Spatial simulation models for landscape-level forest research and management

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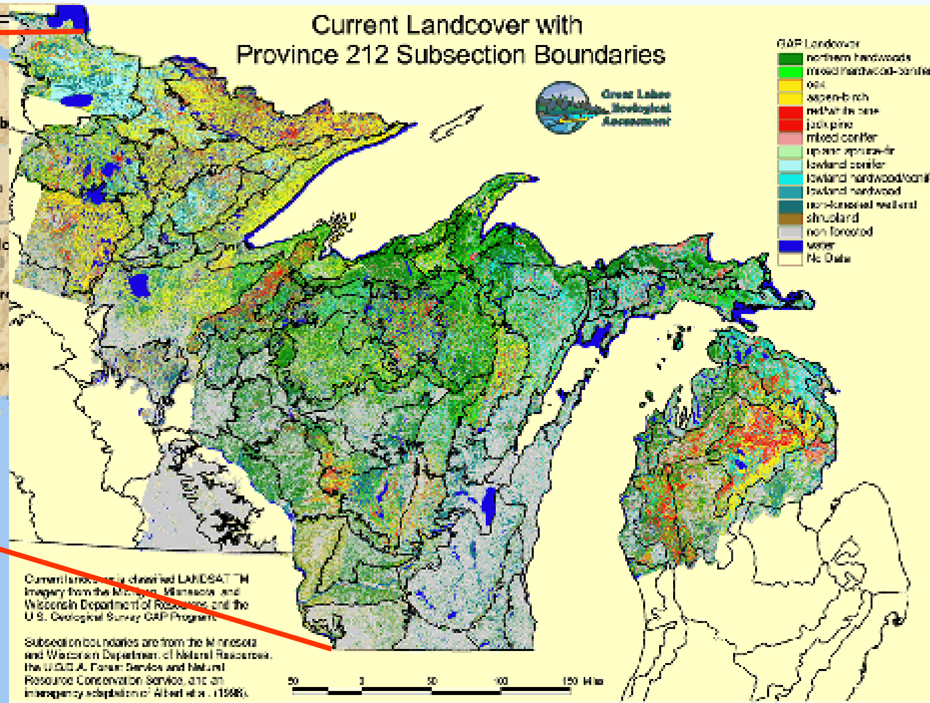


Forestry Sciences Laboratory
Rhinelander, Wisconsin

April 27, 2006

Landscape Ecology

Focuses on 3 characteristics of landscapes:

- Structure - the spatial relationships among the distinctive ecological elements present
- Function - the interactions among the spatial elements (ecological processes)
- Change - the alteration in the structure and function of the landscape over time

Landscape Ecology

- Landscape ecology provides a useful conceptual framework for studying the interaction of forest management and other human disturbances, natural disturbances and forest succession
- Questions about forest sustainability necessarily must be asked at broad spatial and temporal scales

Objectives of talk

- Today I will describe the use of landscape-level simulation models to address:
  - Cumulative effects of multiple landowner management objectives within a landscape
  - Evaluating landscape-level management strategies to reduce the risk of catastrophic wildfire
- Convey the modeling approach we are using
- Models used:
  - HARVEST
  - LANDIS

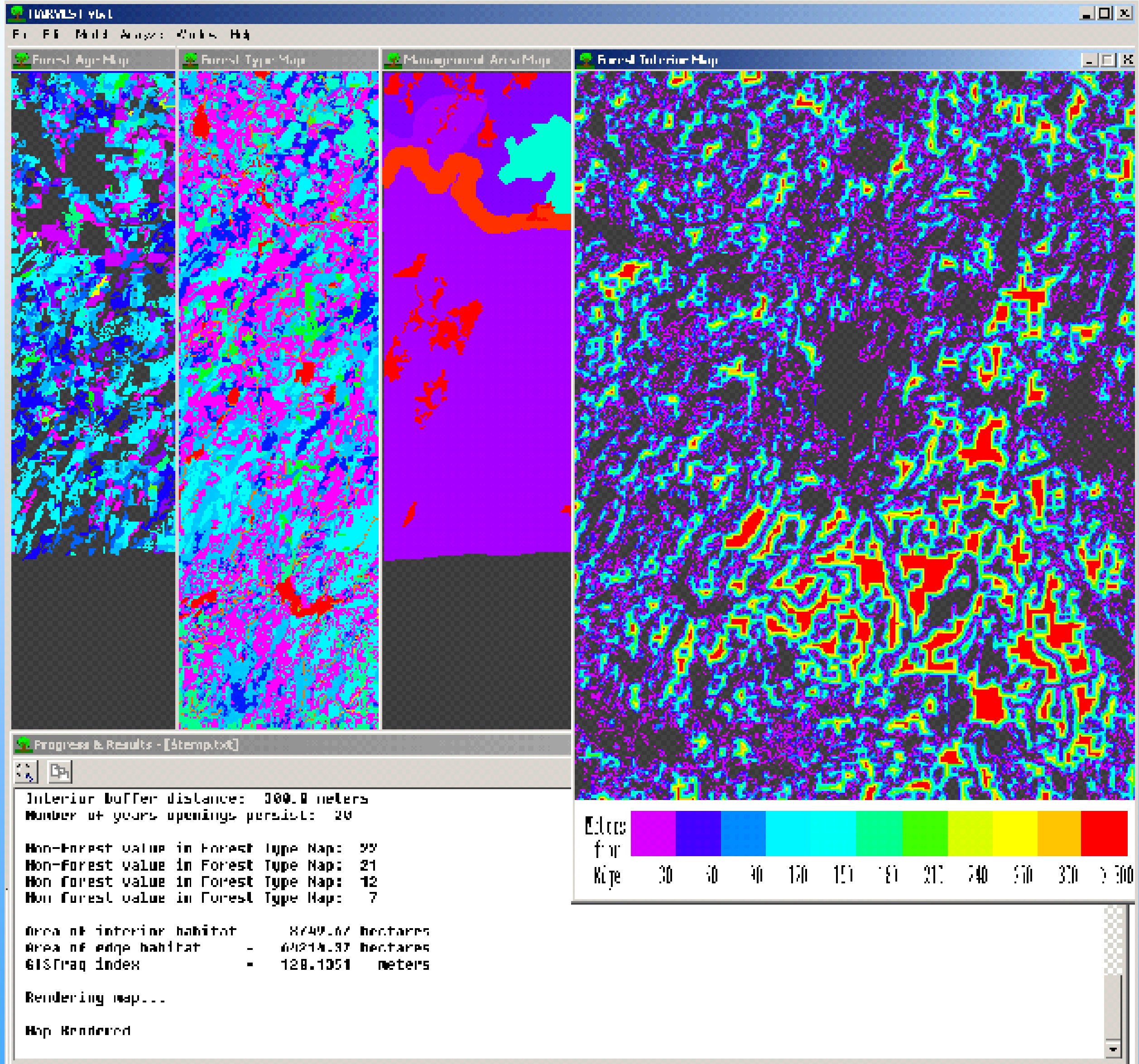
HARVEST
Timber Harvest Simulation Model

- Designed to evaluate the spatial pattern consequences of timber management strategies
  - Provides a coarse-filter evaluation of broad management strategies
  - Focuses exclusively on the spatial pattern of forest openings, forest type and successional stages
  - Stochastic (random), spatial realization of management strategies

HARVEST
Strengths

- Predicts the expected spatial pattern under strategic management options
- Provides visual and quantitative projections of patterns at landscape scale
- Produces objective comparisons of alternatives
- Has limited input data requirements allowing rapid assessment over large areas (>10^6 ha)
- Ease of use

HARVEST User Interface



HARVEST
Limitations

- Not appropriate for tactical planning
- Does not find an optimal solution for an objective function
- Does not simulate forest succession
- Does not account for natural disturbances
- Simplistic assumptions about management logistics and access

Cumulative effects of multiple landowners within a landscape

- Little is known about the cumulative landscape effects of multiple owners who each have a different management objective
  - Forest composition
  - Forest age distribution
  - Forest fragmentation
  - Patch structure
  - Indicators of biodiversity

Background

- Industrial forestland owners manage their forests primarily to produce fiber to supply their paper mills
- State and Federal owners manage their forests for recreation, wildlife, water and timber
- Private citizen owners manage either for wildlife, timber or natural beauty

Background

- It is unlikely that viable populations of some species can be maintained through the actions of a single landowner
  - Population viability is a function of the combined actions of multiple landowners
  - Each owner affects the mosaic of forest types, stand structures and age distributions

Study Objective

- Understand the cumulative effects on biodiversity of forest management in a multi-ownership landscape that is managed for timber production and recreation
- Focus on landscape patterns, and make inferences about how those patterns might affect biodiversity

Montreal Process Working Group

- Twelve governments agreed on criteria and indicators to monitor the conservation and sustainable management of temperate and boreal forests at the national level
  - Information on trends is an essential step in measuring progress toward the goal of sustainable forest management
  - Includes ecosystem functions and attributes (biodiversity, productivity, among others)

Montreal Process Indicators

Criterion 1. Conservation of Biological diversity

Indicators

1.1 Ecosystem diversity

1.1.a Extent of area by forest type (i.e., proportion)

1.1.b Extent of area by age class or successional stage relative to total forest area (i.e., proportion)

1.1.e Fragmentation of forest types

Montreal Process Indicators

Criterion 2. Maintenance of productive capacity of ecosystems

Indicators

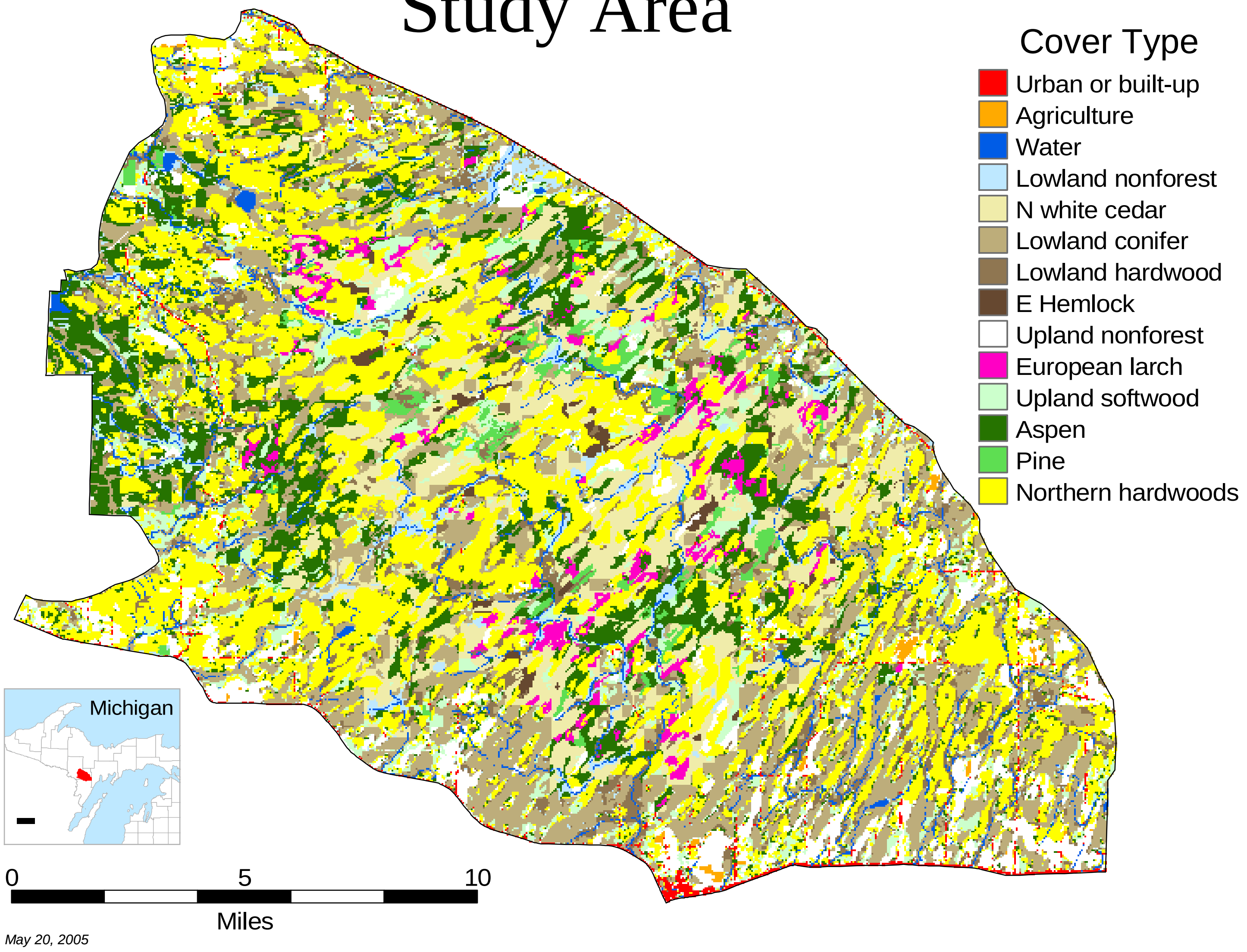
2.c The area and growing stock of plantations of native and exotic species

Assumptions

- Higher biodiversity is assumed to be associated with:
  - A distribution of forest types that is moving closer to pre-settlement proportions
  - Larger patch sizes
  - Lower edge density (assumes relatively high edge density in current landscape)
  - Reduced fragmentation
- Higher productivity is assumed to be associated with:
  - Increasing area of plantations

Michigan
Wisconsin
Lake Superior
Lake Michigan
50°0'0"N
40°0'0"N
30°0'0"N
105°0'0"W
90°0'0"W
75°0'0"W
0
25
Miles
May 23, 2005

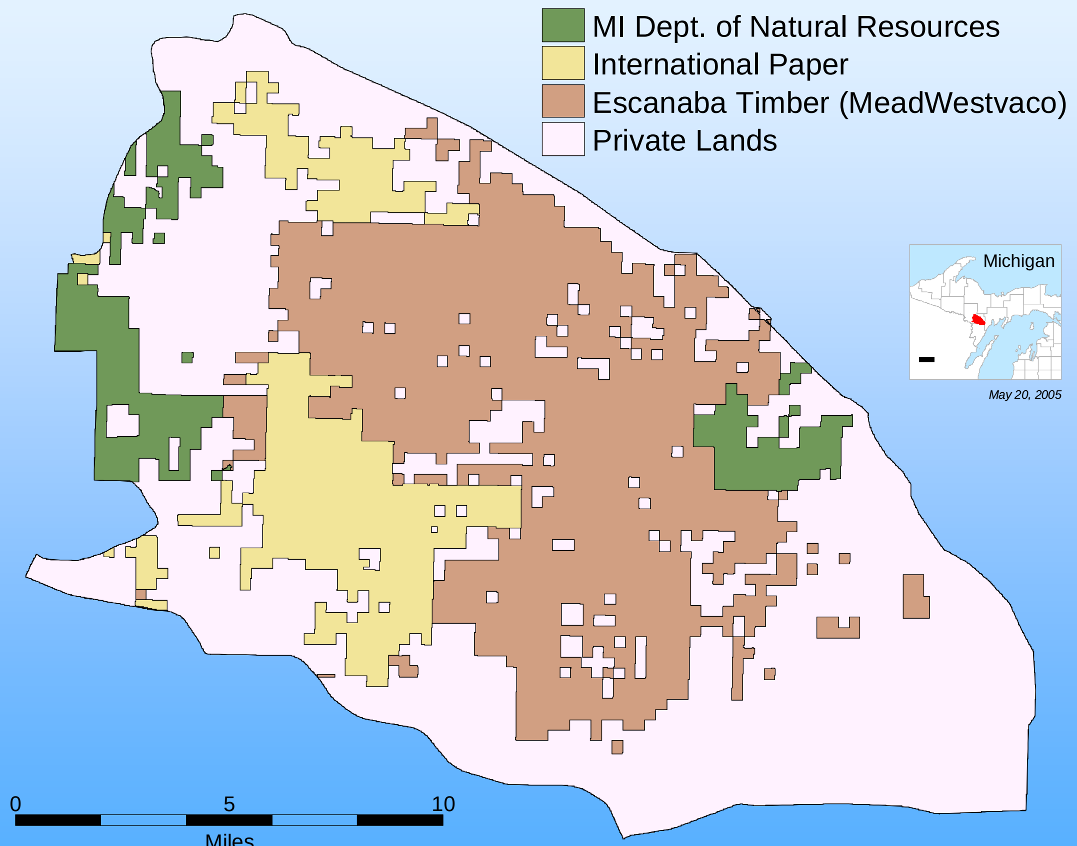
Study Area


Cover Type
Urban or built-up
Agriculture
Water
Lowland nonforest
N white cedar
Lowland conifer
Lowland hardwood
E Hemlock
Upland nonforest
European larch
Upland softwood
Aspen
Pine
Northern hardwoods
Michigan
0
5
10
Miles
May 20, 2005

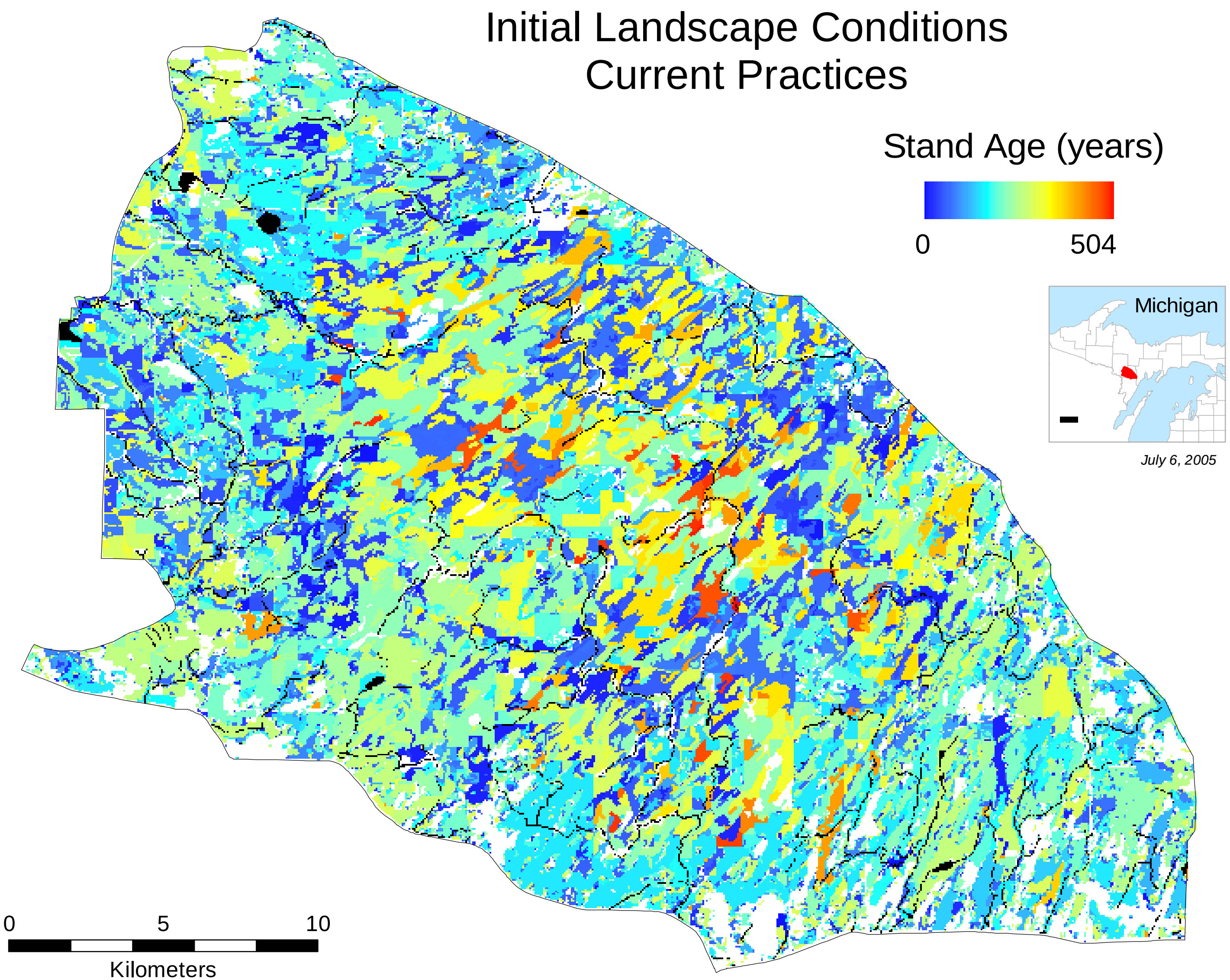
Owners and their objectives

- Escanaba Timber LLC – 22,002 hectares
  - softwoods, primarily even-aged
- International Paper – 7,828 hectares
  - hardwoods, primarily uneven-aged
- Michigan Dept. of Natural Resources – 4,426 hectares
  - slightly less intensive, mix of even and uneven-aged
- Non-industrial private forest landowners – 33,896 hectares
  - 40% unmanaged (from Timber Owners survey)

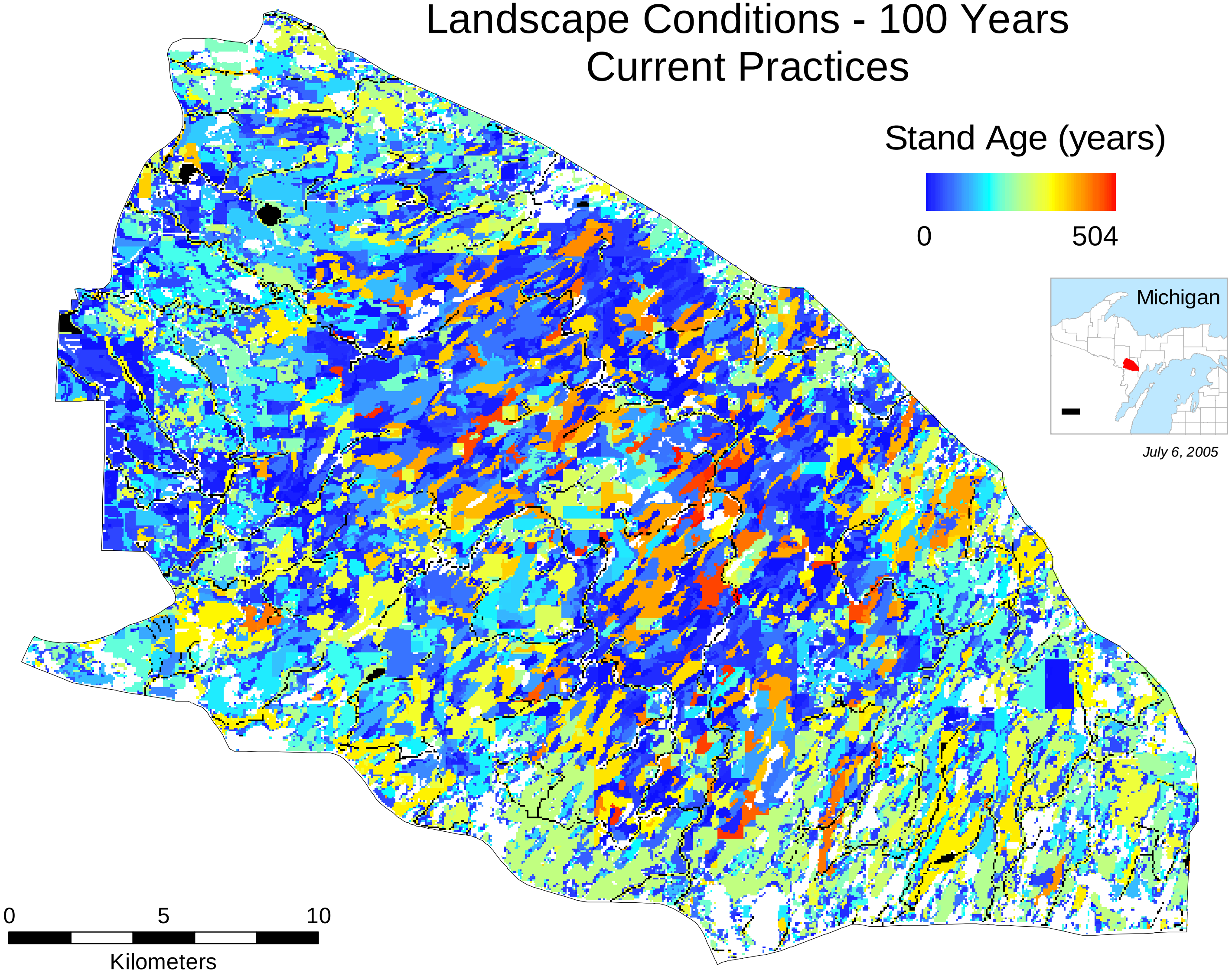
Ownership Boundaries

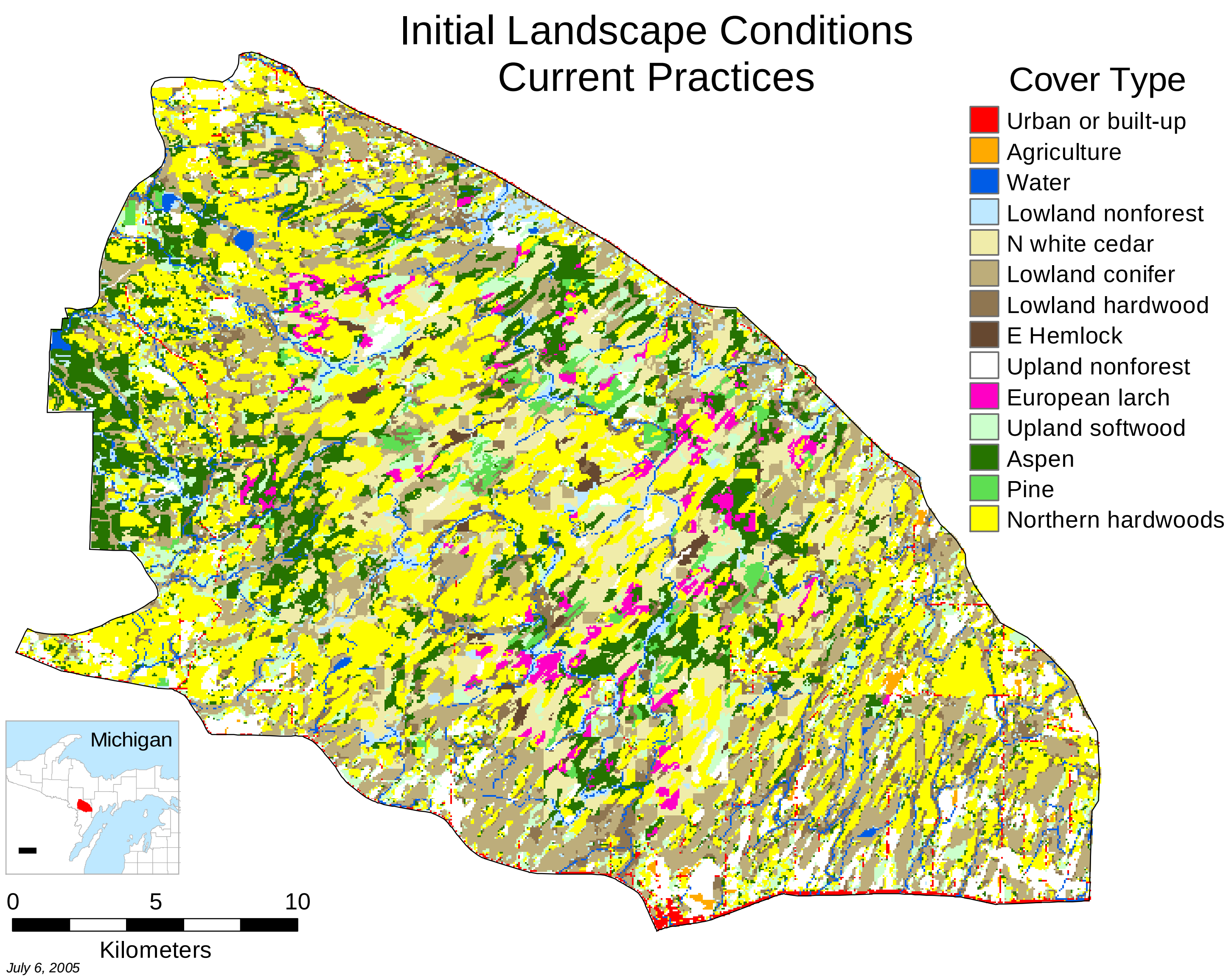


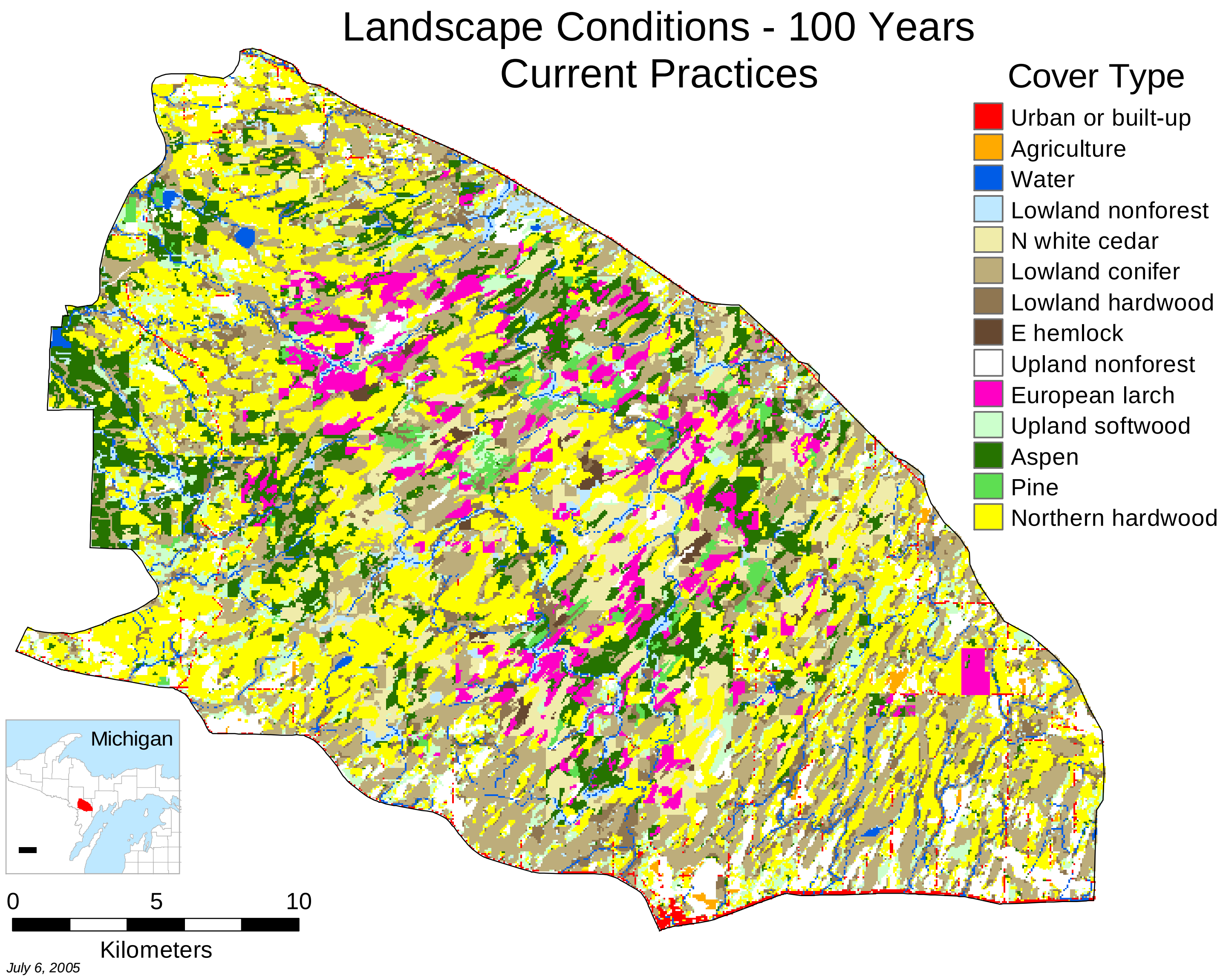
Results


Initial Landscape Conditions
Current Practices
Stand Age (years)
0
504
Michigan
July 6, 2005
0
5
10
Kilometers

Landscape Conditions - 100 Years
Current Practices




Initial Landscape Conditions
Current Practices
Cover Type
Urban or built-up
Agriculture
Water
Lowland nonforest
N white cedar
Lowland conifer
Lowland hardwood
E Hemlock
Upland nonforest
European larch
Upland softwood
Aspen
Pine
Northern hardwoods
Michigan
0
5
10
Kilometers
July 6, 2005


Landscape Conditions - 100 Years
Current Practices
Cover Type
Urban or built-up
Agriculture
Water
Lowland nonforest
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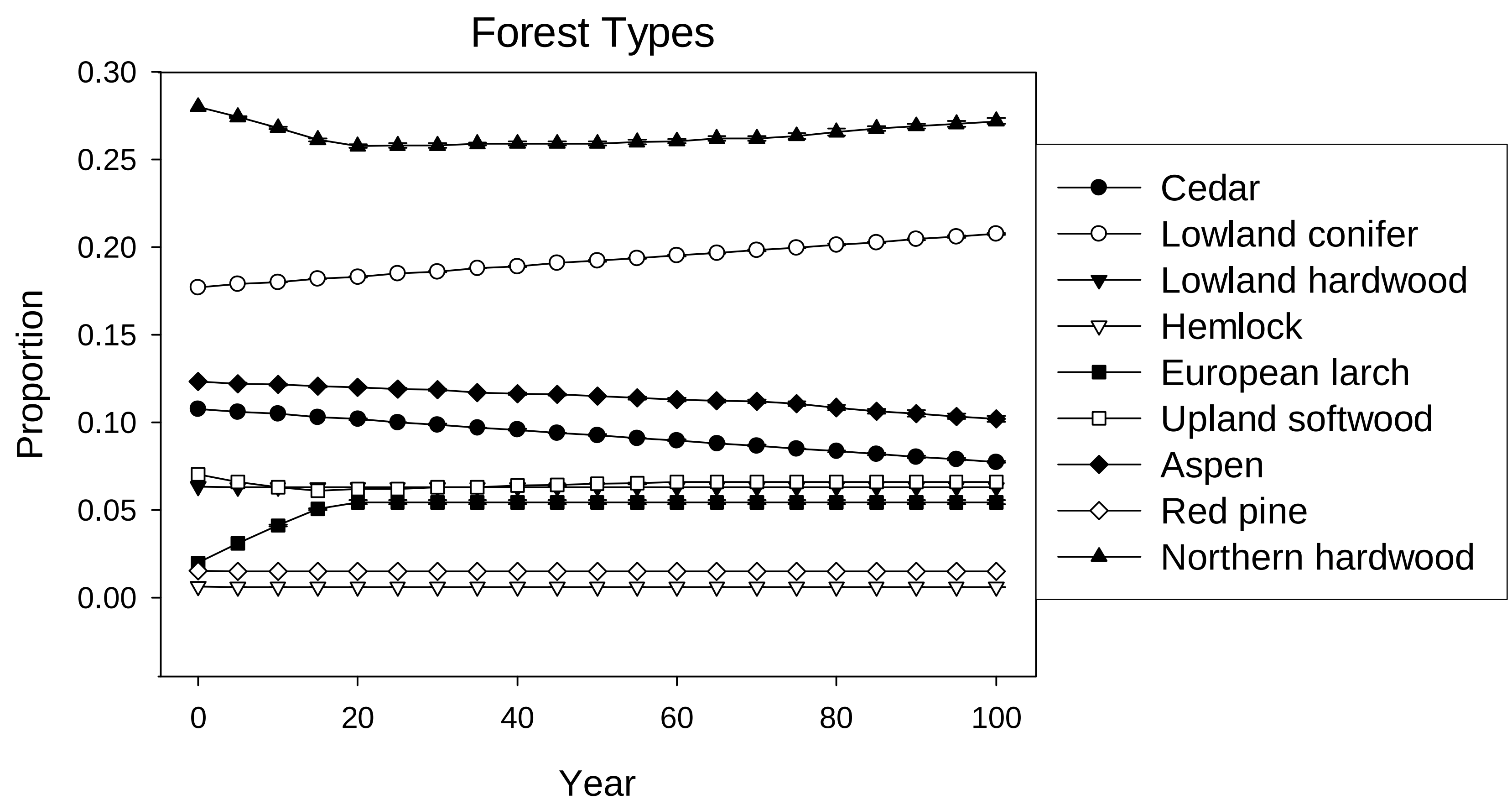
Lowland conifer
Lowland hardwood
E hemlock
Upland nonforest
European larch
Upland softwood
Aspen
Pine
Northern hardwood
Michigan
0
5
10
Kilometers
July 6, 2005

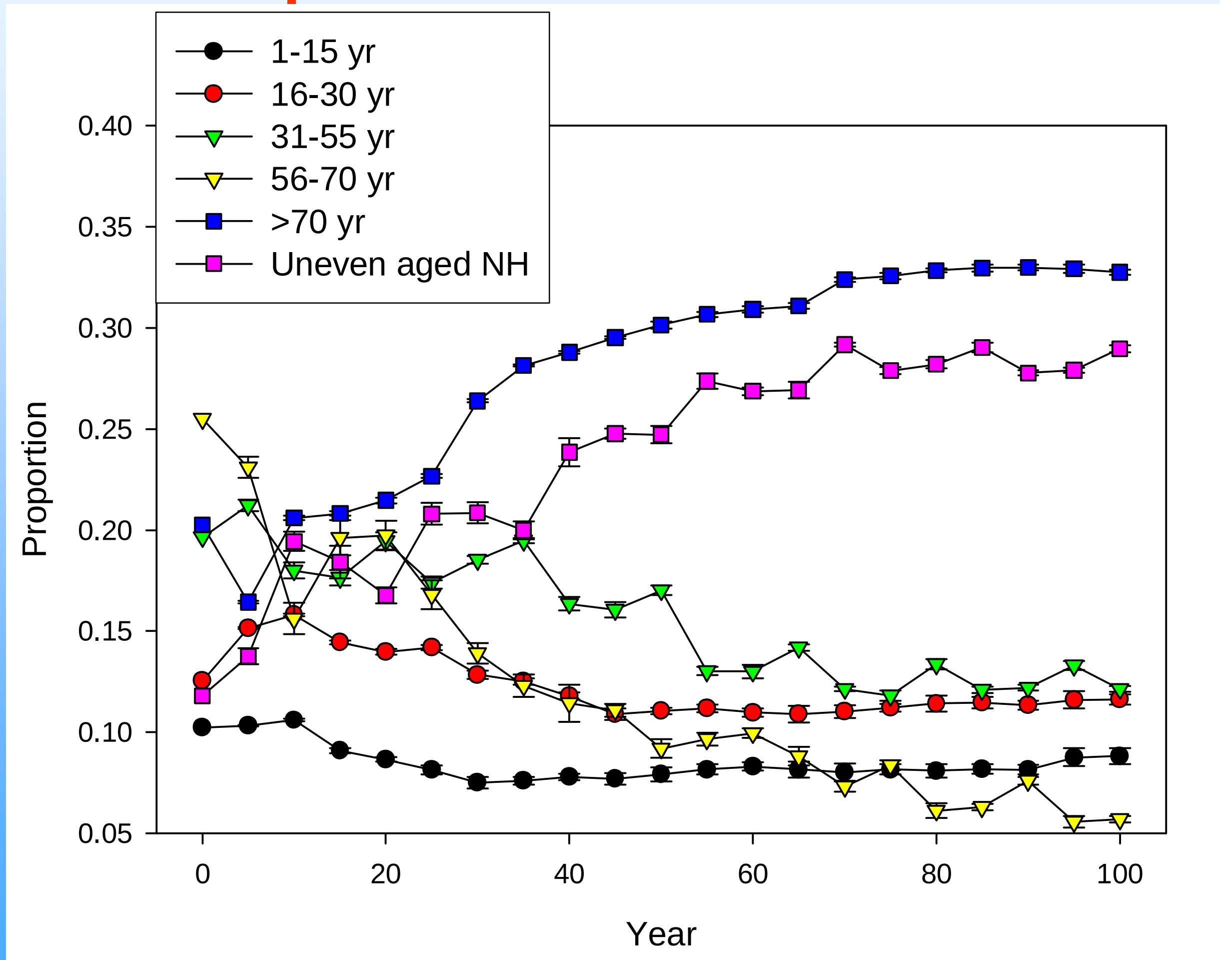
Higher biodiversity is assumed when the distribution of forest types is closer to pre-settlement conditions



Pre-settle-ment*
(0.04)
(0.38)
(0.01)
(0.09)
(0.00)
(0.01)
(0.02)
(0.01)
(0.45)

* GLO - Corner et al. 1995

Higher biodiversity is assumed when the distribution of seral stages is closer to pre-settlement conditions



Pre-settlement*

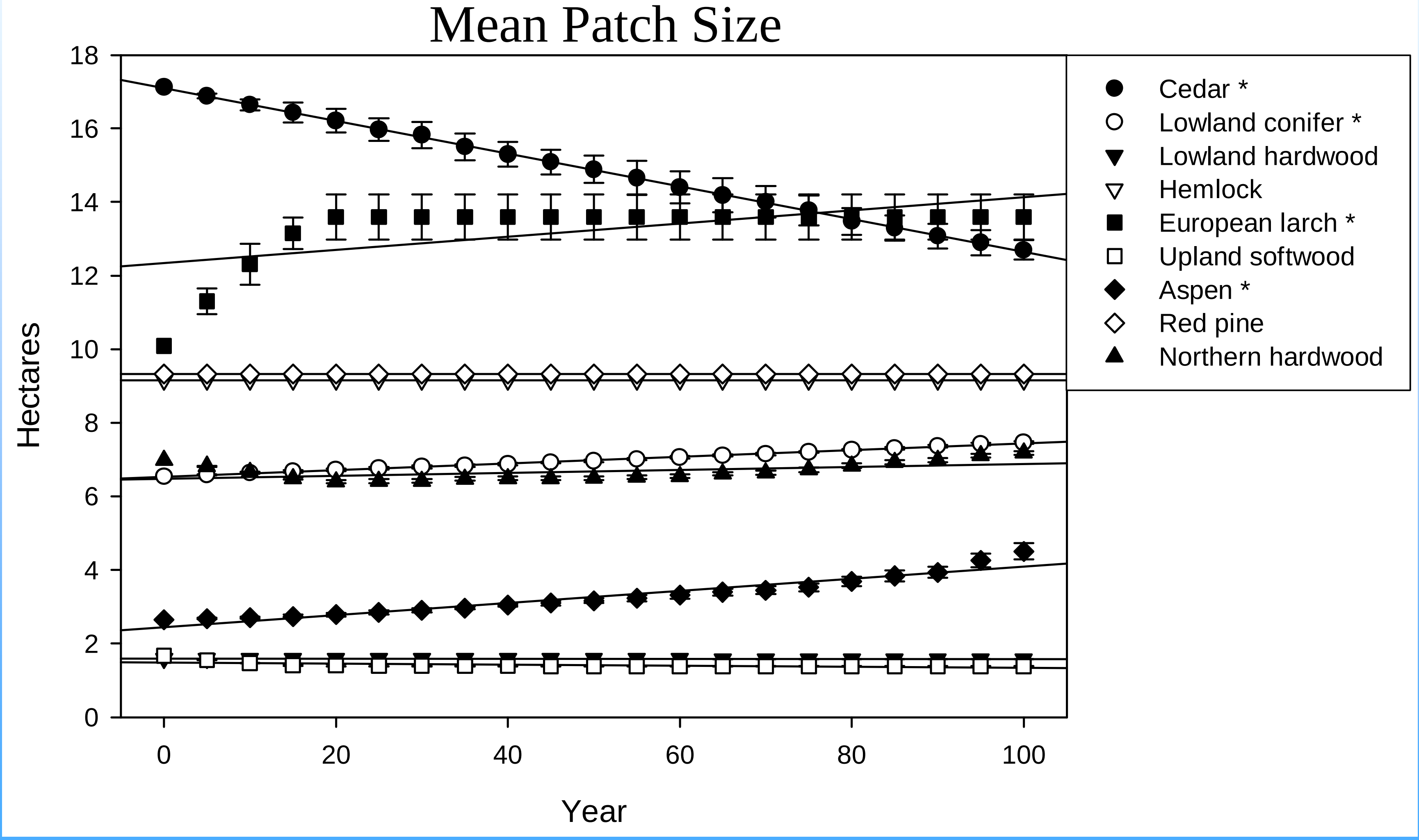
(0.5-0.6)

(0.3-0.4)

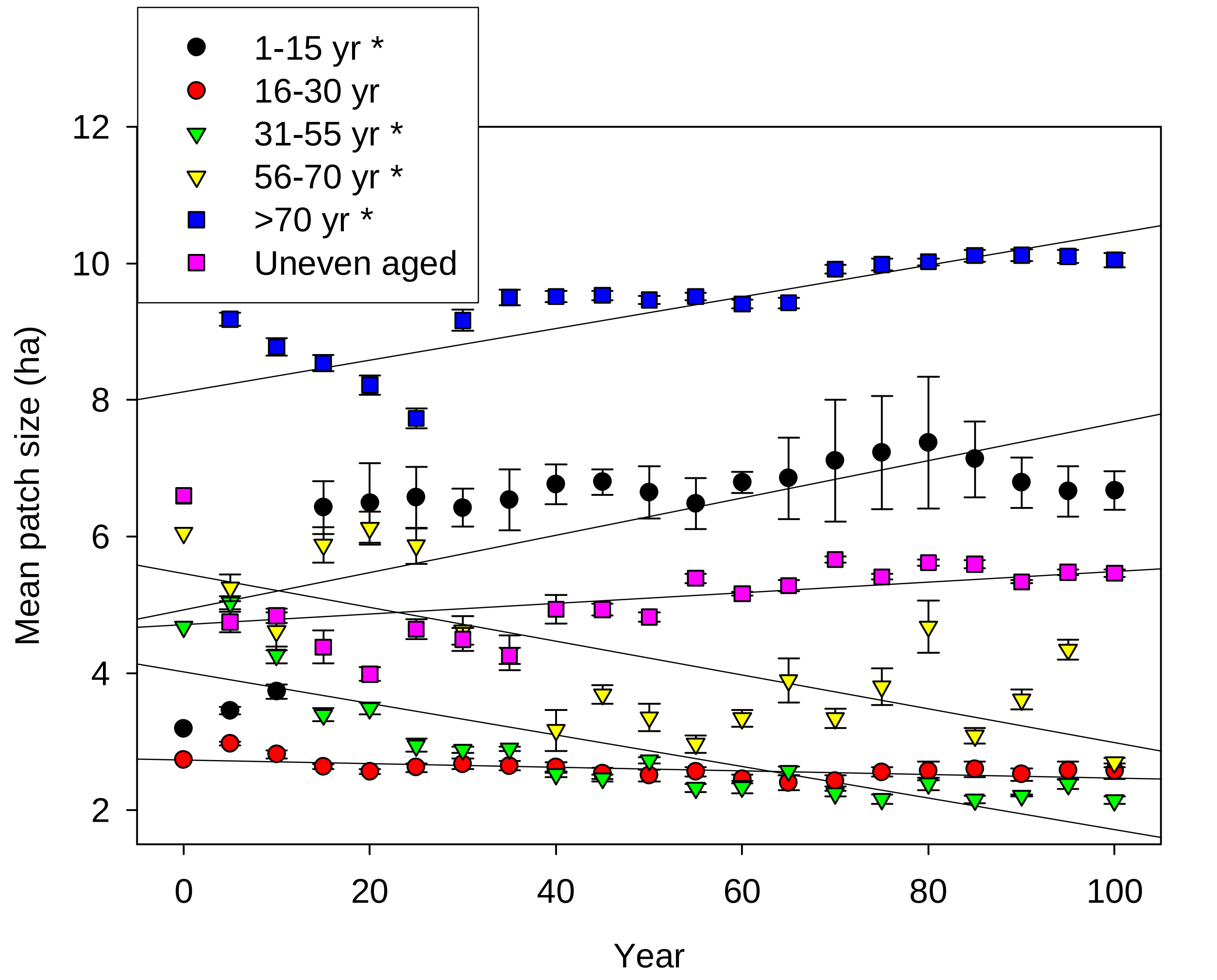
(relatively low)

*Reference condition database (Swaty)

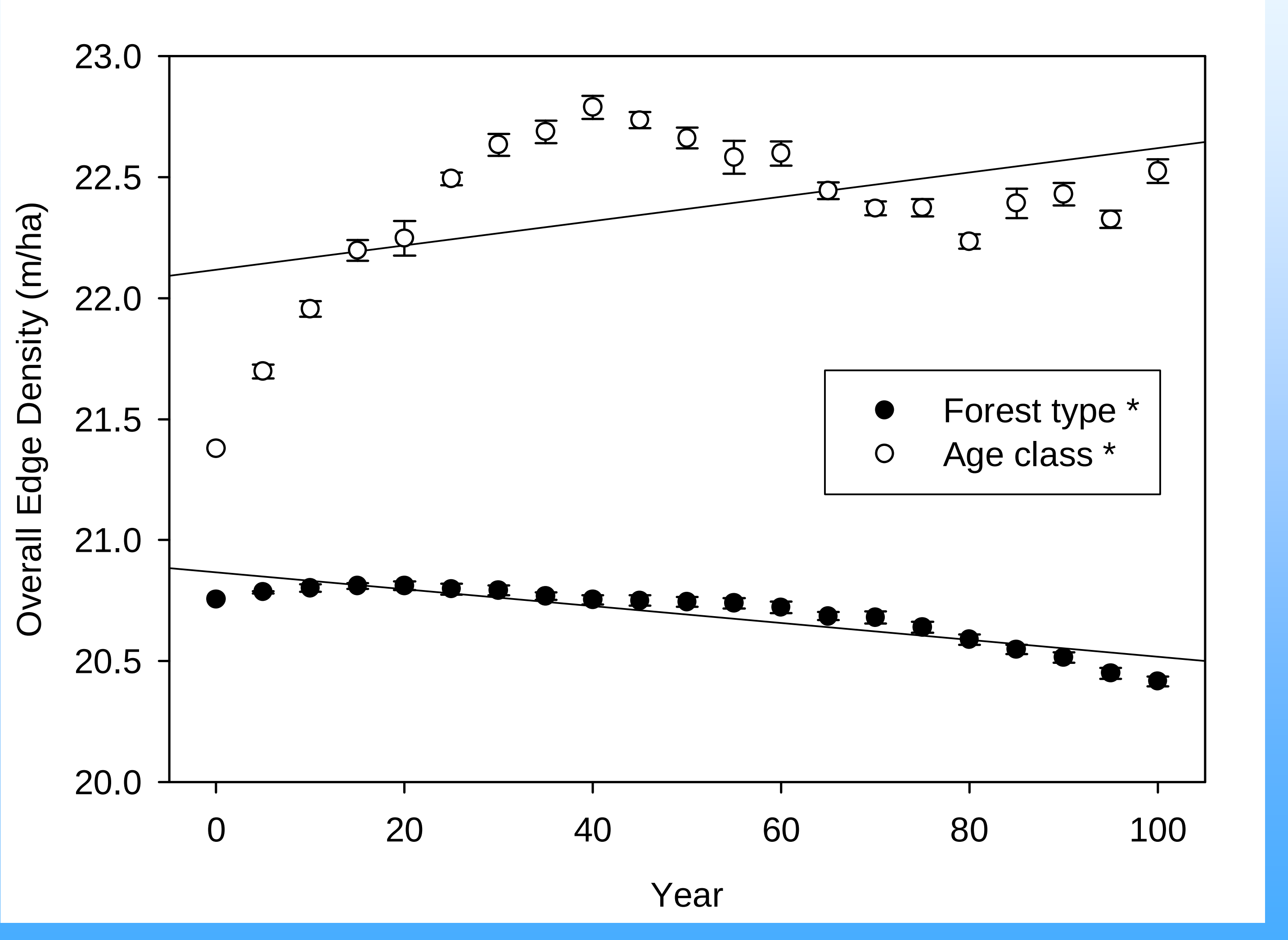
Higher biodiversity is assumed to be associated with larger patch sizes



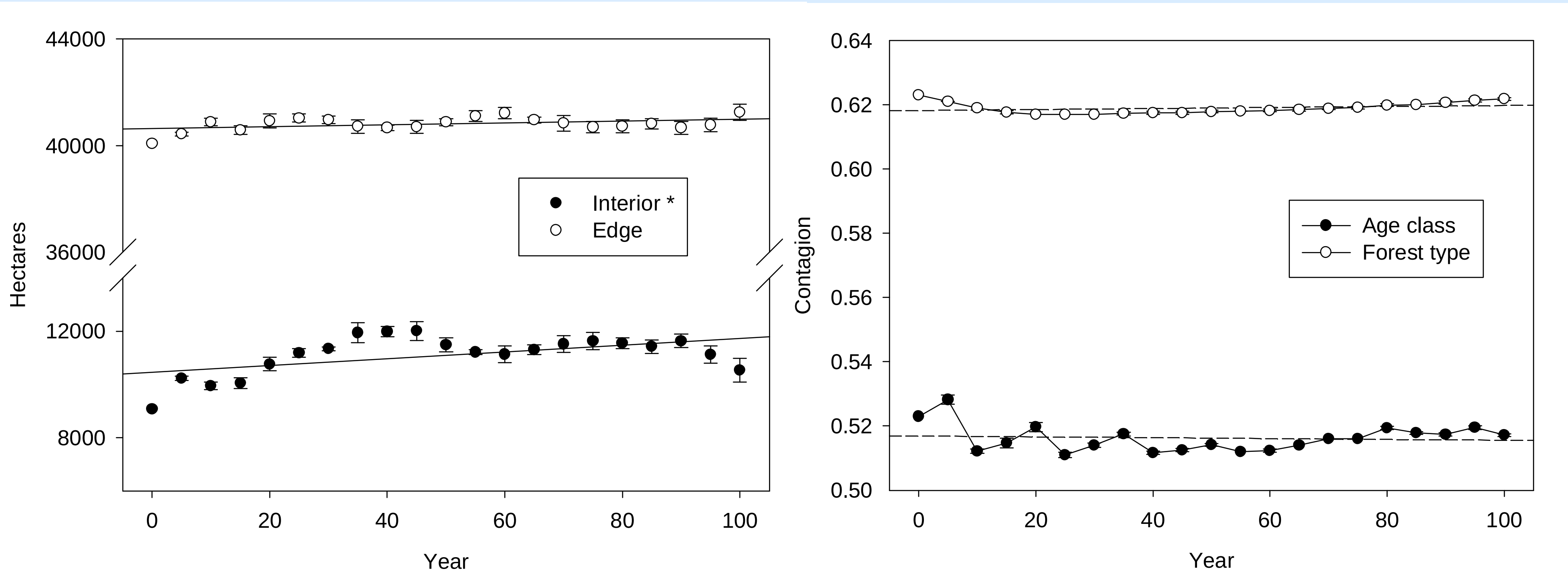
Higher biodiversity is assumed to be associated with larger patch sizes



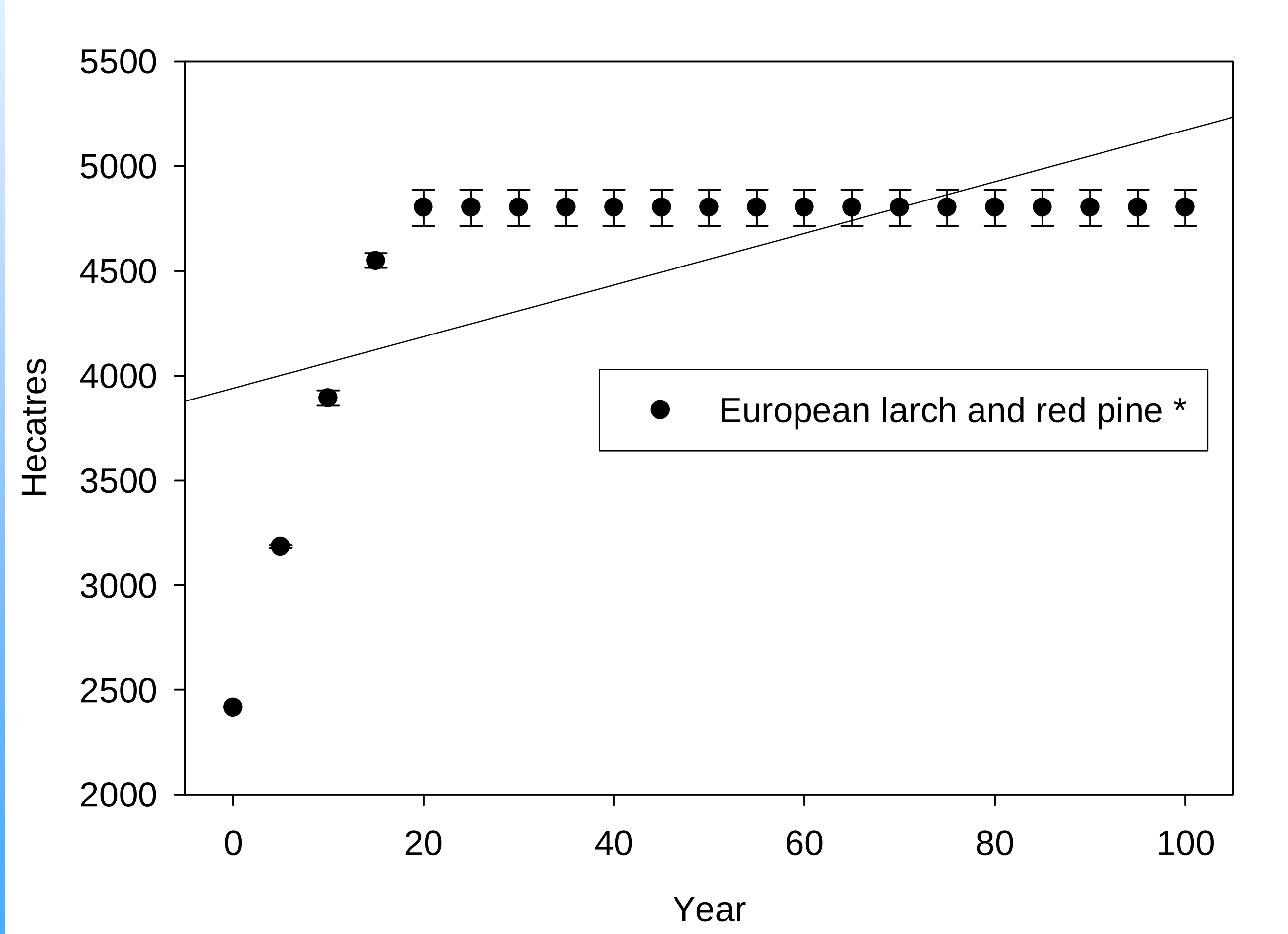
Higher biodiversity is assumed to be associated with lower edge density



Higher biodiversity is assumed to be associated with reduced fragmentation



Higher productivity is assumed to be associated with increasing area of plantations



Conclusions

- Some measures show trends considered favorable for sustainability and conservation while others do not
- However, it appears that trends in this landscape are generally favorable for sustainability
- Each owner provides habitat conditions that cumulatively produce a positive result
- Our approach provides a tool for evaluating cumulative effects on multiple ownership landscapes
  - Determine how the actions of each owner influence the overall pattern
  - Evaluate cooperative strategies to improve landscape patterns

Reducing the risk of catastrophic wildfire in the wildland-urban interface

- One component of the US National Fire Plan is to reduce the risk of wildfire through hazardous fuels reduction
  - Remove accumulated fuel from forests
  - Change composition to less flammable types
  - Modify the spatial configuration of fuels:
    - Reduce likelihood of spread
    - Reduce fuels near ignition sources (people)

Ecosystem Influence on Fire in the Midwestern U.S.

- Fire ignitions are primarily determined by presence of ignition sources and by land type
  - Housing and population density, roads
  - Climate
  - Soil water retention
- Fire spread is primarily determined by vegetation characteristics
  - Flammability of living tissue (e.g., needles)
  - Amount and flammability of dead biomass
  - Connectedness of fuels

Human Influence on Fire in the Midwestern U.S.

- Humans are the predominant cause of fire ignitions in the Lake States (97%).
- State and Federal agencies follow a strict fire suppression policy.
- Modern fire regime relative to presettlement periods:
  - Fire frequency is now much greater, especially near human homes and transportation networks
  - Modern fire rotations have increased by an order of magnitude

LANDIS - Disturbance and Succession Simulation Model

- Process-based model to simulate forest dynamics at landscape scales
  - Disturbance (including vegetation management)
  - Succession
  - Broad spatial (10^3-10^6 ha) and temporal (centuries) scales
- Useful to evaluate the spatial and composition consequences of alternative scenarios
  - Timber management
  - Fuels management
  - Land use management
  - Global change (climate, human population, air pollution)

LANDIS - Disturbance and Succession Simulation Model

Distinct processes simulated by LANDIS:

- By ecological unit (land type)
  - Succession
  - Windthrow
  - Fuel accumulation and decomposition
  - Fire (ignition, intensity and spread)
- By management unit
  - Harvest
  - Fuel reduction (including prescribed burning)
- Landscape-wide
  - Biological agents (e.g., insects, disease, etc.)
  - Human effects (fire ignition and suppression)

LANDIS - Disturbance and Succession Simulation Model

LANDIS data structure

- Landscape is represented as a grid of cells
- Model tracks age cohorts of each species (presence/absence or biomass) rather than individual trees
- Succession process establishes and ages cohorts, and simulates natural mortality (senescence)
- Multiple disturbance processes can be invoked to simulate death or reduction of cohorts. The harvest module can establish cohorts (by planting.)

LANDIS - Disturbance and Succession Simulation Model

Succession

- Succession is simulated using the life history attributes of tree species
  - Longevity
  - Establishment coefficient (land type dependent)
  - Shade tolerance
  - Fire tolerance
  - Sprouting ability
  - Age of sexual maturity
  - Maximum seeding distance
- Understory species are not currently simulated

LANDIS - Disturbance and Succession Simulation Model

Windthrow

- Windthrow events are simulated stochastically using a mean return interval (frequency of events), severity class, and a size distribution, all of which are land type dependent
- This is a top-down disturbance (i.e., older cohorts are more susceptible to mortality than younger cohorts)

LANDIS - Disturbance and Succession Simulation Model

Fuel

- Model tracks 5 fuel classes for fine and coarse fuels, and a live fuel class
- Quantity of fuel depends on species and their age
- Quality of fuel depends on the species
- Relative rates of fuel accumulation and decomposition are age and land type dependent

LANDIS - Disturbance and Succession Simulation Model

Fire

- Fire is a bottom-up disturbance (i.e., younger cohorts are more susceptible to mortality than older cohorts)
- Fire ignition processes are land type dependent
  - Can be modified by the presence of humans
- Fire spread processes are vegetation dependent
- Fire effects (severity of damage) are dependent on fuel class, fire tolerance of species and age of cohorts present on a burned site

LANDIS - Disturbance and Succession Simulation Model

Harvest (vegetation and/or fuel management)

- Harvest prescriptions are targeted to forest types within Management Areas (spatial zones)
  - Ranking methods are criteria to determine the order in which stands are selected for harvest
  - Temporal parameters determine when the prescription is applied
  - Removal masks determine which cohorts are removed by the harvest

LANDIS - Disturbance and Succession Simulation Model

Biological Disturbance Agents (insects, disease)

- Probability of disturbance depends on the presence of hosts and the disturbance agent
- Probability of disturbance is based on both local (cell) conditions and neighborhood conditions
- Mortality depends on species susceptibility and is usually top-down (i.e., older cohorts more susceptible)
- Outbreaks can take a number of temporal patterns (chronic, periodic, random, etc.)
- Broad-scale spatial dynamics of outbreaks and dispersal can be simulated

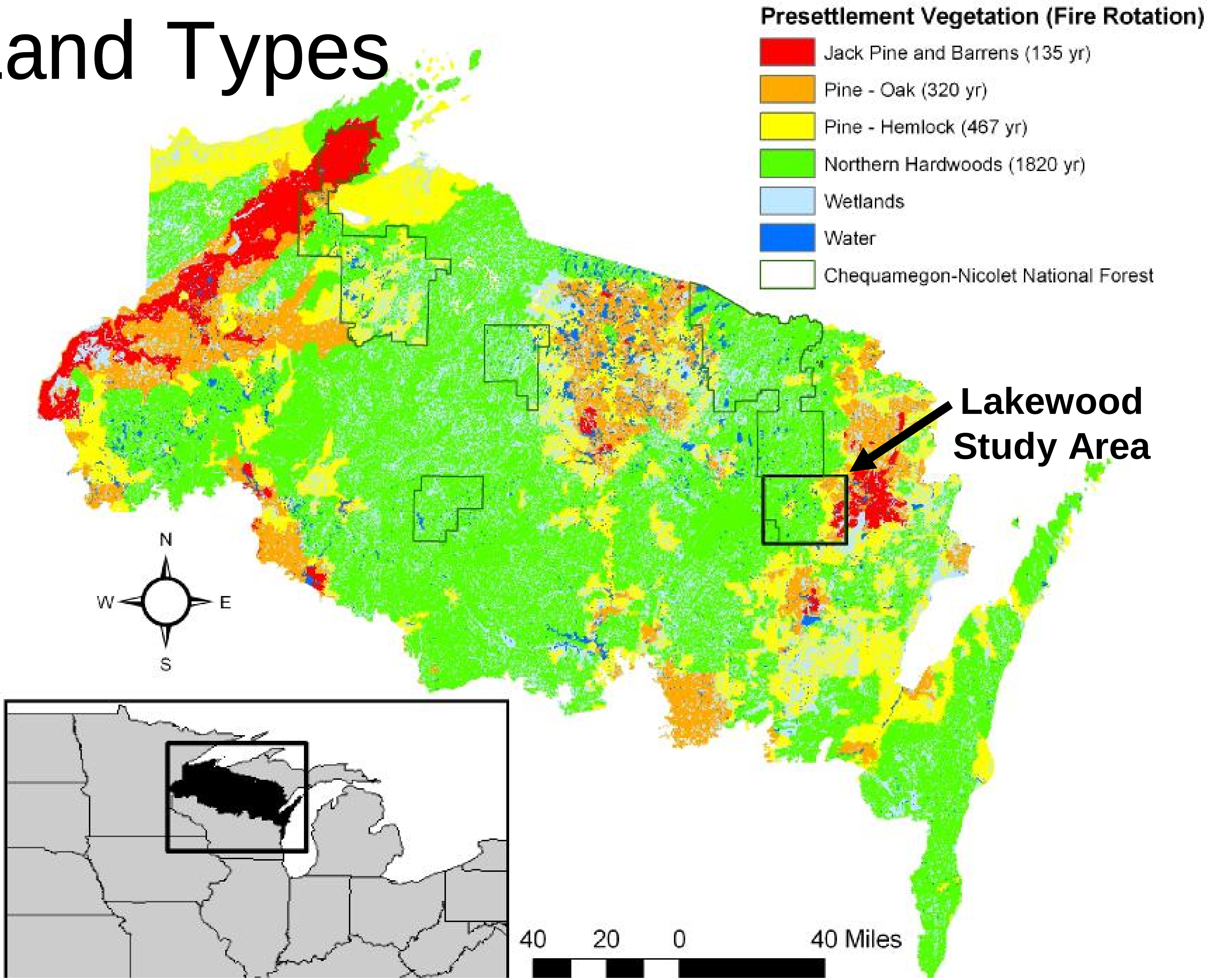
LANDIS Strengths

- Flexible, realistic options to simulate multiple disturbances and management strategies
- Simulates succession and disturbances as distinct processes, which allows for complex interactions
- Forest composition, age and spatial pattern change as an emergent property of the simulations
- Useful to compare strategic management options
- Can be parameterized for any forested system
- Software is completely modular, so users can develop their own process modules

Case Study: Lakewood Unit Chequamegon-Nicolet NF

- Contains fire-prone ecosystems dominated by jack and red pine
- A relatively high proportion of privately-owned inholdings with rapid population growth

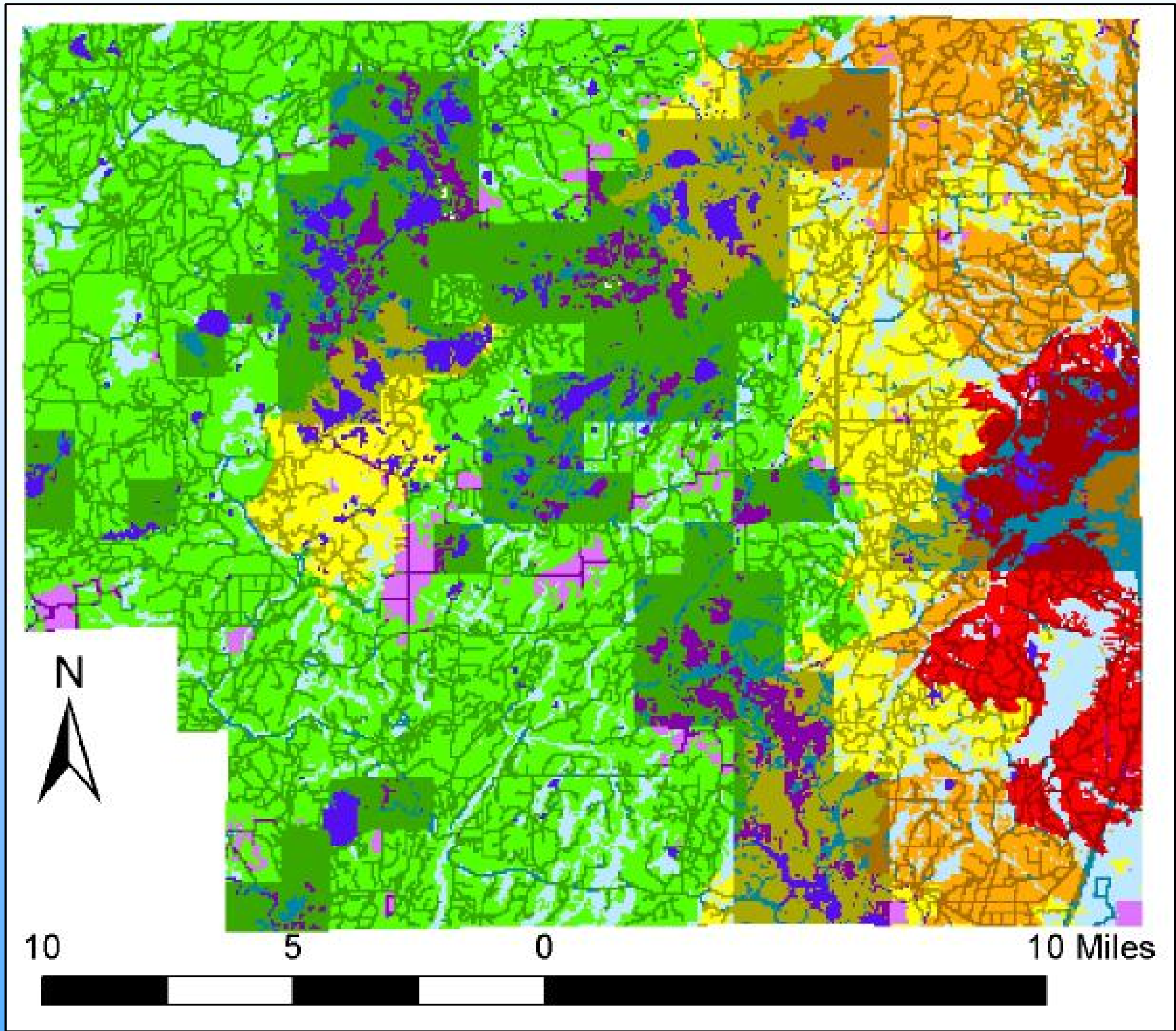
Land Types


Presettlement Vegetation (Fire Rotation)
Jack Pine and Barrens (135 yr)
Pine - Oak (320 yr)
Pine - Hemlock (467 yr)
Northern Hardwoods (1820 yr)
Wetlands
Water
Chequamegon-Nicolet National Forest
Lakewood
Study Area
N
W
E
S
40
20
0
40 Miles

Management Problem

- The probability of forest fire ignitions is primarily a function of housing density
- The probability of large fires is dependent on ecosystem properties that control fire spread:
  - soil water retention
  - flammability of vegetation types
- How can the forest be managed to reduce the risk of wildfire damage to timber and private property resources?

Fire Regime



Forested Land Types

1
2
3
4

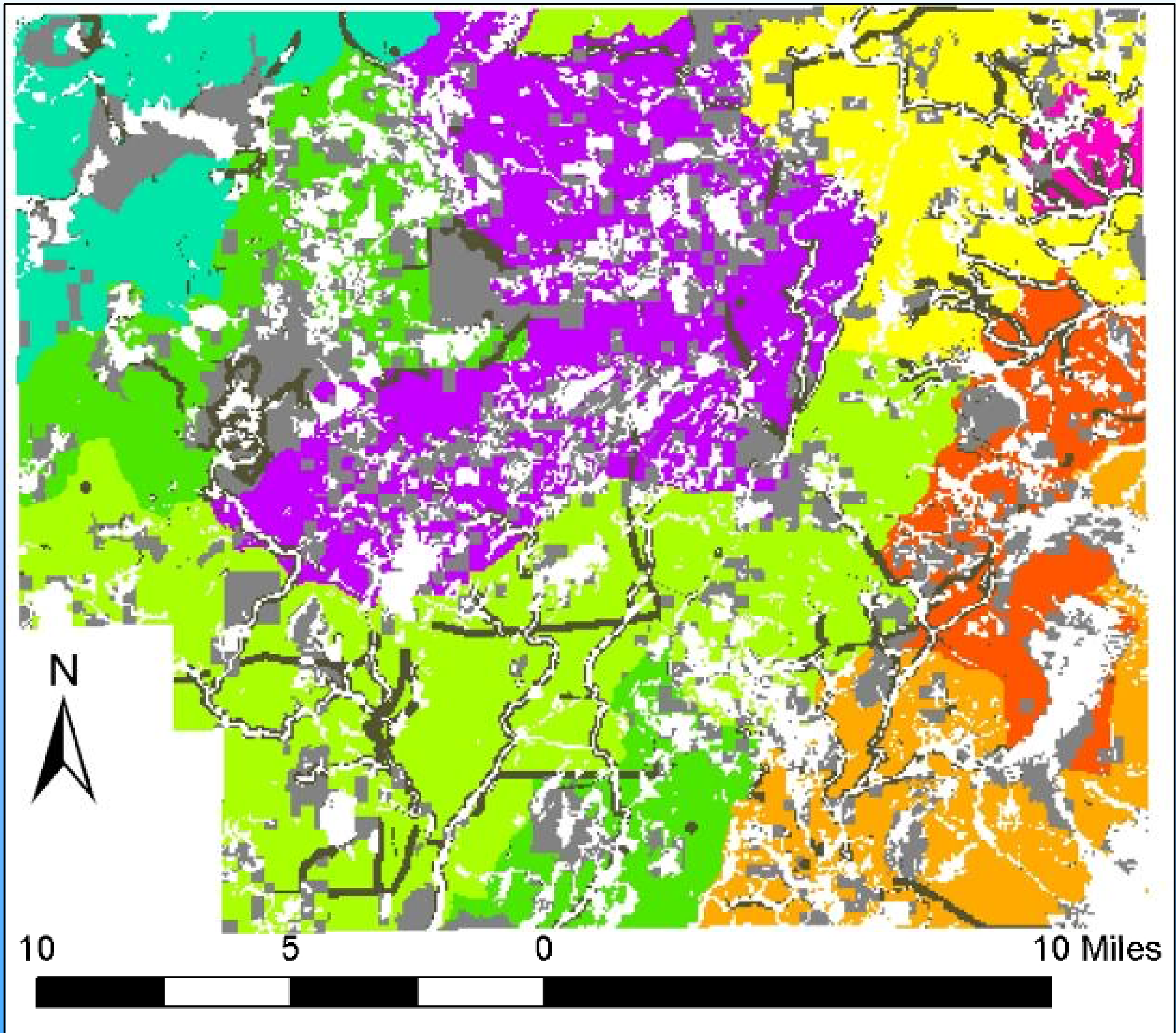
Increasing Fire Rotation

Nonforested Land Types

Open Field
Wetland
Water

Shaded = higher ignitions: >= 4.4 Houses/km^2 & Roadsides

Harvest Regime



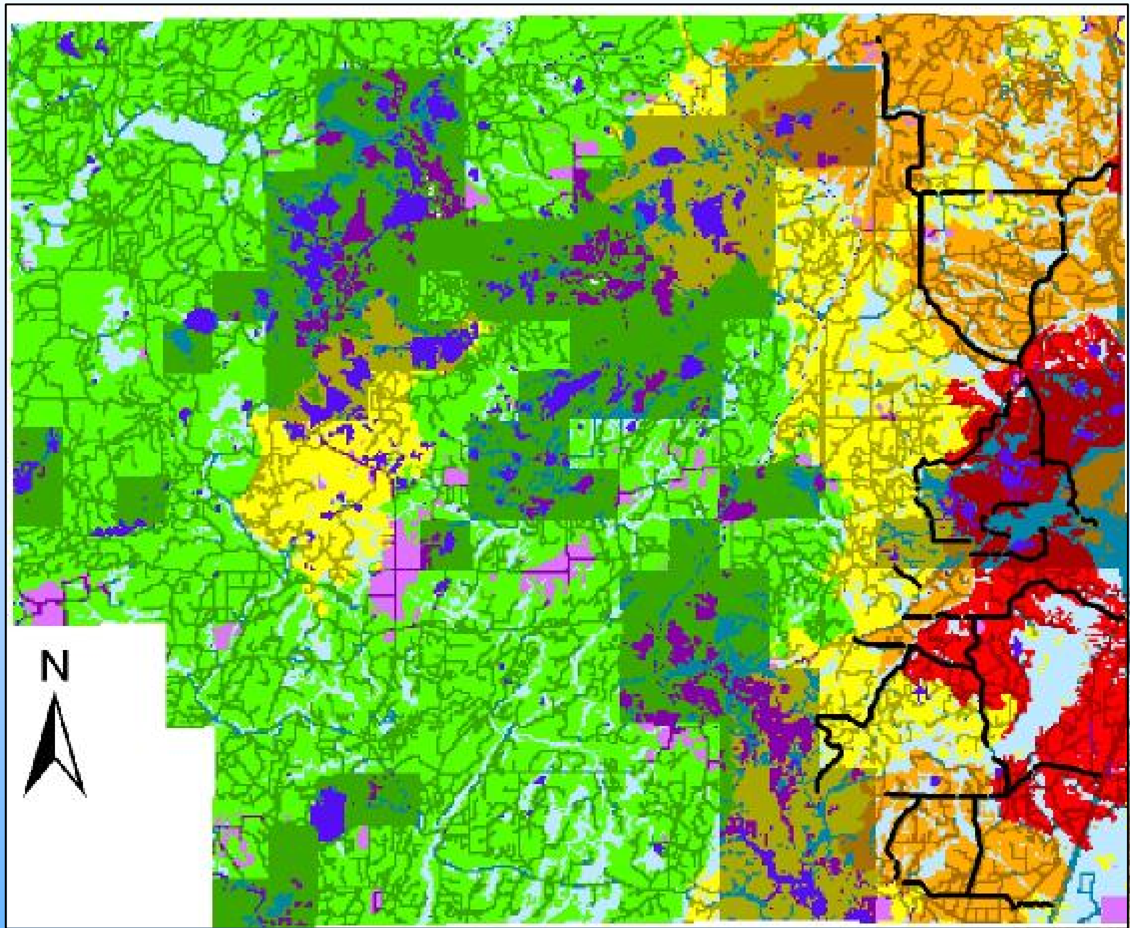
Management Area

- Aspen-Conifer
- Aspen-Hardwood
- Northern Hardwood
- N. Hwd - Interior
- N. Hwd – Early Succ.
- Oak-Aspen
- Red-White-Jack Pine
- Natural Oak-Pine
- Low Intensity Corridor
- No Management

Potential Fire Risk Reduction Strategies Evaluated

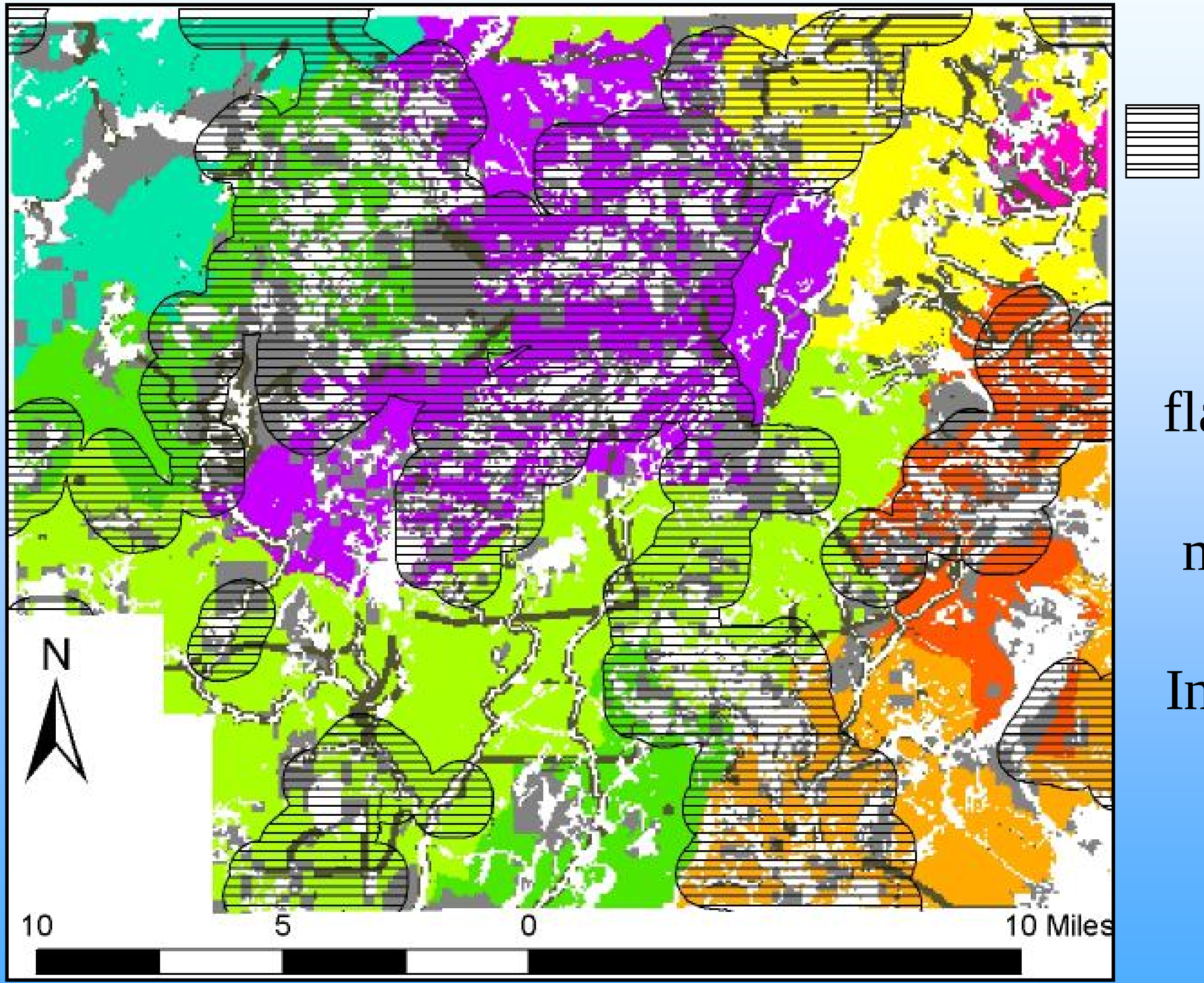
1. Eliminate Debris Burning Permits
   – ~25% reduction in ignition intensity
2. Roadside Fuel Treatments
   – Areas next to roadsides (where ignition rates are high) are cleared of fuels
3. Strategic Fire Breaks
4. Fire Protection Zones
   – “Risky” forest prescriptions are moved away from the Wildland-Urban Interface (WUI)

Strategic Fire Breaks



<u>Probability of Fire Breach:</u>
(Road + Firebreak)
State Roads – 0.5 %
County Roads – 1%
Paved Back Roads – 5%
FS Dirt Roads – 20%
Firebreak Only – 40%

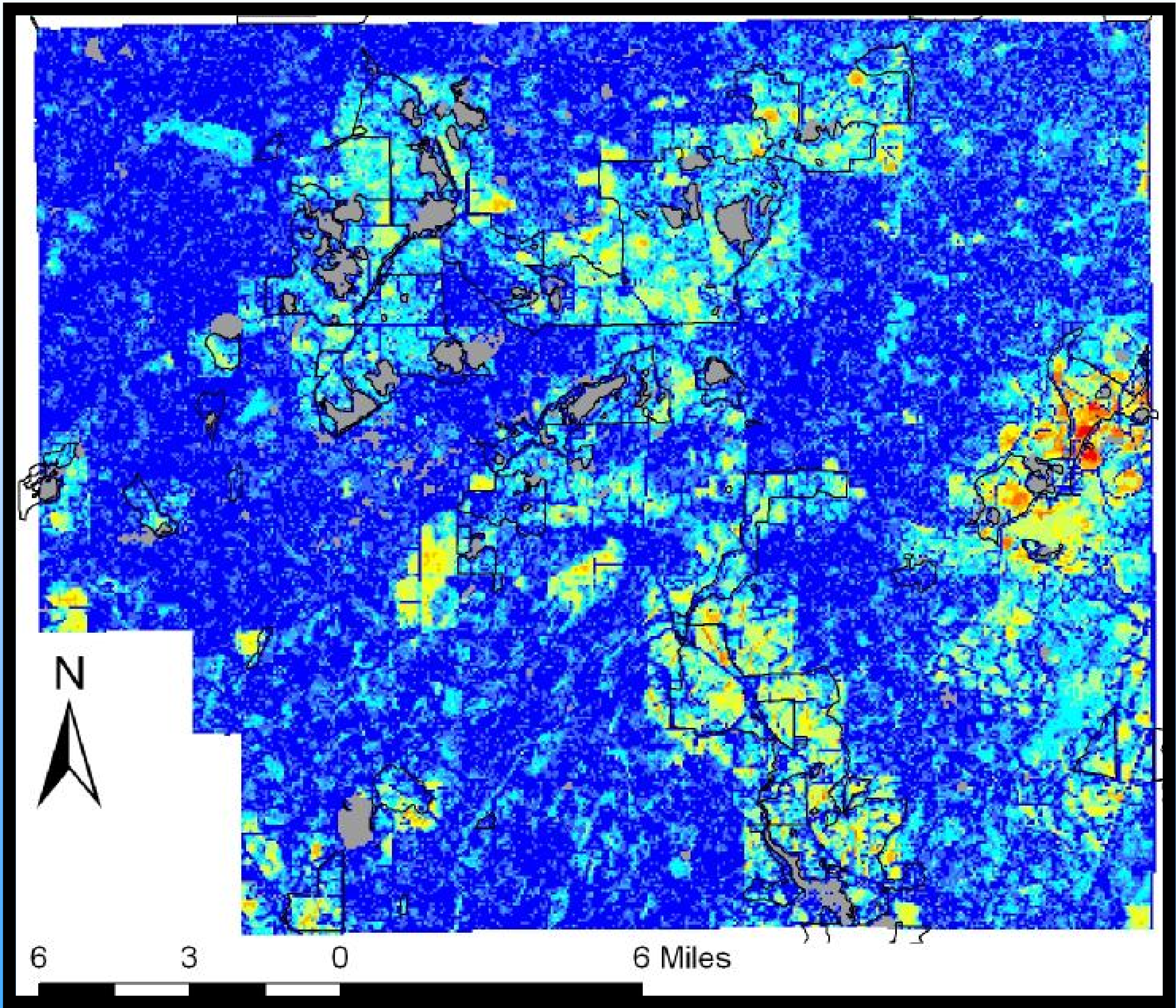
Fire Protection Zones



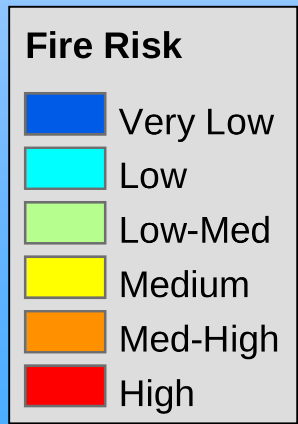
1 km WUI Protection Zones

The more flammable Pine and Oak types are moved outside the Wildland-Urban Interface Protection Zones

Likelihood of Fire



Cell-scale frequency of burning after 50 replicate simulations of 250 years



Conclusions

- Ignition prevention – has the largest impact on the likelihood of fire
  - Fire education and enforcement should be increased
- Fire Protection Zones (landscape management) are also effective
  - Simple redistribution of forest types can reduce fire likelihood with little impact on ecological and timber goals
- Roadside treatments
  - Most effective outside of the WUI
- Strategic Fire Breaks
  - Have local but not landscape effects

Key messages

- These models are useful to evaluate the cumulative effects of landscape-level management strategies
- They are flexible and general enough to be used in many ecosystems and to answer a wide variety of questions
- By incorporating site-level processes in a landscape-level model, site-level research can be scaled to policy-relevant scales

Acknowledgments

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U.S. National Fire Plan
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HARVEST - www.ncrs.fs.fed.us/4153/harvest/harvhome.asp
LANDIS - www.ncrs.fs.fed.us/4153/landis/