# Remote Sensing Applications: Forestry

## IRS Chapter 18

**John C. Femiani**
Miami University

# Introduction to Forestry

- **Forestry**: Science and practice of forest management
- **Focus**: Sustainable resource use for human benefit
- Includes **timber**, **carbon sequestration**, and **biodiversity**

# What is Forestry?

- **Management of forests** for multiple objectives
- Ensures **sustainable use** of forest resources
- Goals include:
  - Timber and nontimber products
  - Water quality and yield
  - Carbon storage and biodiversity

# Historical Roots of Forestry

- **Middle English origin**: Forests as hunting reserves
- **Modern purpose**: Conservation and resource management
- Historic focus on wildlife and hunting remains relevant

# Defining Silviculture

- **Art and science** of forest cultivation
- Focuses on **establishment, growth,** and **health** of forests
- Goal: Meet **landowner and societal needs** sustainably

# Purpose of Forest Measurements

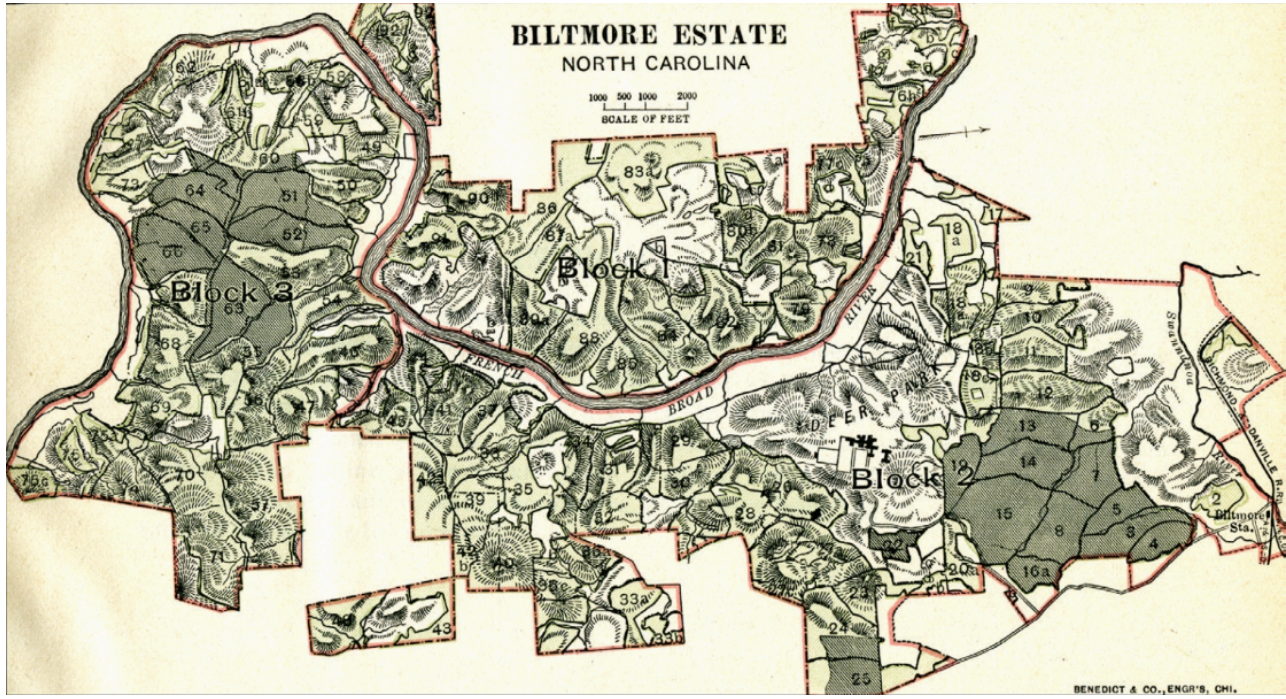
- **Quantitative data** for decision-making
- Focus on **forest stands** as the unit of management
- Mapping and measurement for resource assessment

# Understanding Forest Stands

- **Forest stand**: Group of similar trees in a contiguous area
- **Mapping** stands supports resource management
- Originated in **medieval Germany**; introduced in U.S. by Pinchot

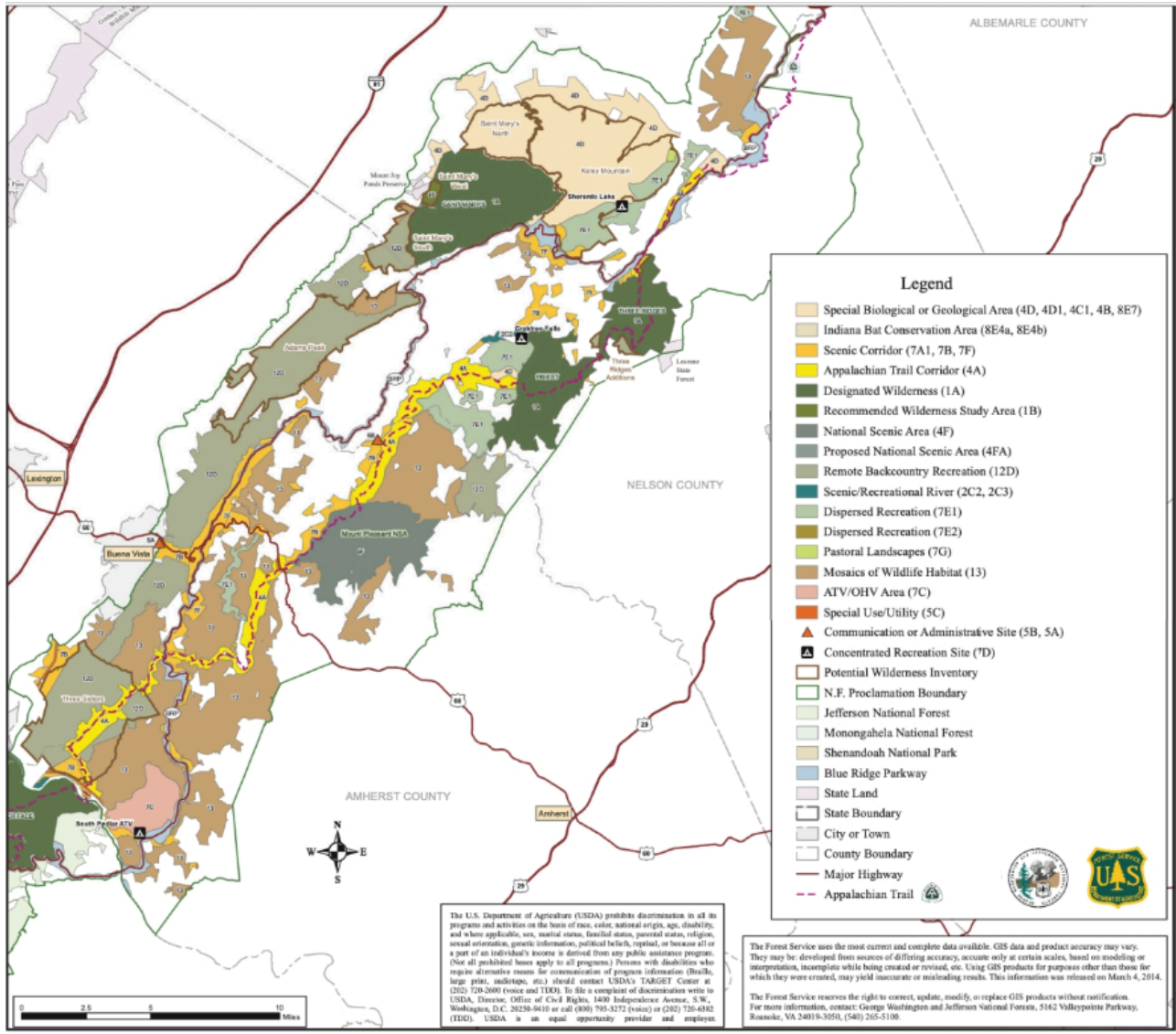
# Early Stand Mapping in the U.S.

- **First stand map**: Biltmore Estate, North Carolina (1893)
- Created by **Gifford Pinchot**
- Early example of systematic forest management



# Modern Stand Mapping and Remote Sensing

- Uses **satellite and aerial imagery**
- Increasing use of **lidar** for high-resolution mapping
- Digital mapping tools for forest assessment



# Climatic Influence on Tree Species

- **Species range** is climate-driven
- Key climatic factors:
  - Freezing tolerance
  - Season length
  - Growth period

# Soil (Edaphic) Influence on Trees

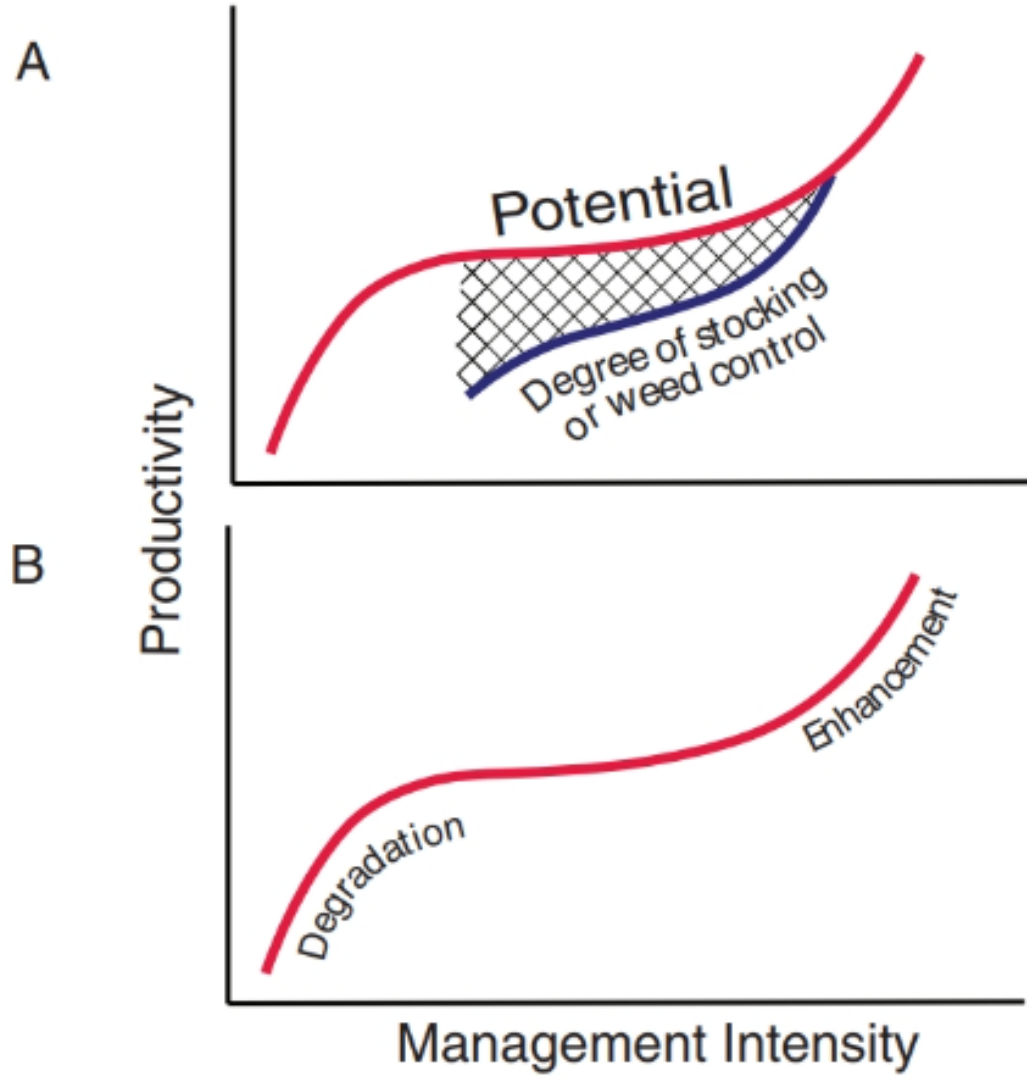
- Soil conditions affect **species presence**
- Key factors:
  - Nutrient availability
  - Water retention
  - Soil texture

# Decision Making in Silviculture

- **Abiotic environment** determines species choice
- Balance of **climatic and soil** conditions
- Goal: Maximize growth while meeting environmental constraints

# Site Productivity and Management Intensity

- **Productivity** varies with management intensity
- Types of management:
  - To potential productivity
  - To improve potential productivity



# Introduction to Leaf Area Index (LAI)

- **LAI**: Quantifies leaf area in a forest
- Linked to **forest productivity**
- Key metric for **ecosystem services**

# Why LAI is Important in Forestry

- Indicates **productivity** and **growth potential**
- Used to assess **forest health**
- Aids in **management decisions**

# Estimating LAI: Passive Methods

- **Passive optical sensors** are widely used
- Common indices for LAI estimation:
  - **Simple Ratio (SR)**:

$$SR = \frac{NIR}{Red}$$

    - Ratio of near-infrared (NIR) to red reflectance
    - Highlights vegetation density and biomass
- **RSR** index often performs well in **boreal forests** (e.g. pine forests)

# Interpreting Simple Ratio (SR) Values

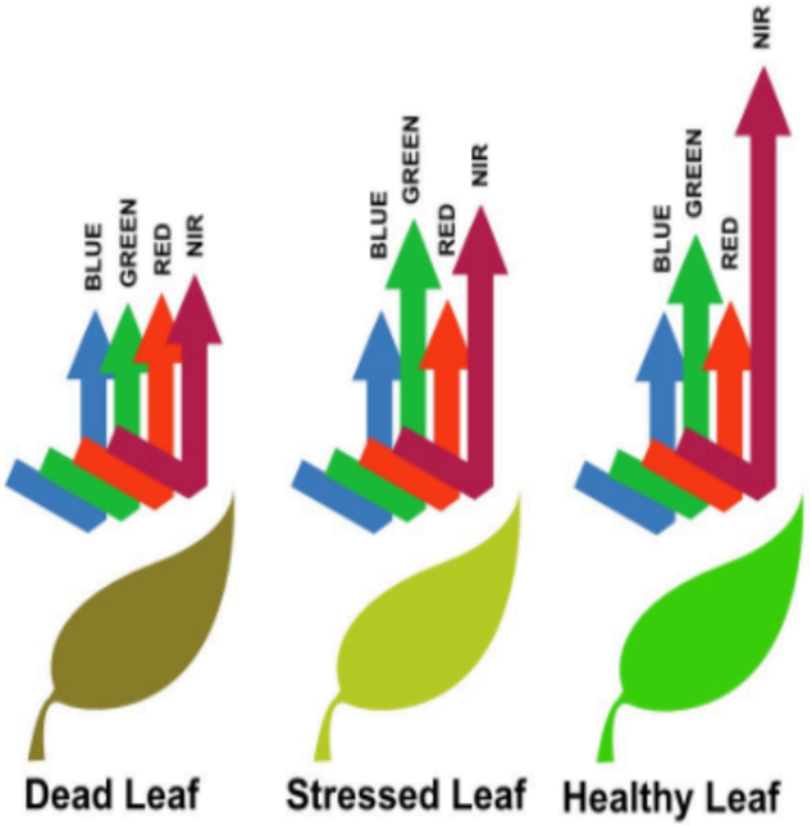
| SR Value | Interpretation |
|---|---|
| Low (0-2) | Sparse or stressed vegetation |
| Moderate (2-6) | Medium density vegetation |
| High (6-10) | Dense, healthy vegetation, high biomass |

# Normalized Difference Vegetation Index (NDVI)

- **NDVI**:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- Measures vegetation health by contrasting NIR and red bands
- Sensitive to **chlorophyll content** and **canopy cover**



# Interpreting NDVI Values

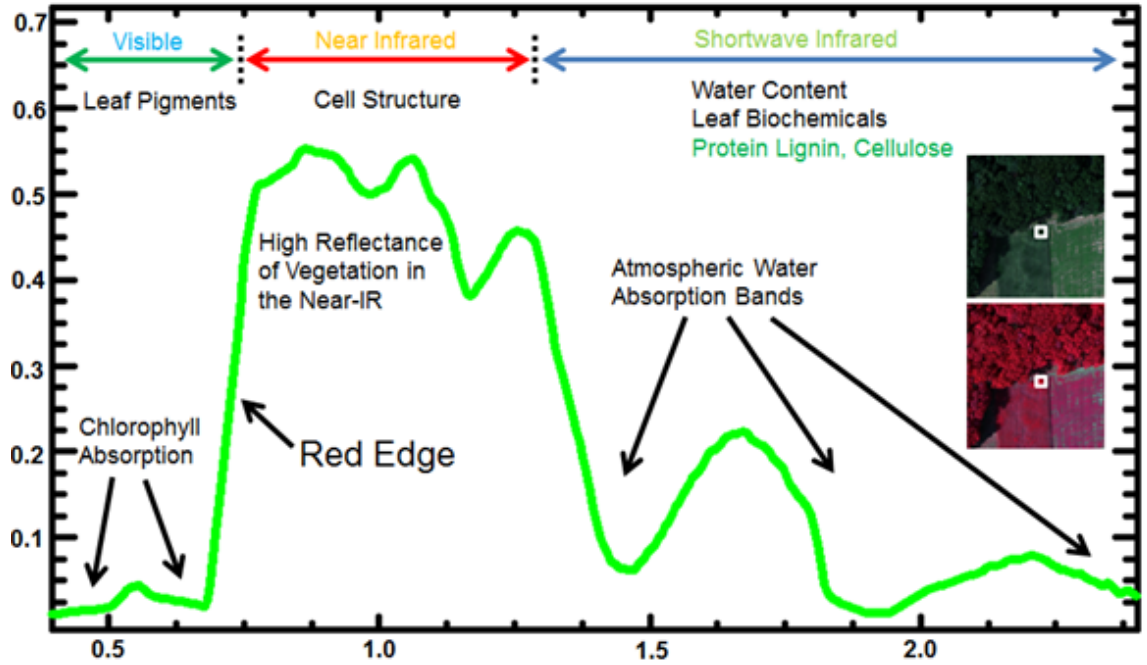
| NDVI Value | Interpretation |
|---|---|
| -1 to 0 | Non-vegetated surfaces (e.g., water, bare soil) |
| 0 to 0.3 | Sparse or stressed vegetation |
| 0.3 to 0.6 | Moderate vegetation density |
| 0.6 to 1 | Dense, healthy vegetation |

# Normalized Difference Moisture Index (NDMI)

- **NDMI**:

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR}$$

- Indicates **moisture content** in vegetation
- Useful for differentiating **healthy** and **stressed vegetation**



# Interpreting NDMI Values

| NDMI Value | Interpretation |
|---|---|
| -1 to 0 | Low moisture content; dry vegetation |
| 0 to 0.2 | Moderate moisture content |
| 0.2 to 0.5 | High moisture content; healthy vegetation |
| >0.5 | Very high moisture; potentially saturated |

# Reduced Simple Ratio (RSR) for LAI

- **RSR** improves upon SR in certain forest types
- Formula:

$$RSR = SR \times \left(1 - \frac{SWIR1 - SWIR1_{\text{min}}}{SWIR1_{\text{max}} - SWIR1_{\text{min}}}\right)$$

# Explanation of RSR Equation

- **Components**:
  - SWIR1: Shortwave infrared reflectance
  - Min/Max values: Define open/closed canopy
- Strengthens local LAI relationships

# Interpreting Reduced Simple Ratio (RSR) Values

| RSR Value | Interpretation |
|---|---|
| Low (near 0) | Sparse canopy or low LAI |
| Moderate | Intermediate LAI |
| High (near 1) | Dense canopy with high LAI |

# Empirical Models for LAI Estimation

- Empirical **regression models** relate indices to field-measured LAI
- Models vary by **species and region**
- Two examples: Norway spruce and loblolly pine

# LAI Estimation for Norway Spruce

- **Equation** for Norway spruce:

$$LAI = 0.18 \cdot RSR + 1.04$$

# Explanation of Norway Spruce LAI Model

- **RSR component**: Captures variation in canopy structure
- Regression constants derived from **field data**
- Applied in Finnish boreal forests

# LAI Estimation for Loblolly Pine

- **Equation** for loblolly pine:

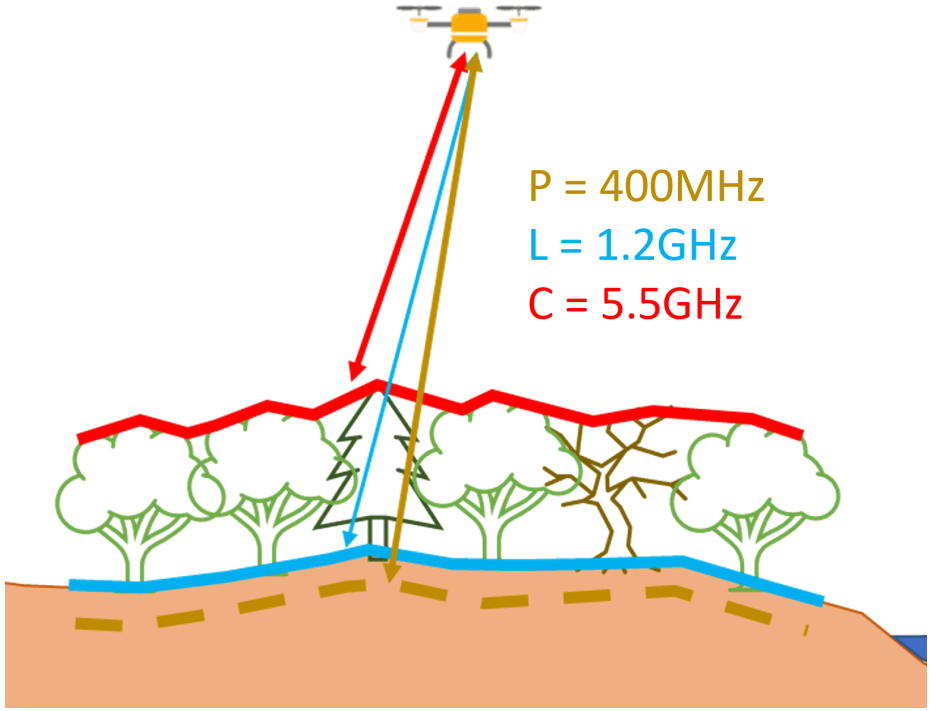
$$LAI = 0.33 \cdot SR - 0.0021$$

# Explanation of Loblolly Pine LAI Model

- **SR component**: Simple Ratio vegetation index
- Regression based on **southeastern U.S. forests**
- Adjusted for loblolly pine characteristics

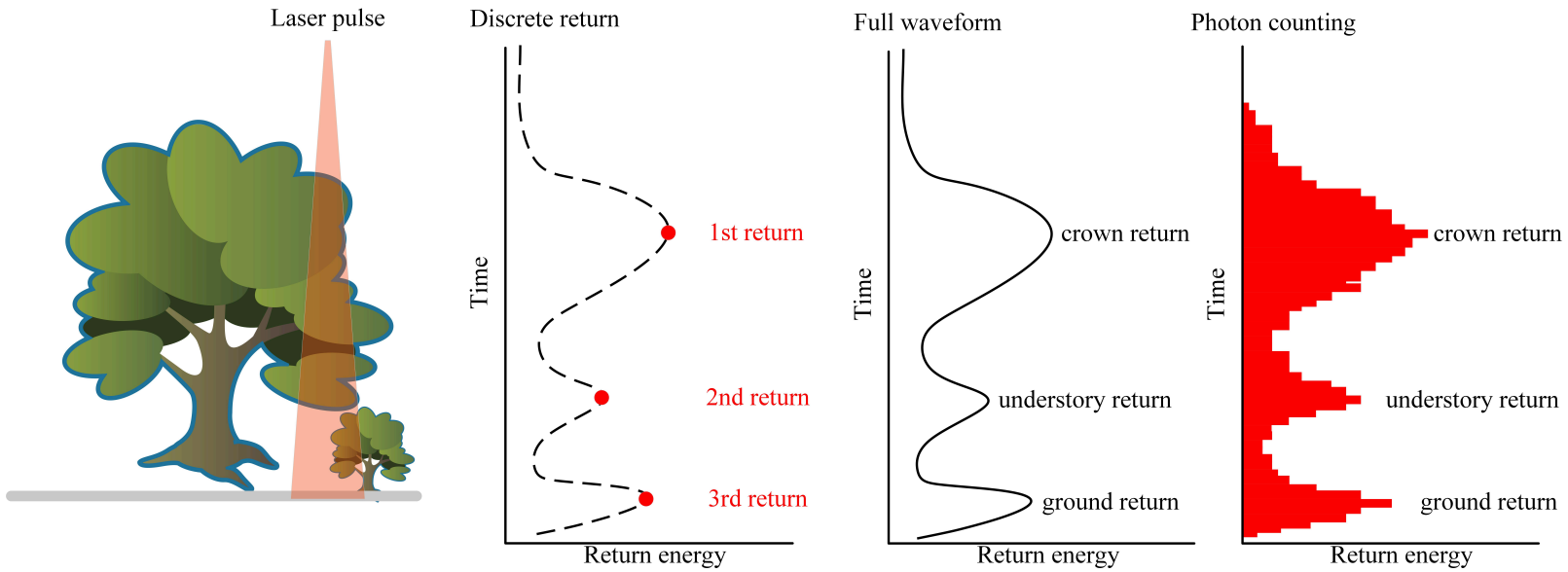
# Estimating LAI: Active Methods

- Active methods include **lidar** and **SAR**
- Measure **3D structure** of canopy
- Provide accurate LAI estimations across vertical layers



# Laser Penetration and Lidar for LAI

- **Lidar** captures detailed canopy structure
- Metrics include **height and leaf penetration**
- Supports accurate vertical LAI distribution



# Using Synthetic Aperture Radar for LAI

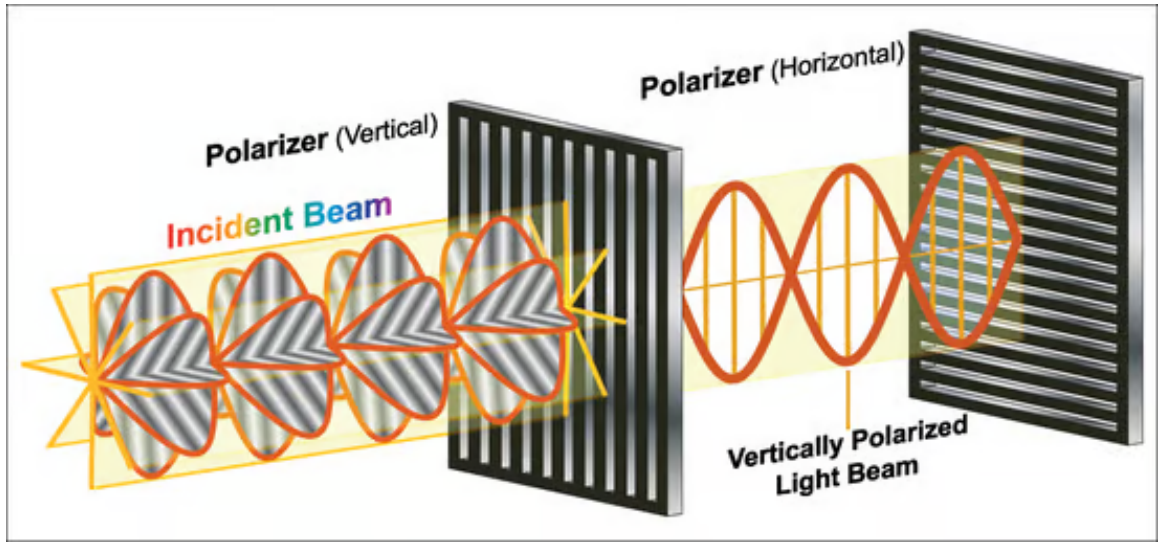
- **SAR**: Measures backscatter from forest canopy
- Preferred for **LAI estimation** in cloudy regions
- Uses X, C, and L frequency bands
  - The X and C Bands of Sentinal data are roughly leaf-sized.

# Relative Difference Polarization Index (RDPI)

- **RDPI**: Index for SAR-based LAI estimation
- Formula:

$$RDPI = \frac{\sigma^0_{VH}}{\sigma^0_{VH} + \tau \cdot \sigma^0_{VV}}$$

- **Challenge:** Correct use requires knowledg of radar heading, terrain slope, etc.

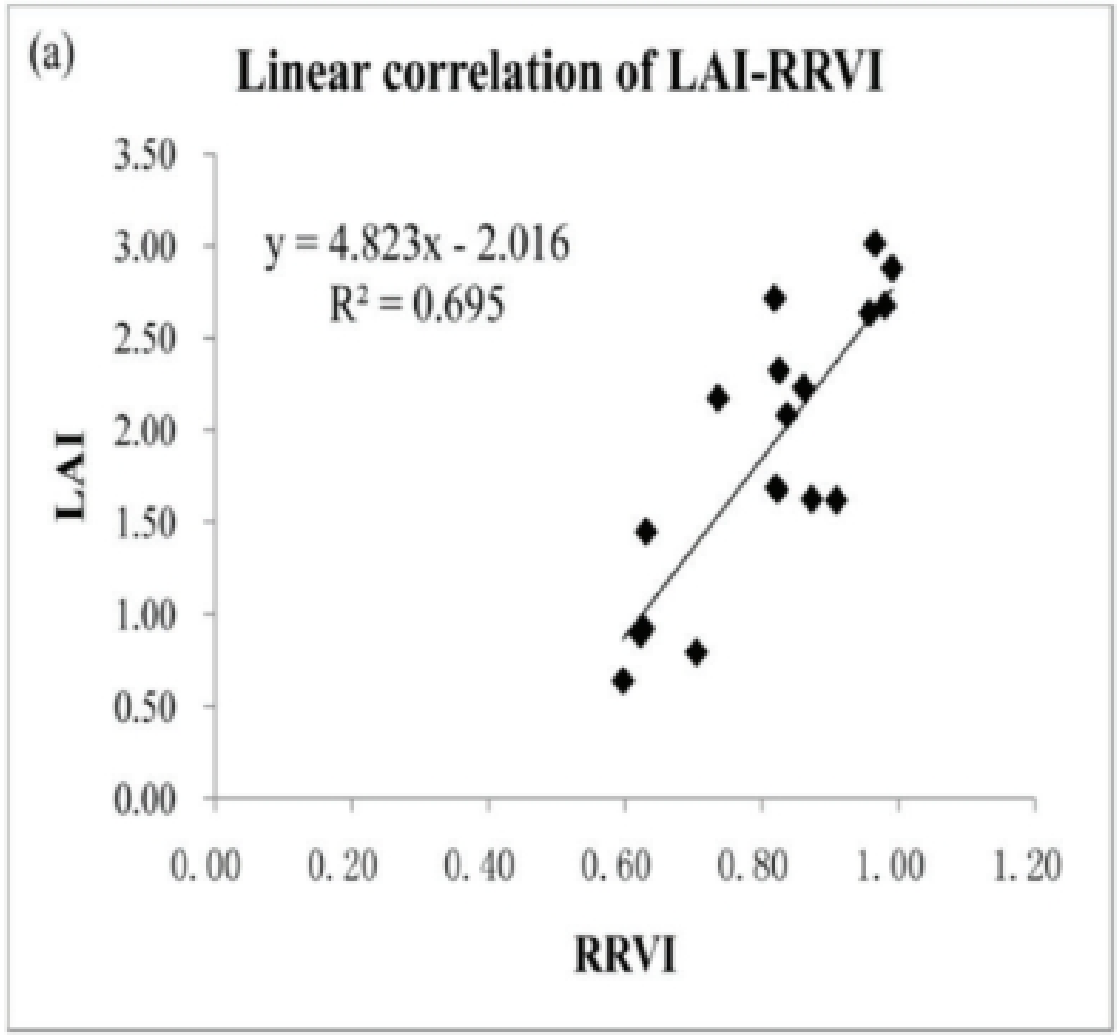


# Radar Ratio Vegetation Index (RRVI)

- **RRVI**: SAR-based vegetation index
- Formula:

$$RRVI = \frac{\sigma^0_{HH}}{\sigma^0_{HV}}$$

(The plot shows it correlates with LAI)

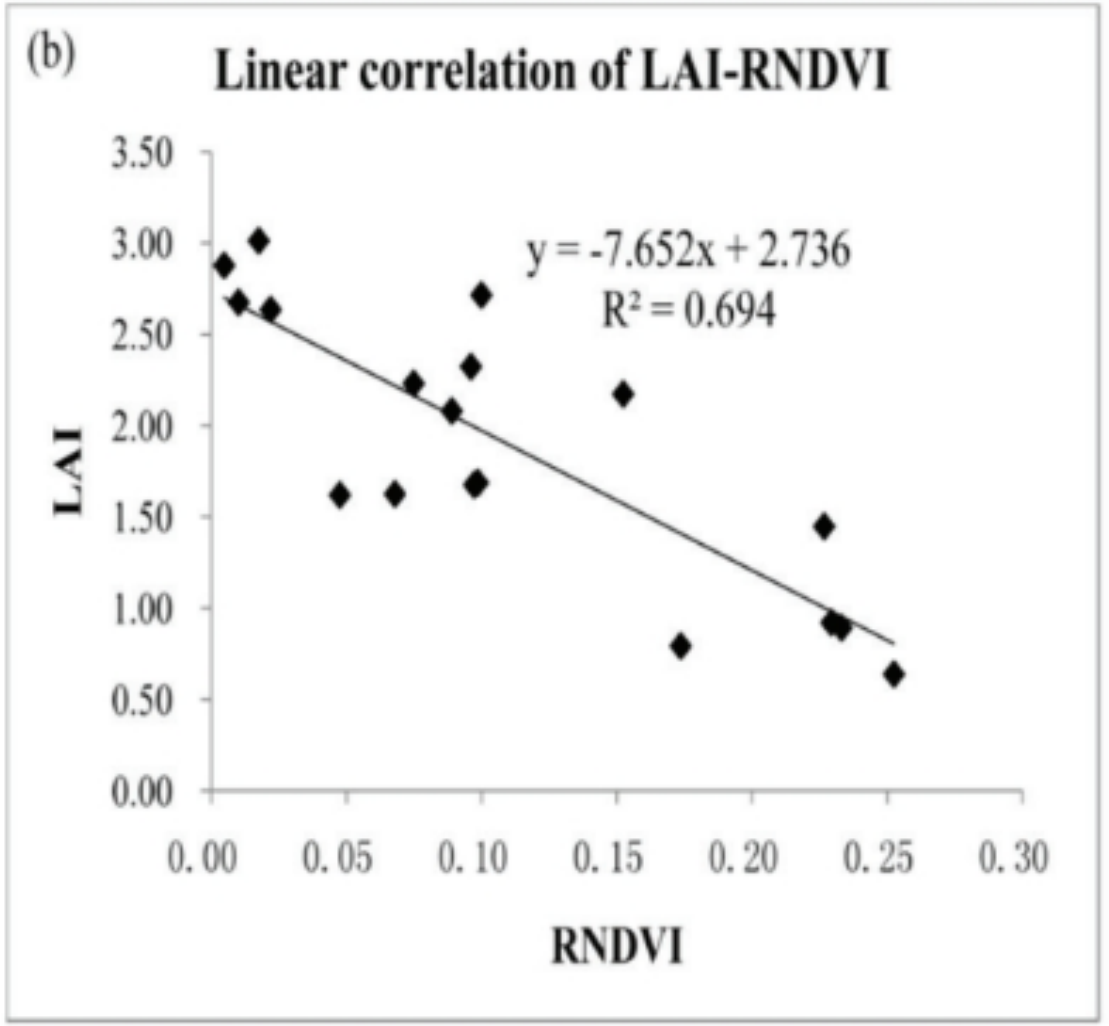


# Radar Normalized Difference Vegetation Index (RRNDVI)

- **RRNDVI**: SAR-based vegetation index
- Formula:

$$RRNDVI = \frac{\sigma^0_{HV} - \sigma^0_{HH}}{\sigma^0_{HV} + \sigma^0_{HH}}$$

(negatively correlated with LAI)



# Managing Competing Vegetation

- Competition affects **tree survival and growth**
- Key to improving **nutrient and water** availability
- **Remote sensing** identifies competition hotspots
- Vertical partitionin of leaf area (e.g. by LiDAR)
- Hyperspectral data to detect species
- Techniques include **seasonal index analysis**
- Ideal for differentiating deciduous and evergreen layers
- Spring and winter comparisons are effective

# Fire!

- Wildfires managed with **remote sensing**
- More than $2B Anually in US
- Includes
    i. Mapping **fuel types** and **burn areas**
    ii. Active Fire Monitoring
    iii. Mapping burned areas.
    iv. Characterizing recovery

# Fuel-Type Mapping

- **Fuelbeds**: Homogeneous landscape units for fire analysis
- Fuel characteristics vary by **species** and **condition**
- Conditions influence **combustion and fire risk**
- Examples shown for Pinus contorta (lodgepole pine)

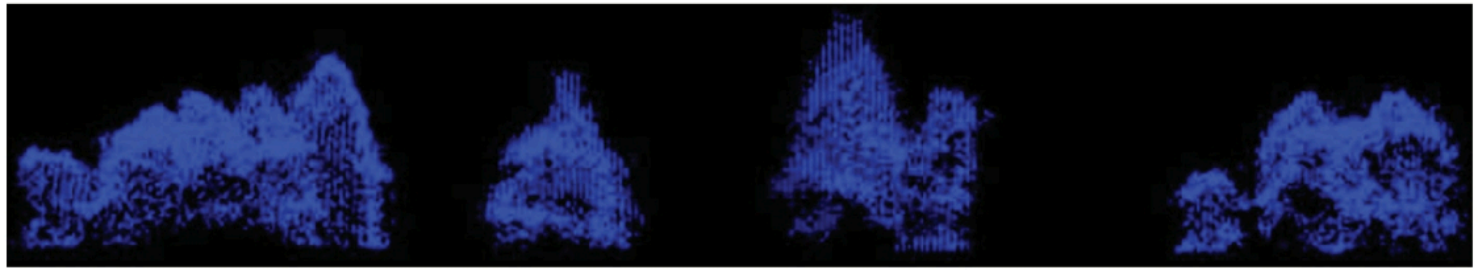
**TABLE 18.2** Select Fuelbed Characteristics for the Same Species, *pinus contorta* (Lodgepole Pine)

| | Overstory cover (%) | Overstory height (feet) | Density (trees/acres) | DBH (inches) |
|---|---|---|---|---|
| 21 | 50 | 5 | 5400 | 0.5 |
| 22 | 70 | 50 | 402 | 4.6 |
| 23 | 50 | 63.2 | 218 | 8.2 |

*Note:* DBH = diameter at breast height. Shown are Fuel Characteristics Classification System (FCCS) fuels 21, young lodgepole pine forest; 22, mature lodgepole pine forest; and 23, mature lodgepole pine forest with bark beetle damage. FCCS version 3.0 as accessed from Fire and Fuel Tools version 2.0.

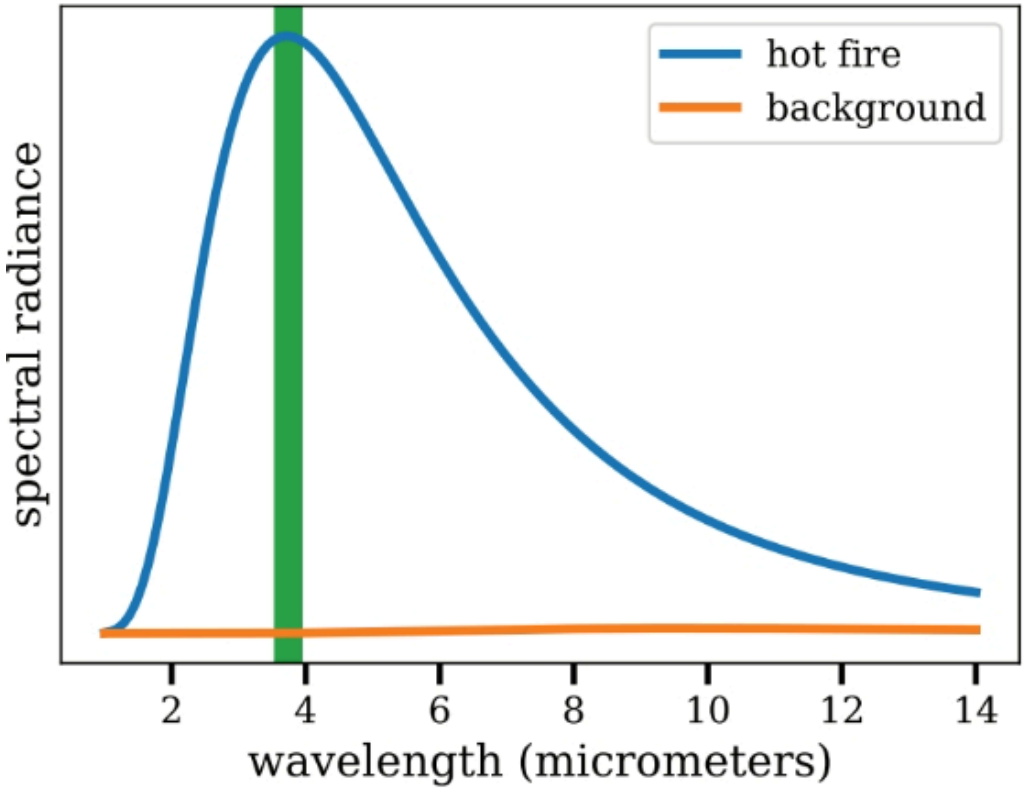
# Remote Sensing and Fuelbed Characteristics

- **Structure from motion** creates 3D fuel maps
- **Multispectral cameras** capture canopy fuels
- Supports accurate fire modeling



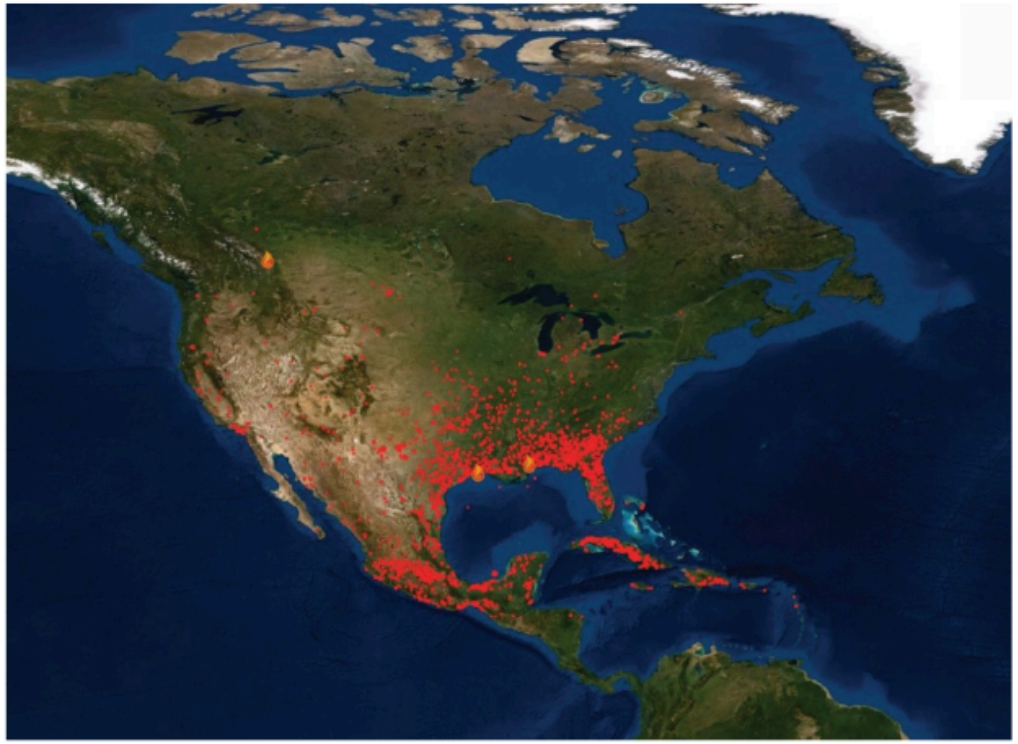
# Active Fire Monitoring Techniques

- **Active fire monitoring** detects heat and energy
- Principle: **Higher temperatures emit shorter wavelengths**
- VIIRS and MODIS sensors used for fire detection



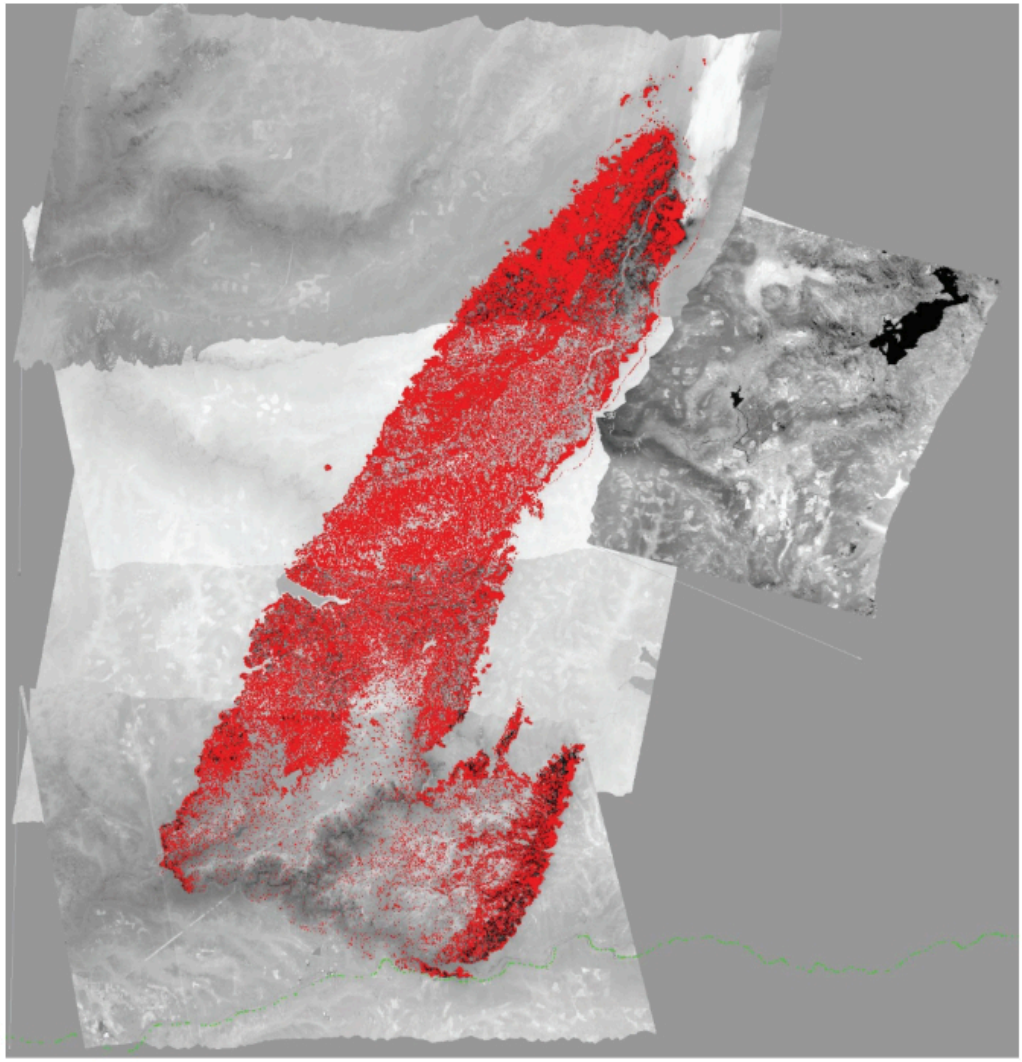
# VIIRS and Day/Night Fire Detection

- **VIIRS**: Uses brightness temperature for night fires
- **Thresholds** set to reduce false positives
- Example of North America fire detection



# Aircraft Thermal Sensors in Fire Monitoring

- **Thermal sensors** monitor large fires
- Gimbal-mounted and scanner systems
- High altitude for wide coverage

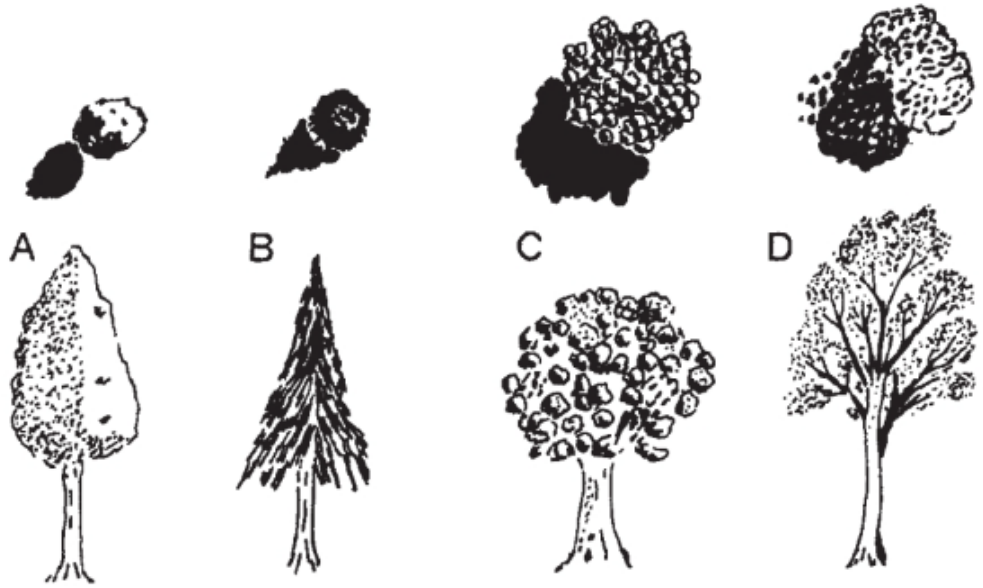


# Identifying Tree Species

- Species identification crucial for **forest management**
- Examines crown **size** and **shape**
- Use of shadows and image patterns

# Crown Shape and Tree Identification

- **Crown characteristics** aid species ID
- Shadows indicate crown structure
- Image patterns reveal tree density



# Forest Photogrammetry Techniques

- Photogrammetry measures **stand characteristics**
- Use of **stereo aerial photography**
- Supports volume and growth analysis

# Crown Closure and Stand Density

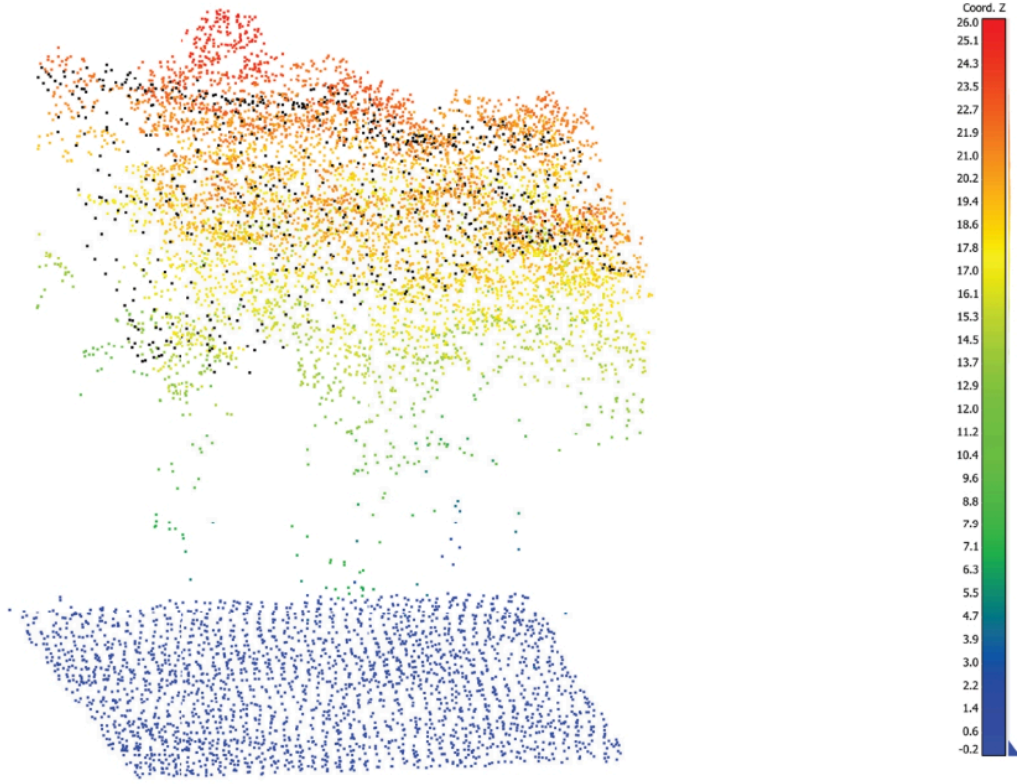
- **Crown closure**: Proportion of area covered by tree crowns
- Indicates **stand density** and **competition level**
- Related to stand productivity

# Estimating Timber Volume

- Timber volume crucial for **economic valuation**
- Field measures include **DBH and height**
- Aerial methods approximate volume for stands

# Role of Lidar in Forest Inventory

- **Lidar** captures 3D forest structure
- Measures heights, crown closure, and leaf area
- Backbone of modern forest inventories



# Summary of Forest Management Goals

- **Sustainable management** of forest resources
- Aims include **productivity, biodiversity,** and **fire control**
- Remote sensing and modern tools play critical roles