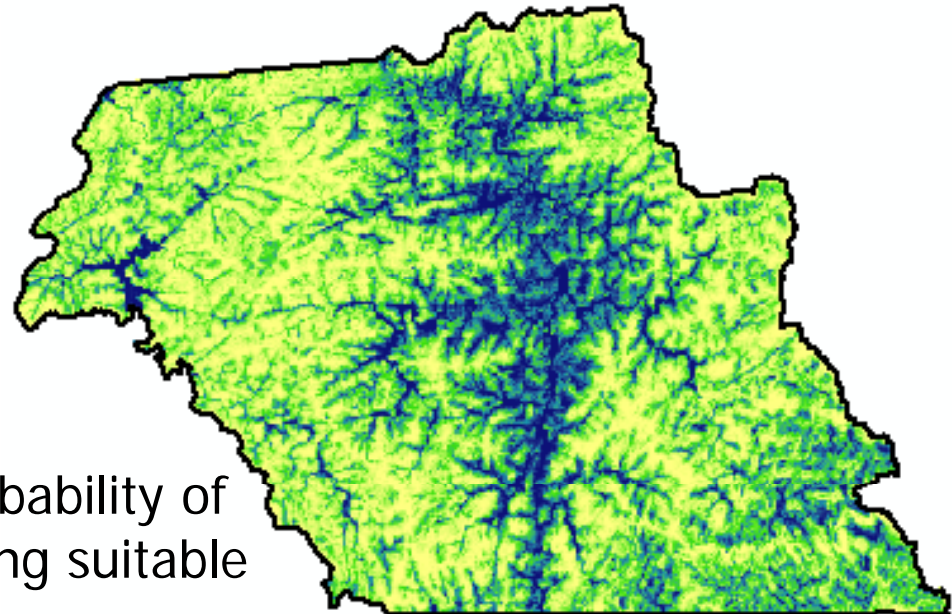
SSURGO Land Capability Class





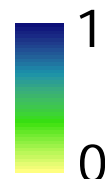
Multiple Logistic Regression Model

$$P_{suitable} = f(\text{Elev, Slope, TRMI, D2STRM})$$

Agriculture Suitability Index



 Suitable  
 Not Suitable

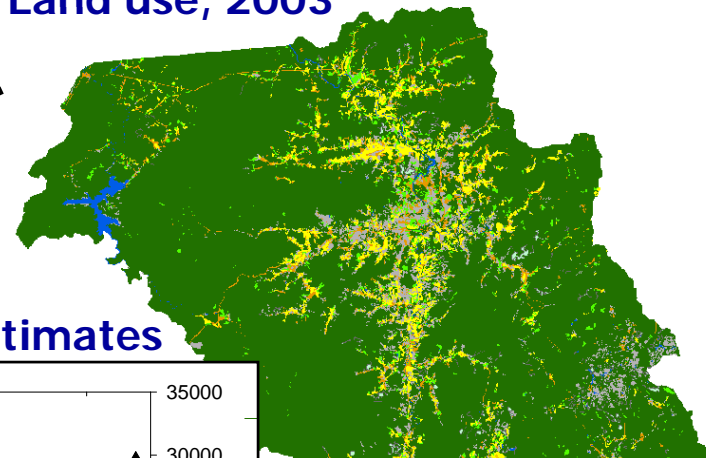
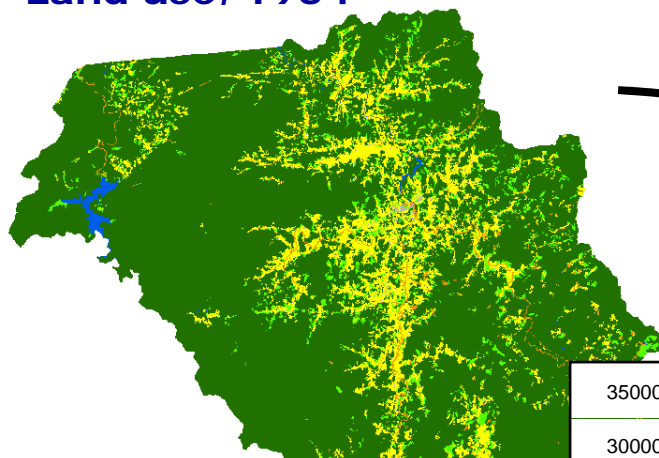
 1  
Probability of  
Being suitable  
0

# Ch 1

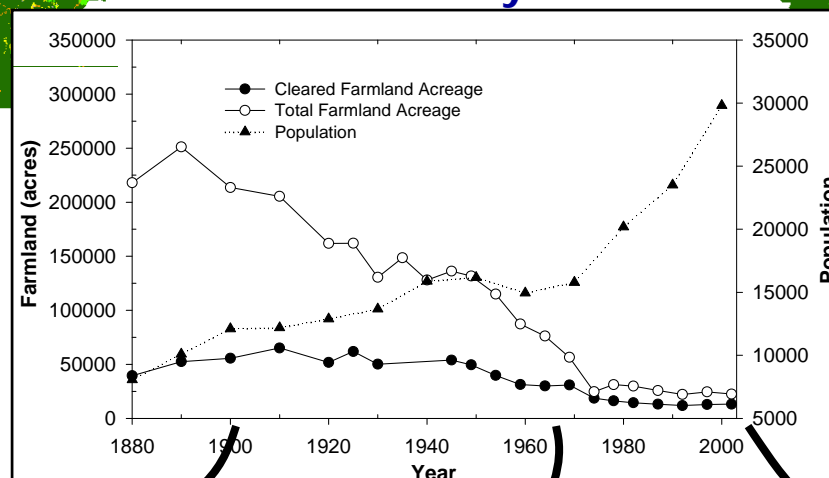
# Spatial-Temporal Land use Model

Land use, 1954

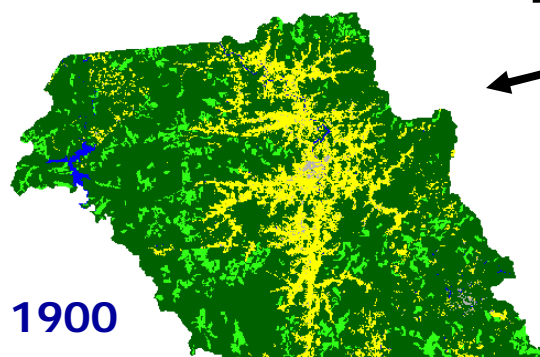
Land use, 2003



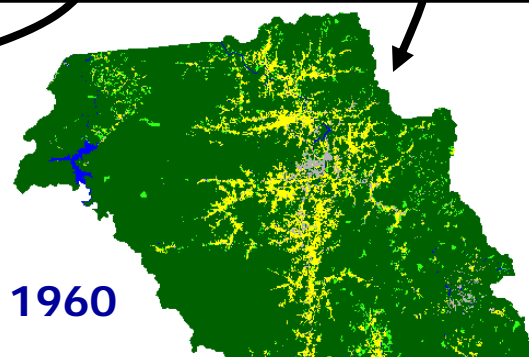
Census / Inventory Estimates



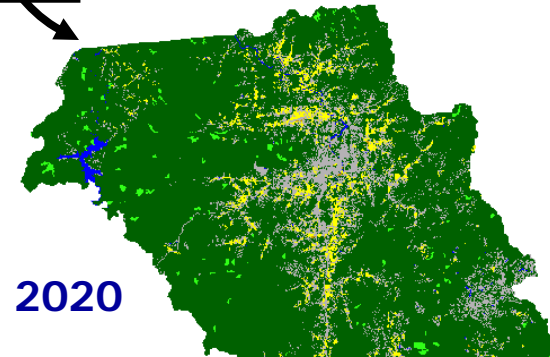
Forecast based on population growth projections and 1990 - 2002 harvest rates



1900



1960



2020



# Ch 1

## Model Validation

### Method:

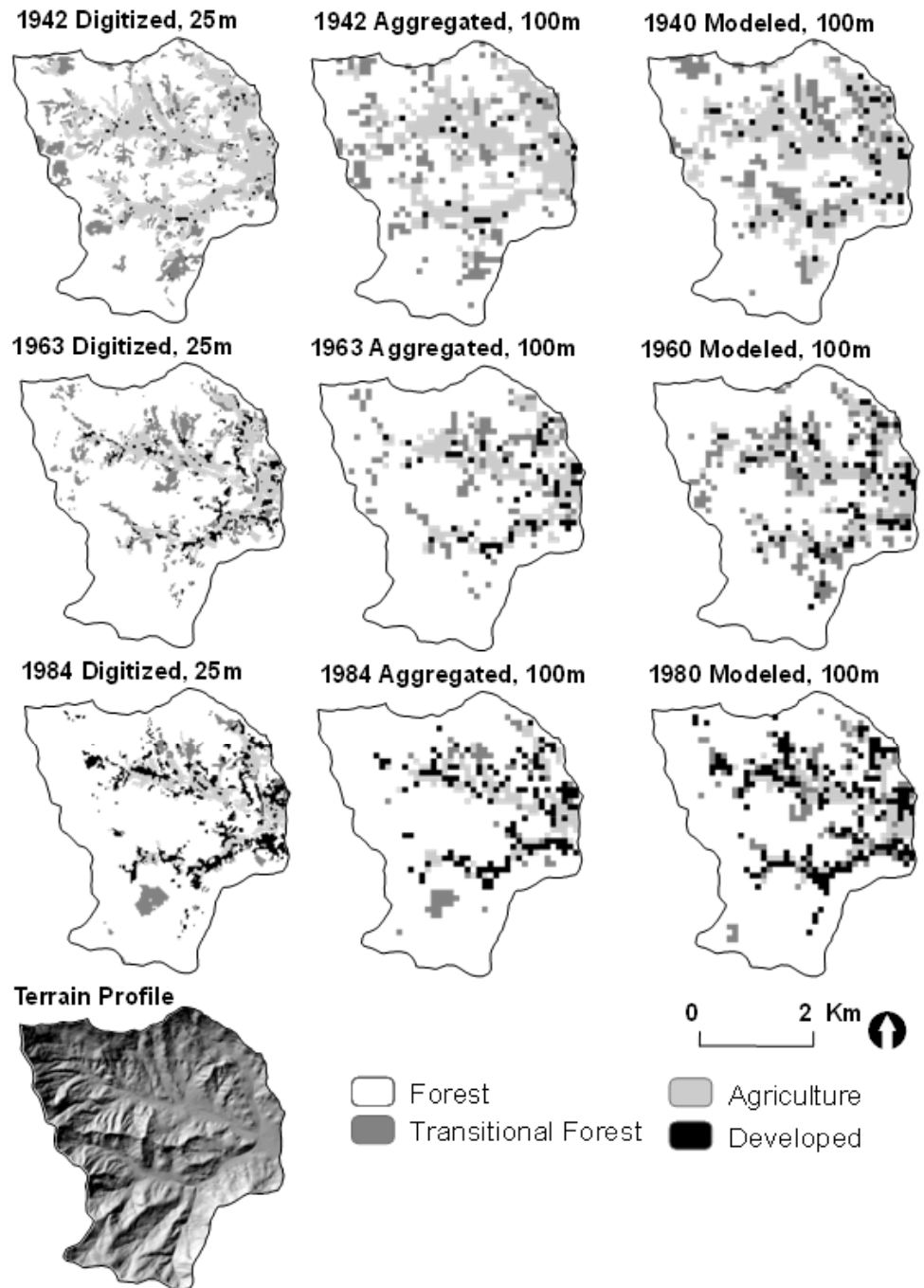
- Components of Agreement
- Pontius and Suedmeyer (2004)
- VALIDATE module in IDRISI

### Average across dates:

Map agreement = 76%

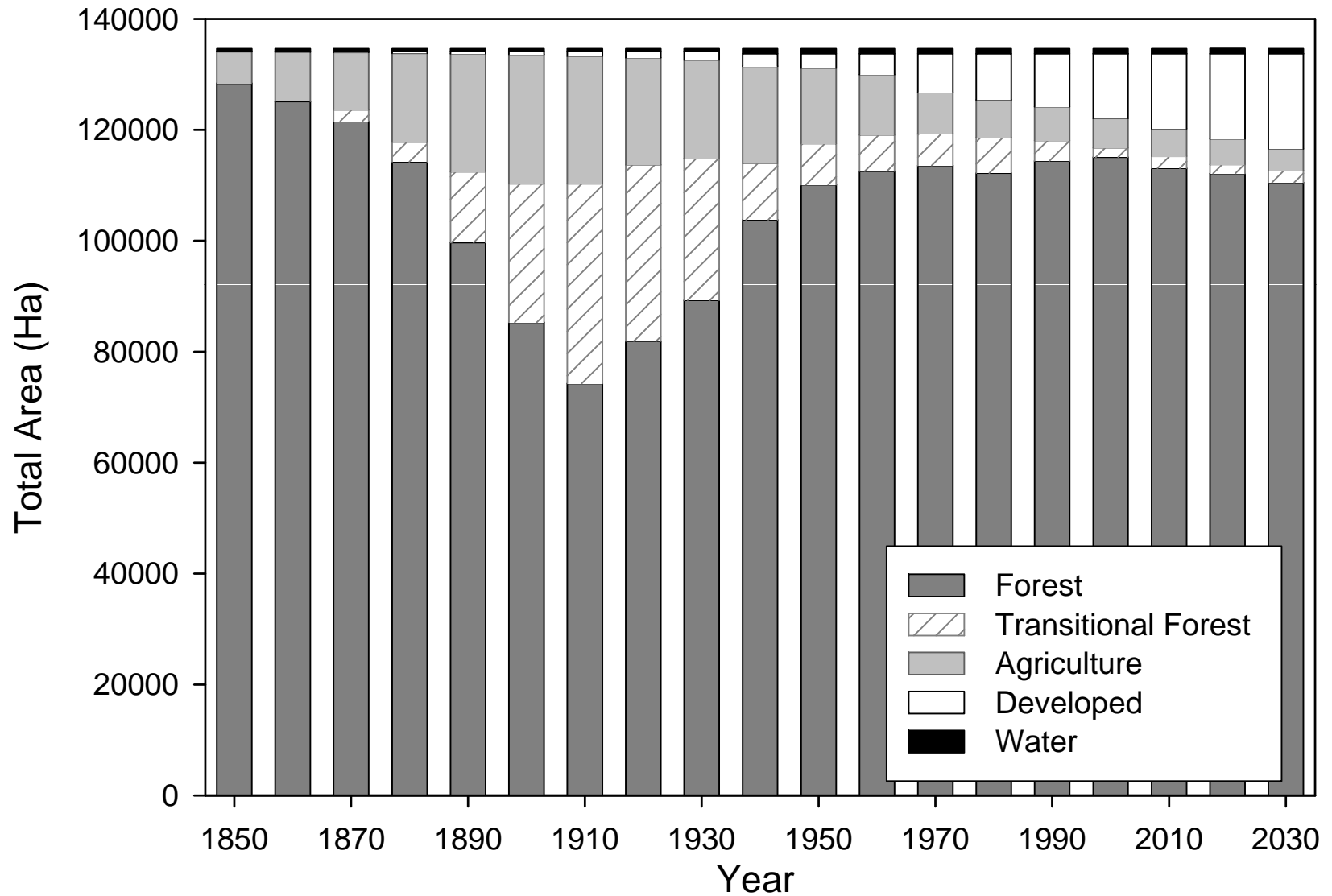
Quantity disagreement = 4%

Location disagreement = 20%



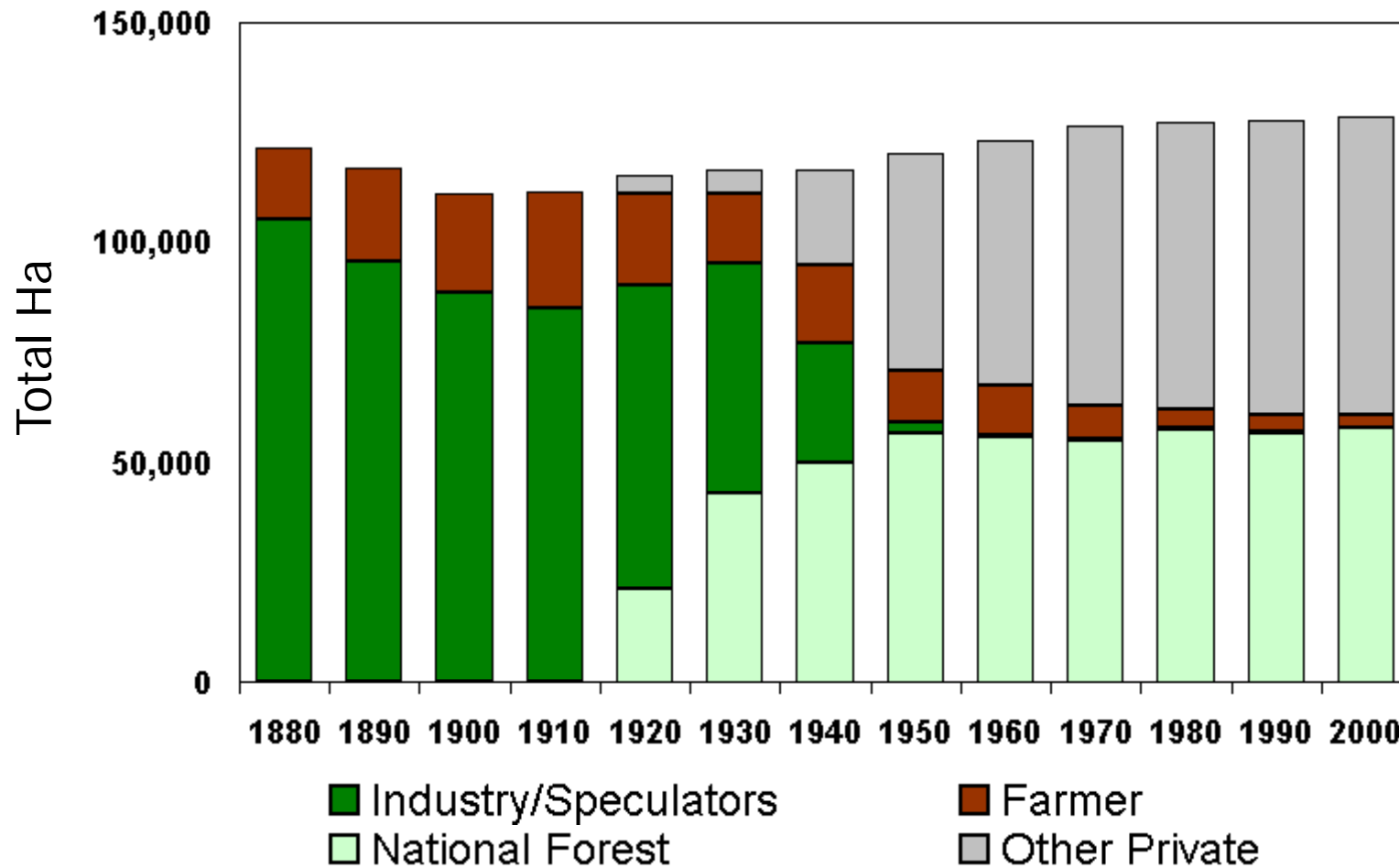
# Ch 1

## Aggregate land use, 1850-2030



# Ch 1

## Forest Ownership Changes



# Ch 1 Ch 1 Conclusions & Contributions

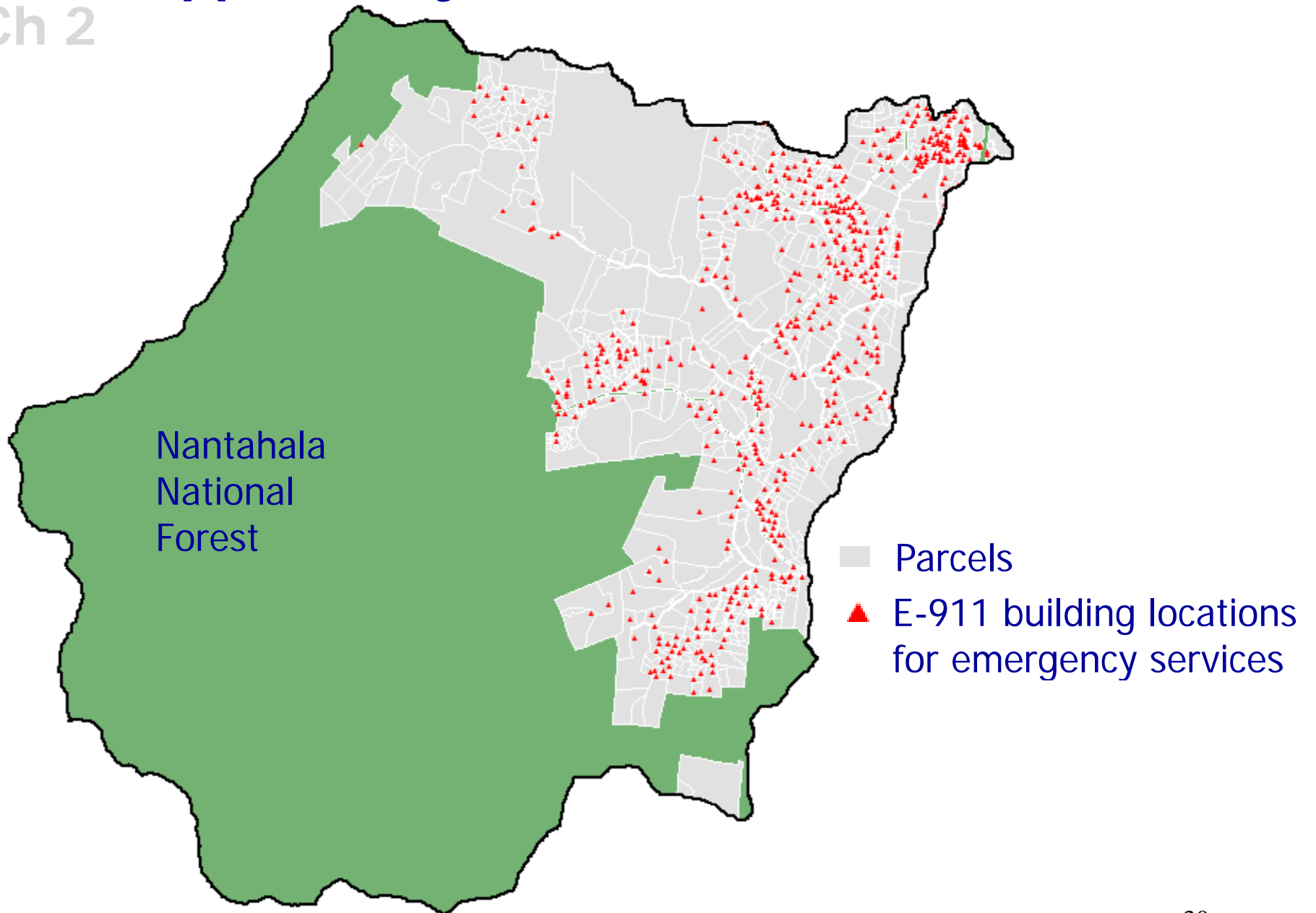
- \* 180 year, logically consistent land use data set
- \* Modeling strategy using simple logic rules and probability maps that can reproduce patterns at a reasonable accuracy
- \* Periodization of land use in the region, illustrating:
  - \* shifts in ownership patterns
  - \* dynamic and declining rates of change
  - \* primary land use trajectories
- \* Evidence of biophysical link between terrain properties and land use trajectories

# Dissertation Chapters

- 1) Land use history, rates of change, and trajectories in Macon County, 1850-2030
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- 3) Decadal reconstruction of major land uses in the region, 1850-2000
- 4) Land-use change effects on aboveground woody biomass

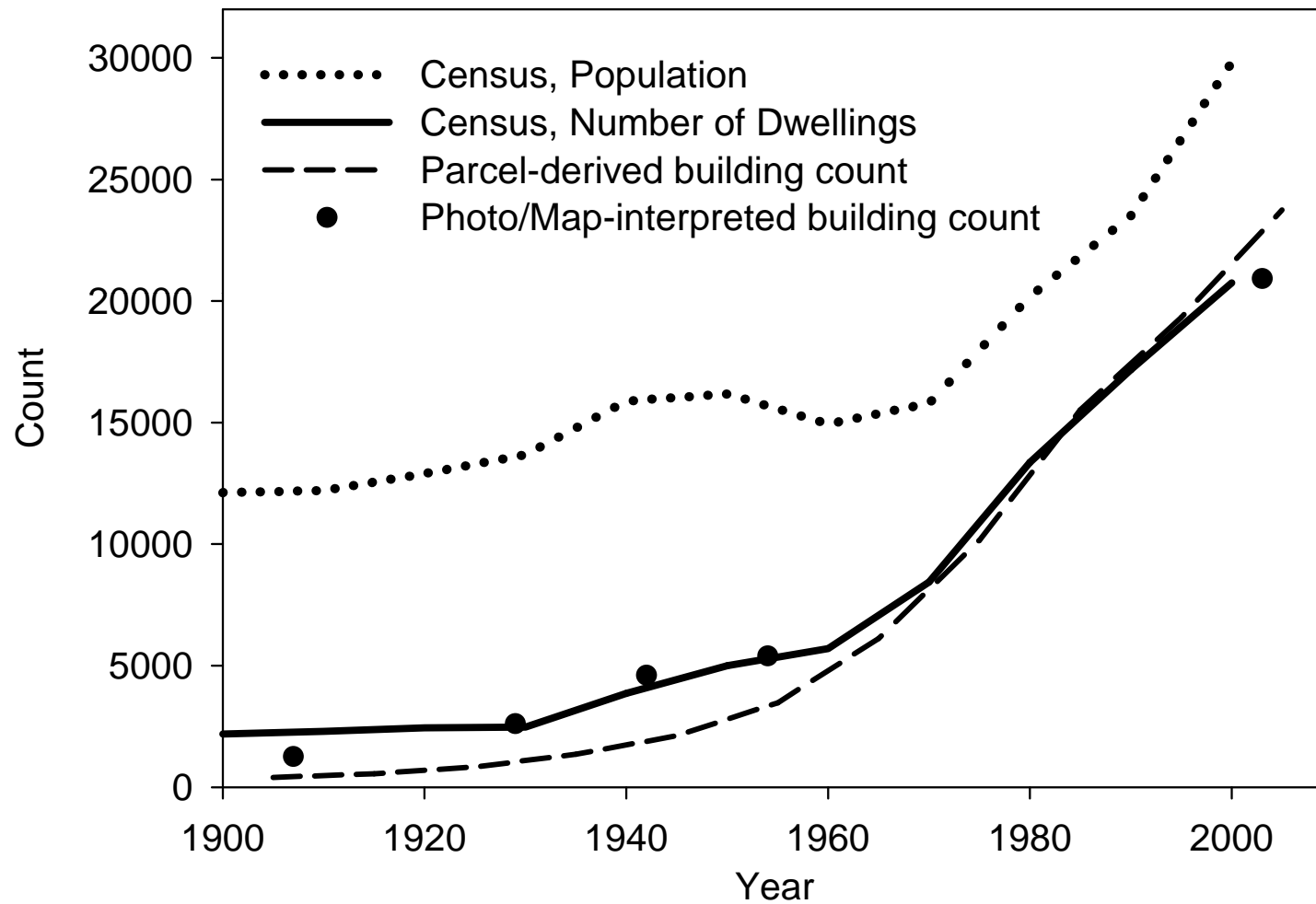
# Opportunity from Government Data

Ch 2



# Comparison of building and census data

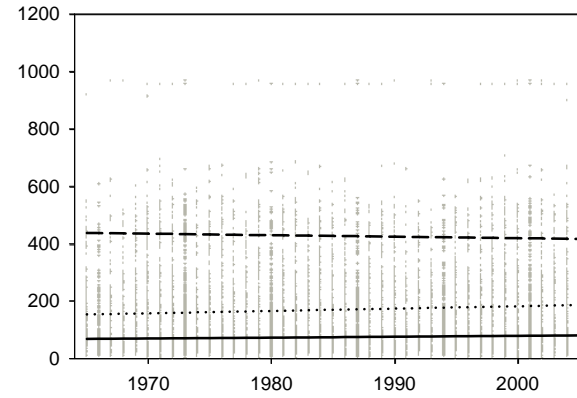
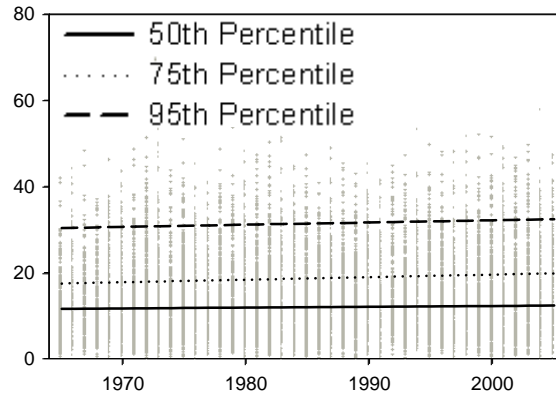
## Ch 2



# Temporal Trends of Development

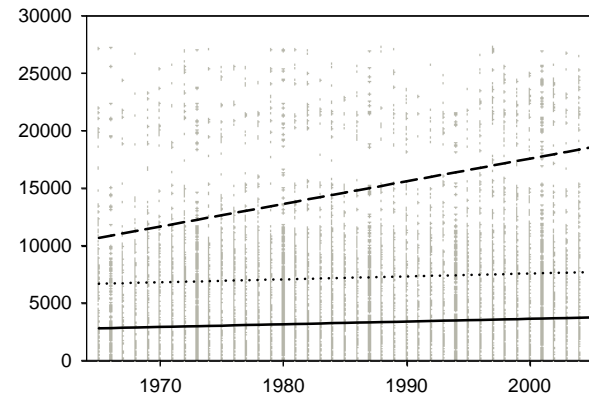
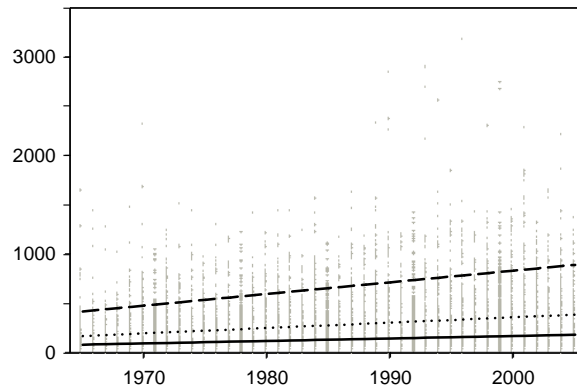
## Ch 2

Slope (%)



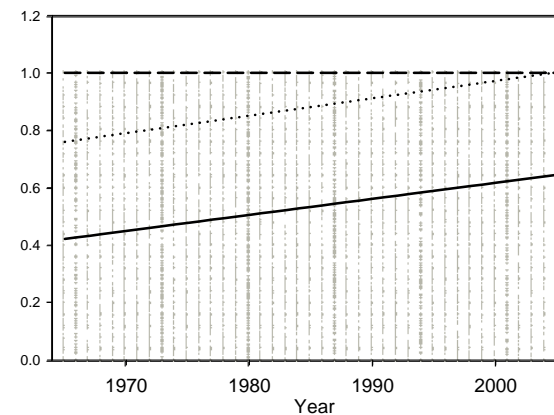
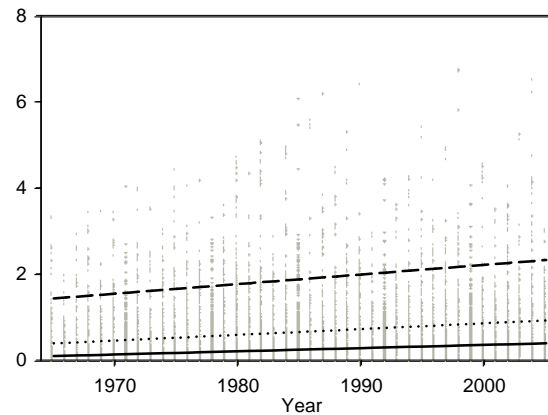
Elevation (m)

Distance to Main Roads (%)



Distance to Cities (m)

Building Density Previous Year



Forest Density Previous Decade (%)



# Temporal Trends of Development

## Ch 2

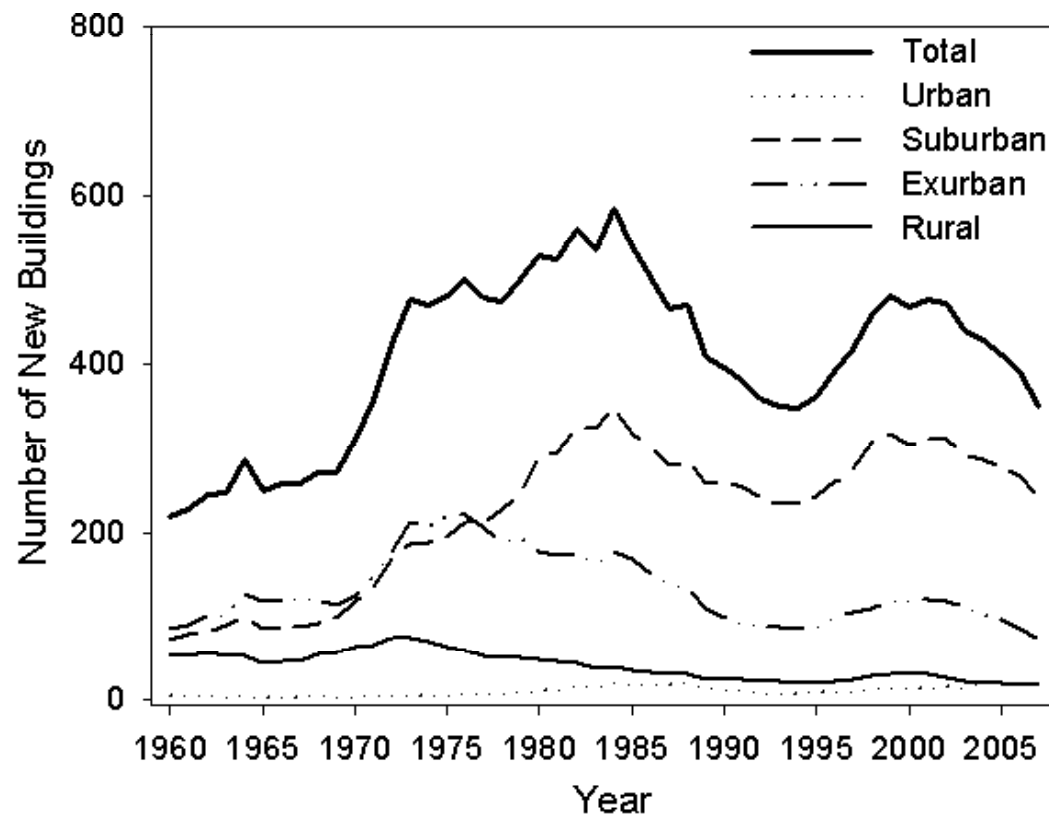
### Building Density Classes (Theobald, 2005)

Urban: > 2.5 bldg/ha

Suburban: 0.25 – 2.5 bldg/ha

Exurban: 0.6 – 0.25 bldg/ha

Rural < 0.6 /bldg ha

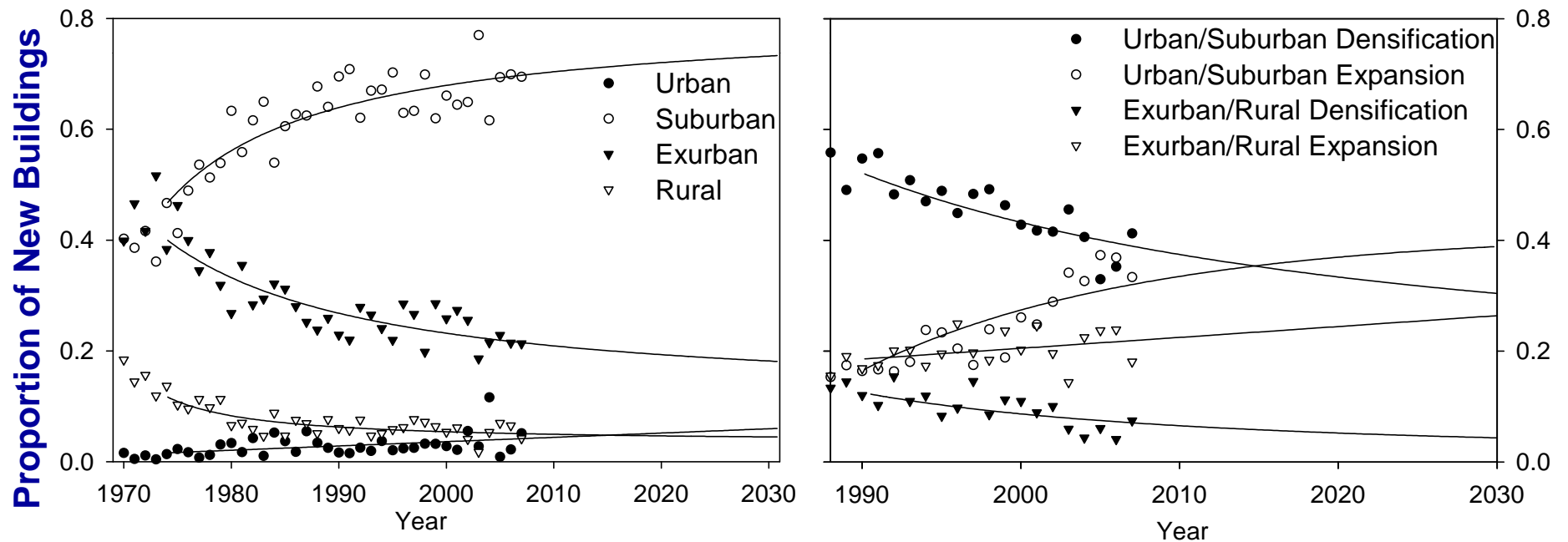


# Changing Development Patterns

## Ch 2

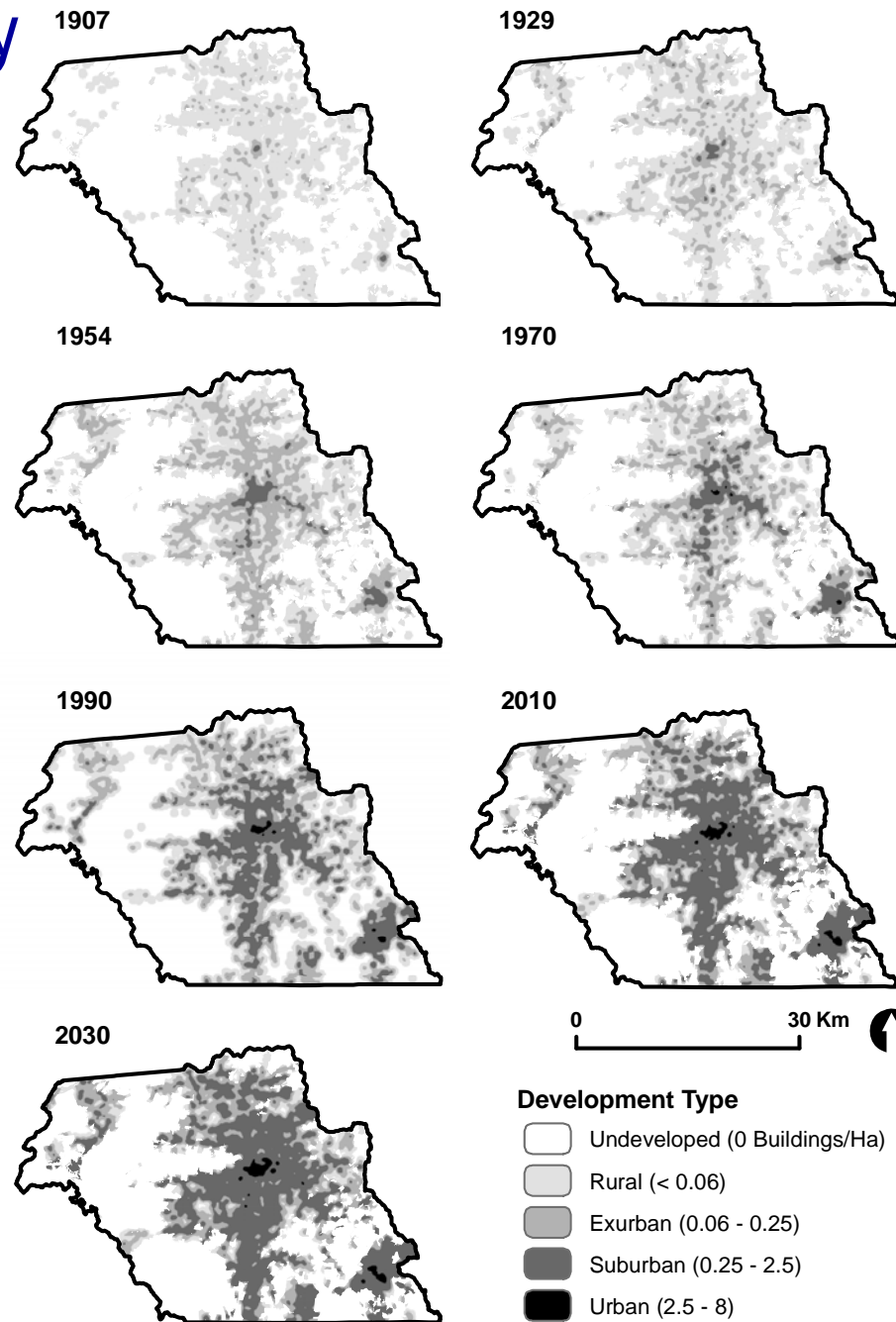
**Densification** = development in areas < 70% forested

**Expansion** = development in areas > 70% forested



# Building Density

## Ch 2



- \* Dynamic temporal trends between terrain variables and new building construction
- \* Strong differential trends in development in forested and non-forested areas at both low and high densities
- \* Method for using county government data sources to analyze spatio-temporal trends
- \* Method for stratifying landscape by building density to aid forecasting

# Dissertation Chapters

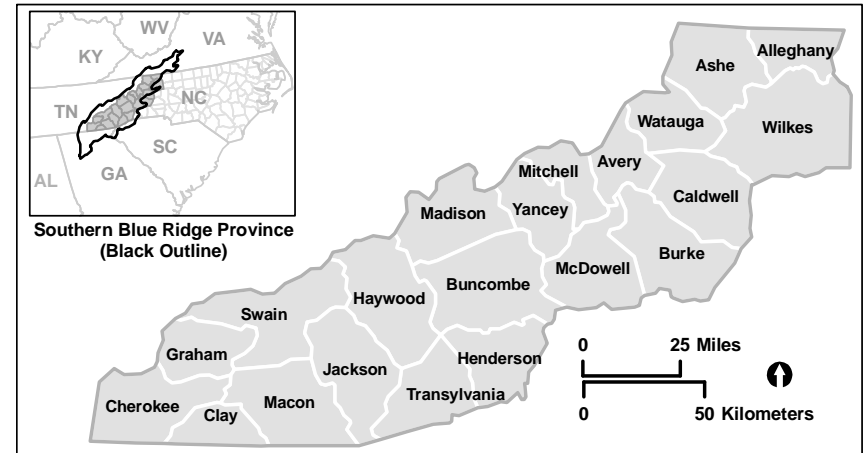
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# Regional Modeling Sequence

## Ch 3

**Objective:** Decadal classification from 1850-2030 for Development, Agriculture, and Forest

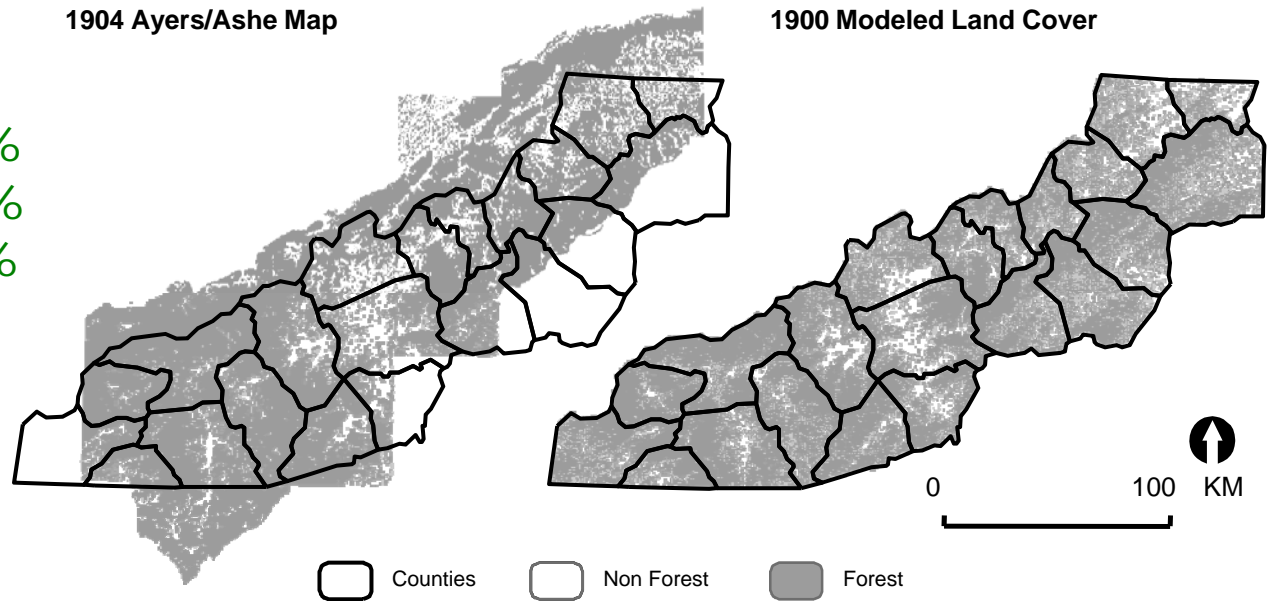
- 1) Generalized version of 2000 NLCD as baseline
- 2) Mask out water/bare rock
- 3) Model Development going backwards in time by “removing” cells each decade based on spatially-disaggregated census Housing Unit estimates.
- 4) Model Agriculture moving forward from 1850 based on Census of Agriculture estimates and the ASI
- 5) All other areas classified Forest



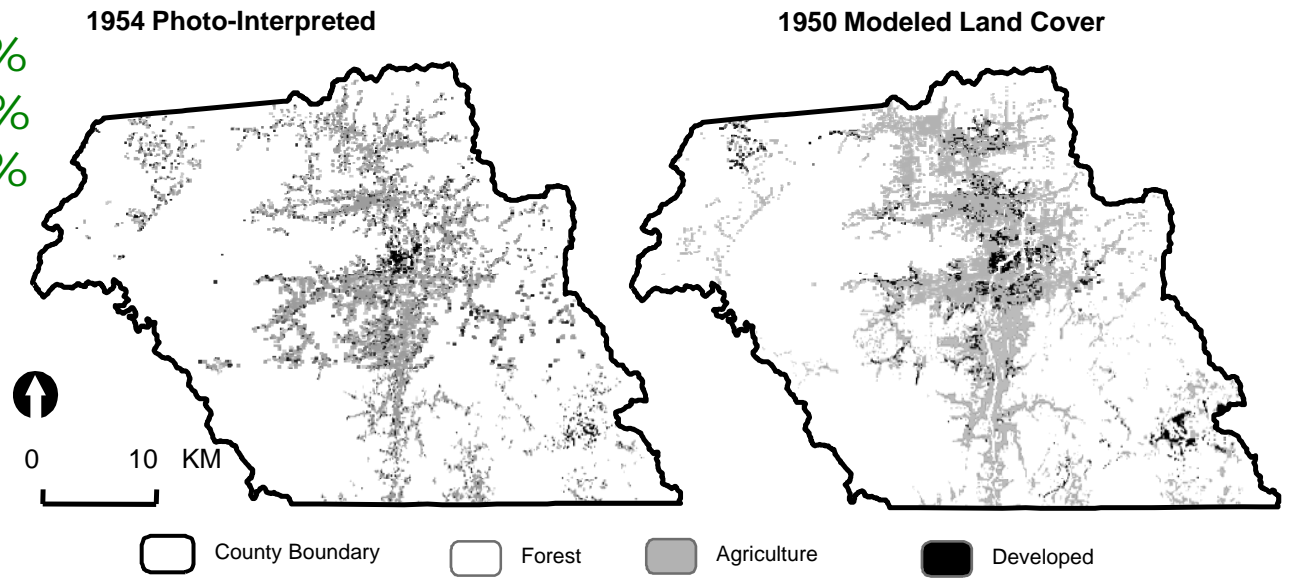
# Regional Model Validation

## Ch 3

Map agreement = 71%  
Quantity disagreement = 3%  
Location disagreement = 26%

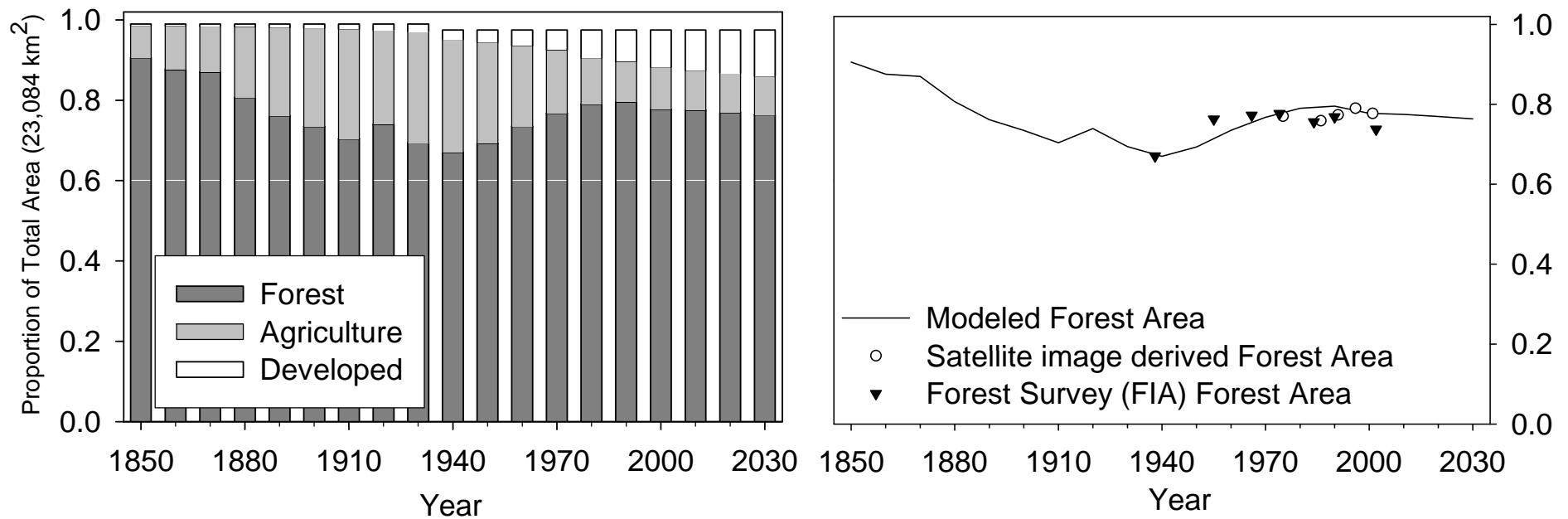


Map agreement = 84%  
Quantity disagreement = 8%  
Location disagreement = 8%



# Ch 3

## Comparison against inventory and satellite forest area estimates





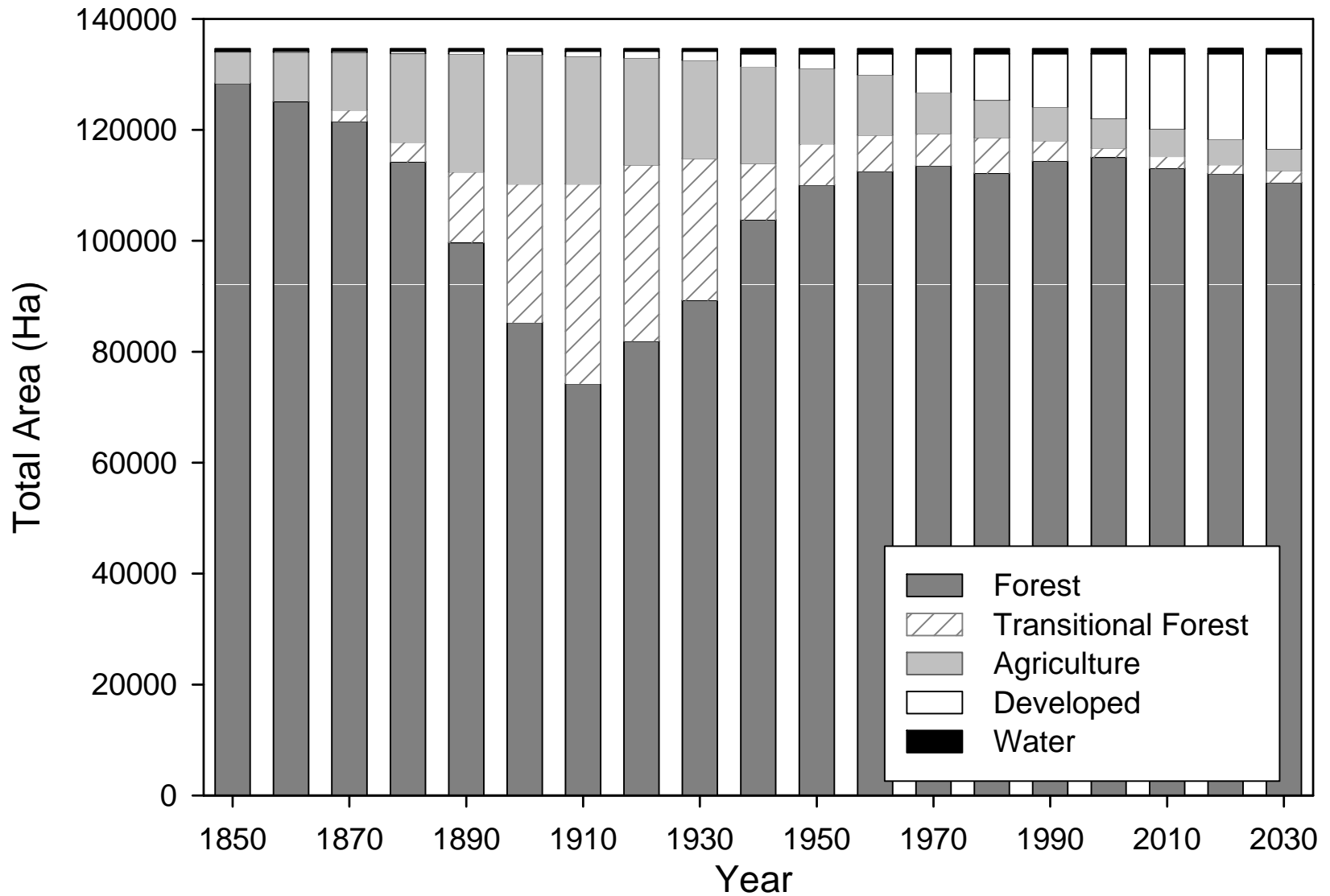
- \* 180 year land cover data set over 21 counties
- \* Method for estimating historic land use in mountainous regions using terrain-based probability models
- \* Estimate of the total area ever used for agriculture in the region (34%)
- \* Semi-automated method for extracting polygon features from historic maps
- \* Method for adjusting county-level census variables to account for changing county boundaries

# Dissertation Chapters

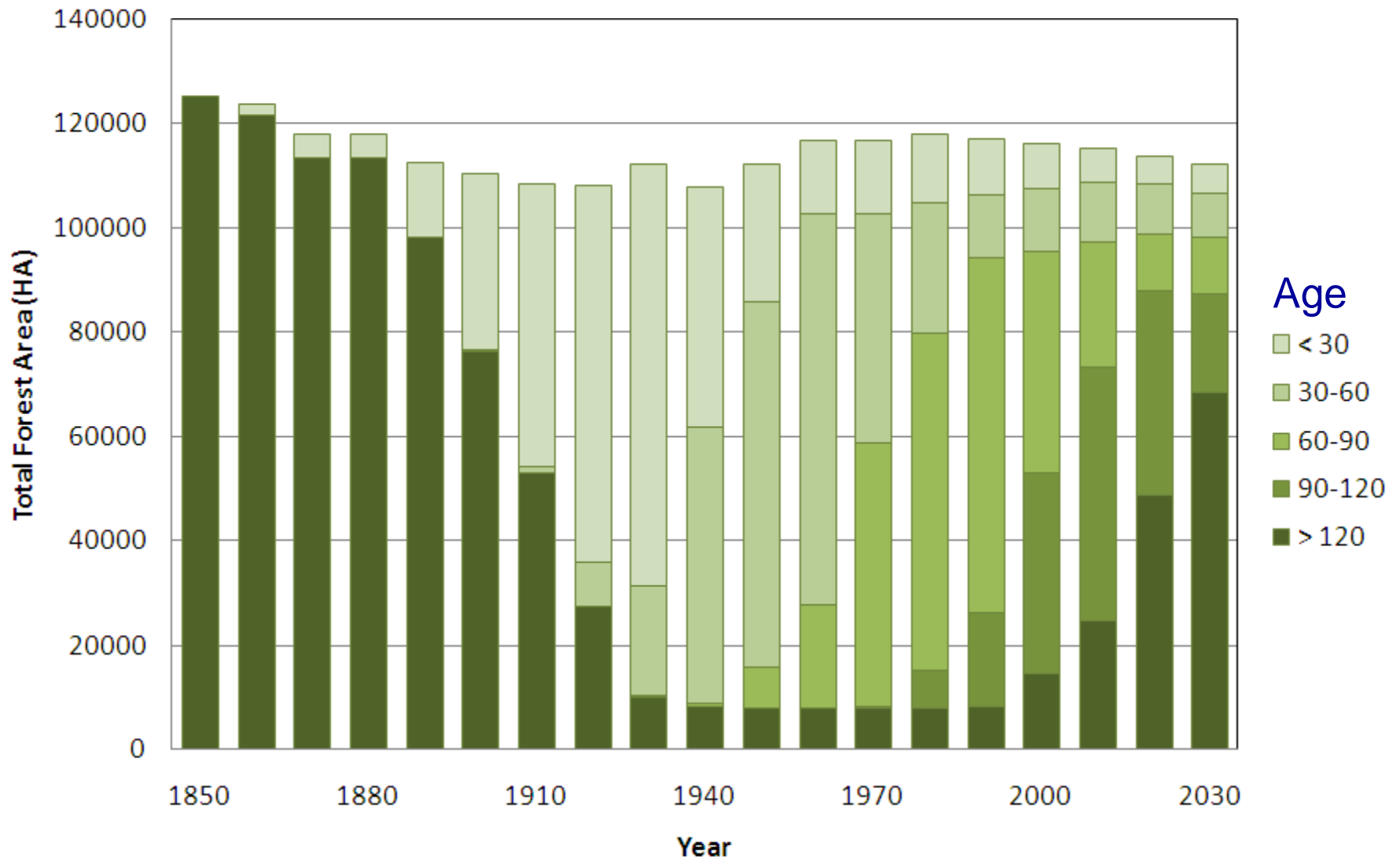
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# Ch 4

## Aggregate land use, 1850-2030



## Ch 4 Stand age since establishment

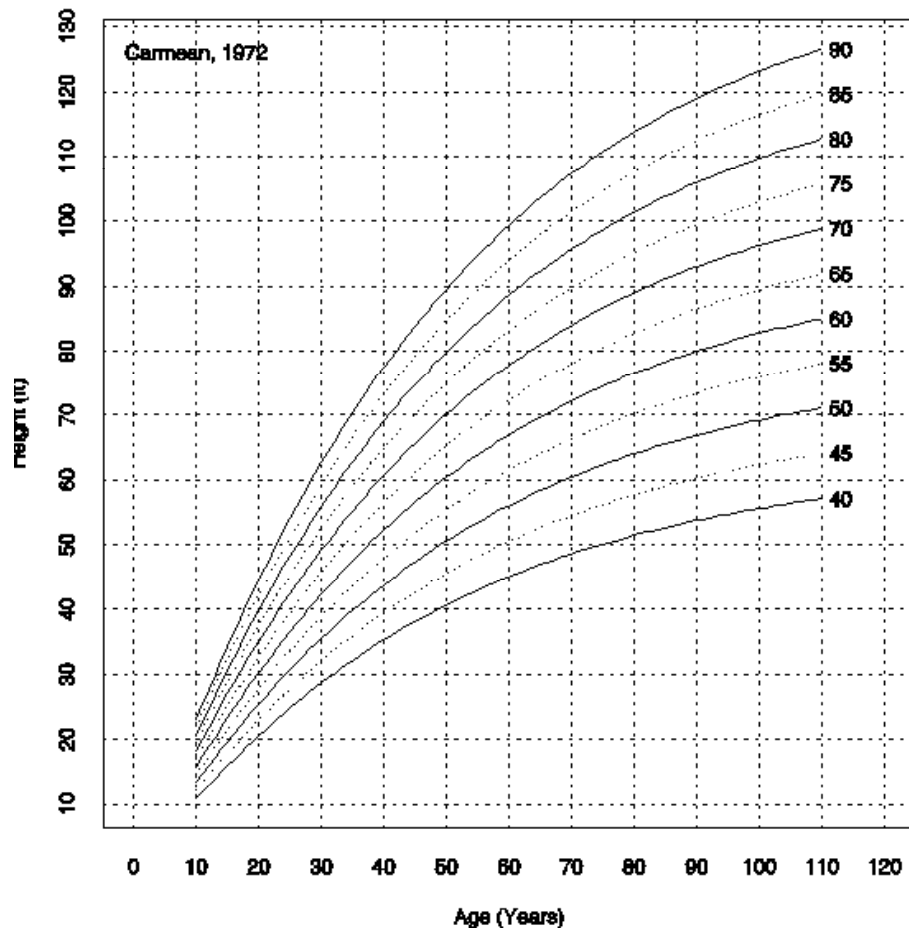


# Ch 4

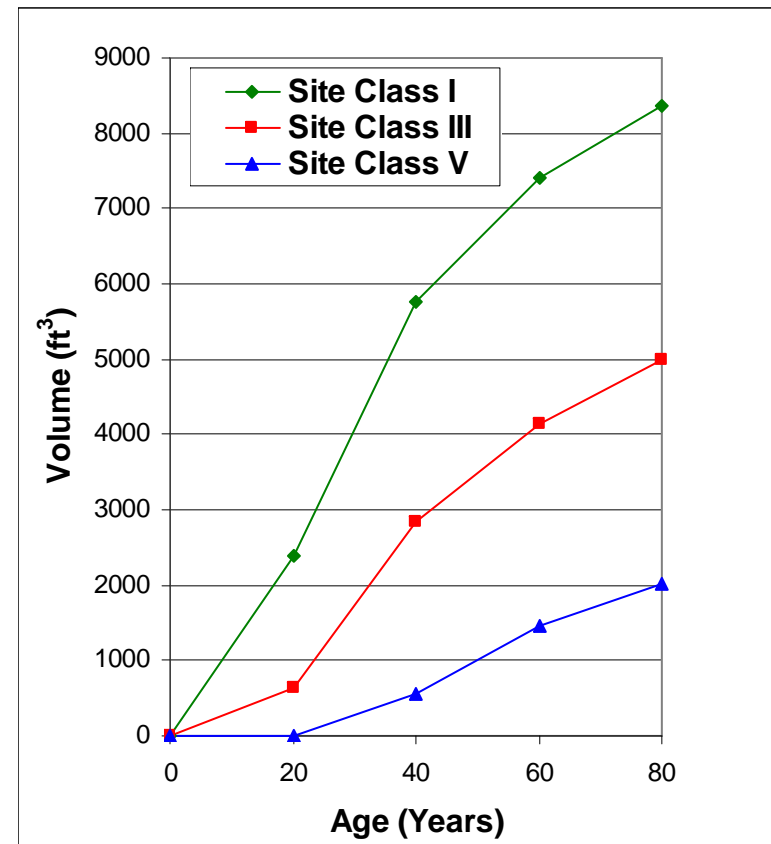
# Age-Yield Equations

Estimate growth based on measure of site quality

### Site Index Curve

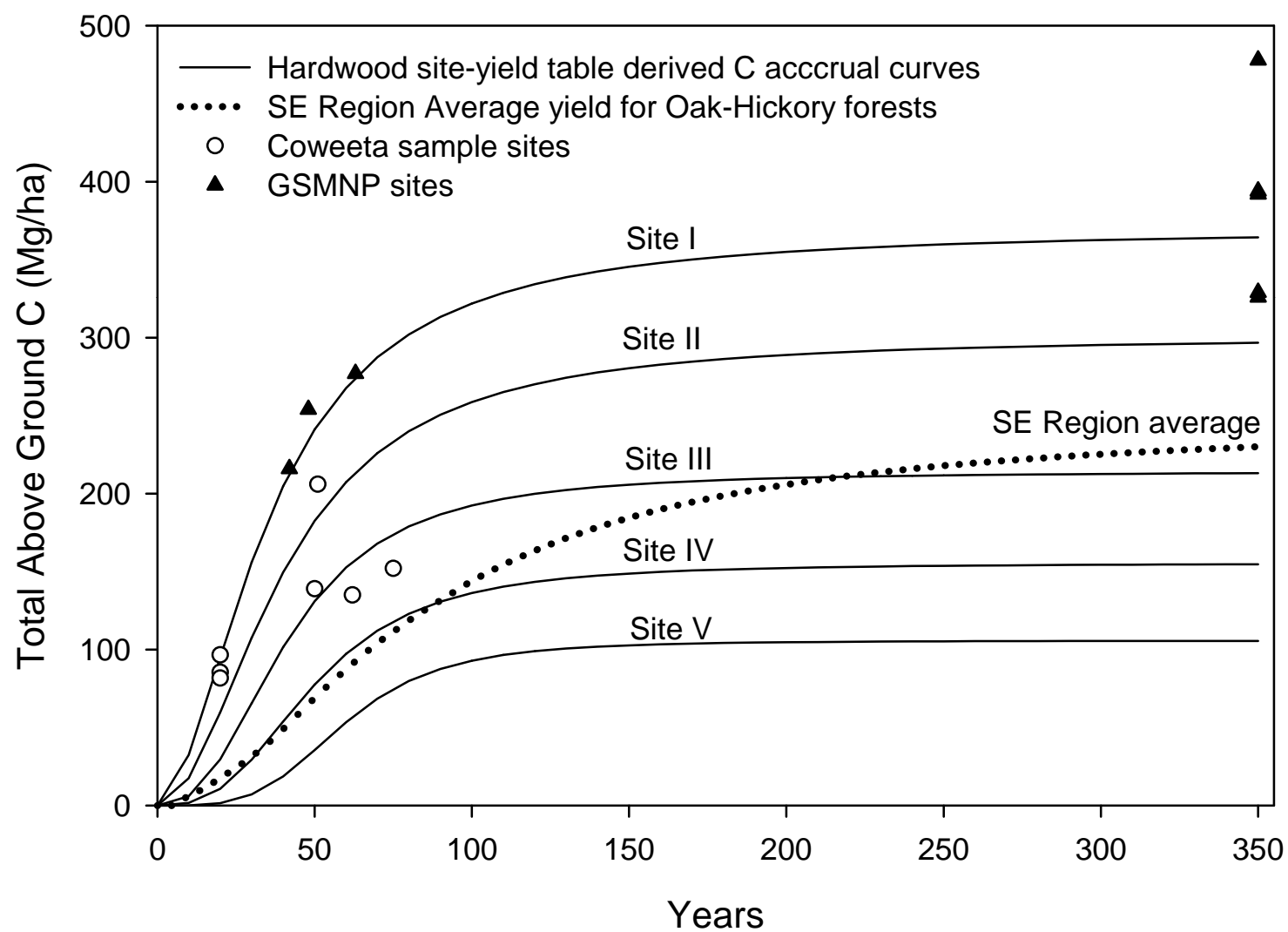


### Site Yield Equation



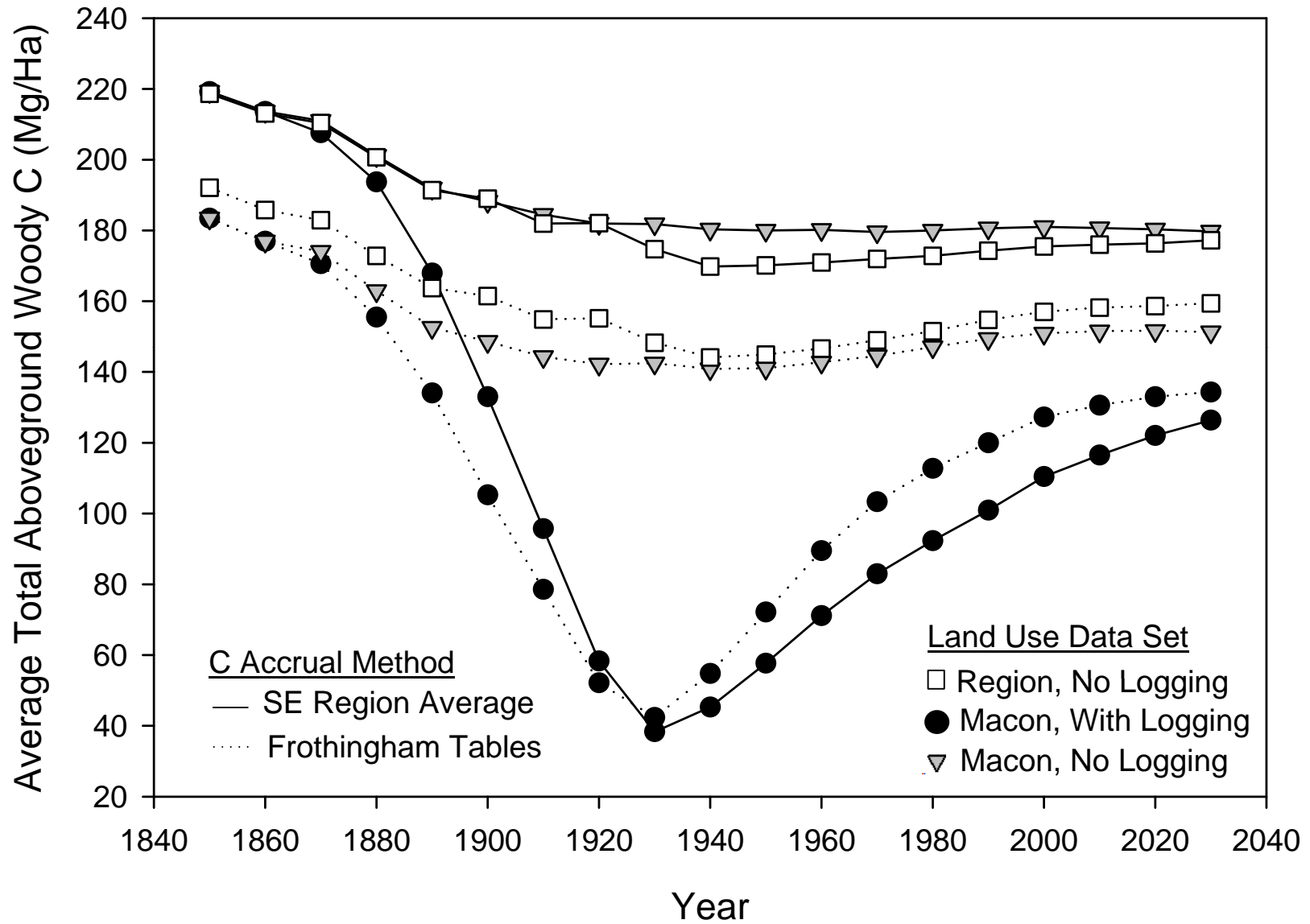
## Ch 4 Frothingham Yield Curves (1931)

Site Class	Elevation	Terrain Position	Forest Type
<b>Site I:</b> "Best Cove Soils"	2000-4000 ft	Narrow coves; broader coves long since cleared for agriculture	Mixture of species, often dominated by hemlock or yellow poplar
<b>Site II:</b> "Moist slopes and coves"	2000-4000 ft	Northerly slopes, lower slopes at about the same elevation as cove forest	Chestnut and several species of oak and hickory dominate
<b>Site III:</b> "Soils of intermediate quality"	Up to 5000 ft	Upper moist slopes	Mixture of "Northern Hardwoods"
<b>Site IV:</b> "Better dry slopes and ridges"	Unspecified	Found chiefly on southerly or westerly exposures , but often covers east slopes as well around to the northeast	More drought resistant species; estimate 2/3 of total forest area in this class
<b>Site V:</b> "Poorer dry slopes and ridges"	Unspecified	Unspecified	Unspecified



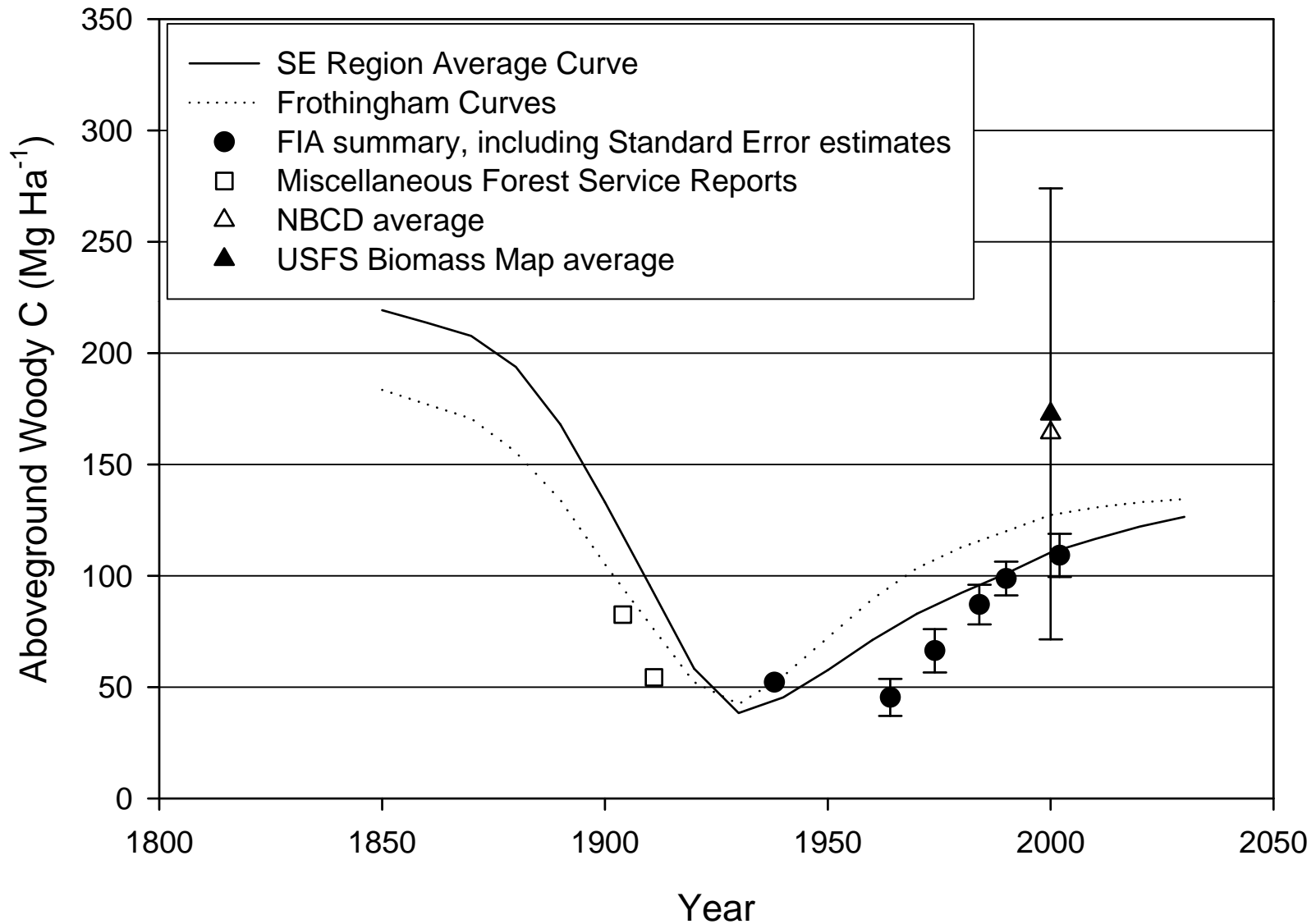
# Aboveground Woody C Accrual

Ch 4





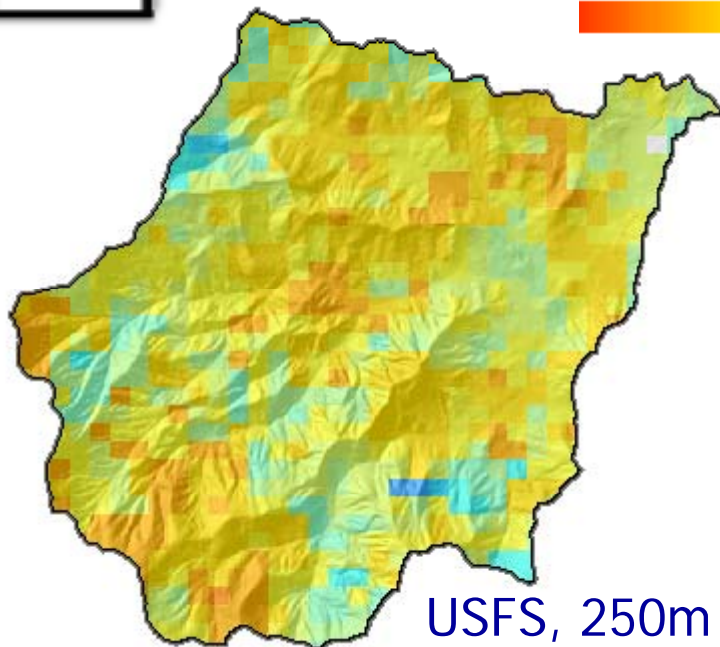
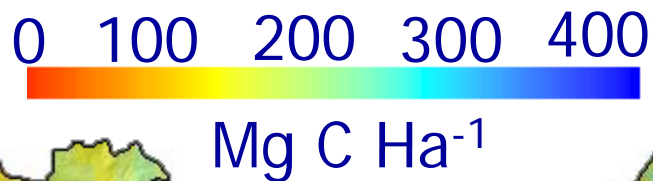
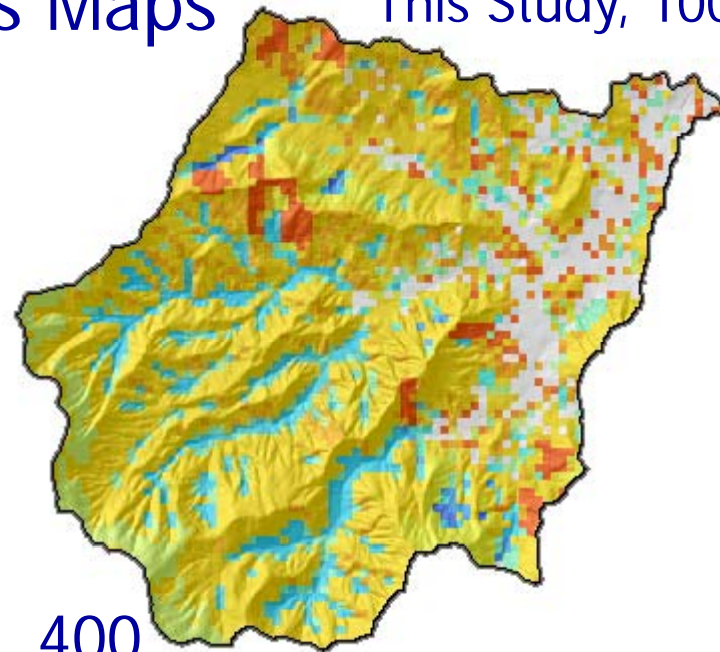
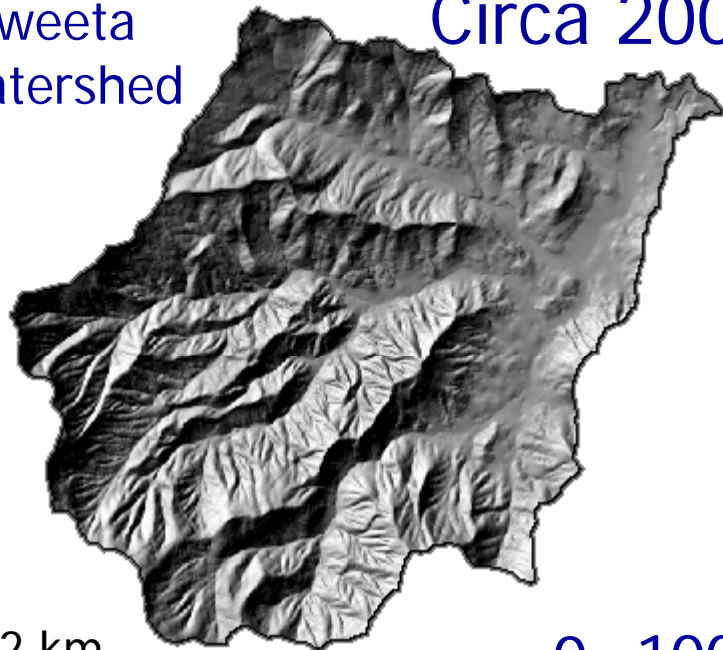
## Comparison against Independent Estimates



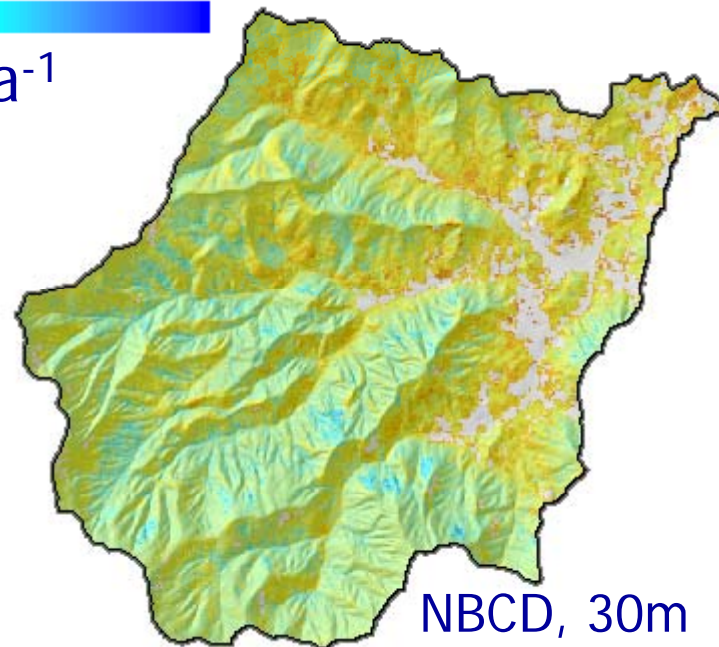
Coweeta  
Watershed

# Circa 2000 Biomass Maps

This Study, 100m



USFS, 250m



NBCD, 30m

- \* Historic estimate of aboveground woody C (AWC) pool in the region
- \* Estimate of aggrading AWC, but at a declining rate
- \* Estimate of relative effects of industrial logging (84%) and agriculture expansion and abandonment (16%) on AWC
  - \* Estimate of maximum AWC recovery (85% of 1850 pool) assuming no major disturbance and no change in forest area
  - \* Method for modifying bookkeeping-style C models by environmental gradients

## Future Research

### **1) Add disturbance & environmental models:**

- Chestnut Blight & other pathogens
- Fire, windthrows, ice-storms, landslides, etc
- Partial harvest

### **2) Complete C budget:**

- Foliage, CWD, soil

### **3) Modern and historic forest area discrepancies**

### **4) Effects of land-use change on ecosystem services**

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