Fires, Management, and Land Mosaics Interactions

A Generic Spatial Model and Toolkit from Stand to Landscape Scales

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Why Fires?

- ✓A natural process in ecosystems
- ✓Social and economic importance
- ✓National security
- ✓Insurance
- ✓Lives
- ✓…

Fire and Forest Ecosystem

- Forest structure, species composition and diversity
- Increase mortality of young plants
- Ecosystem productivity
- Potential to accelerate the invasion of exotic species or insect
- Soil surface temperatures, nutrients cycling, soil water infiltration, nutrient availability and soil microbial community

Fires are Natural

McKelvey et al 1996

1. Sierra Nevada Ecosystem Project
2. Shorter fire return interval historically
3. Goal is to return to that pattern by fire management

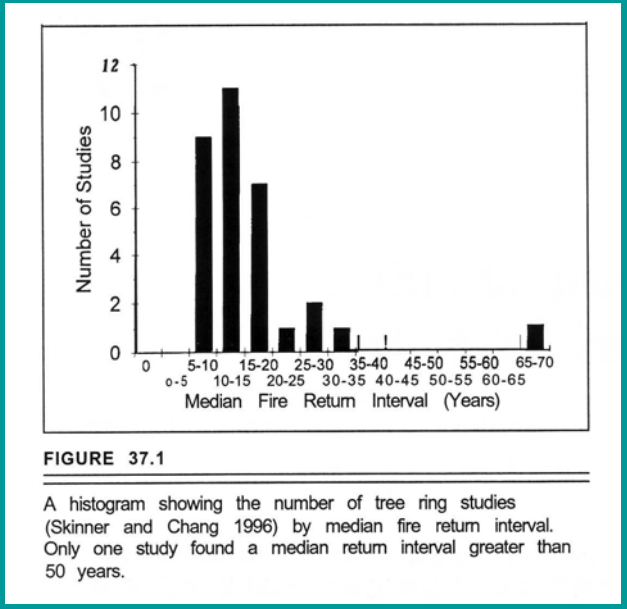
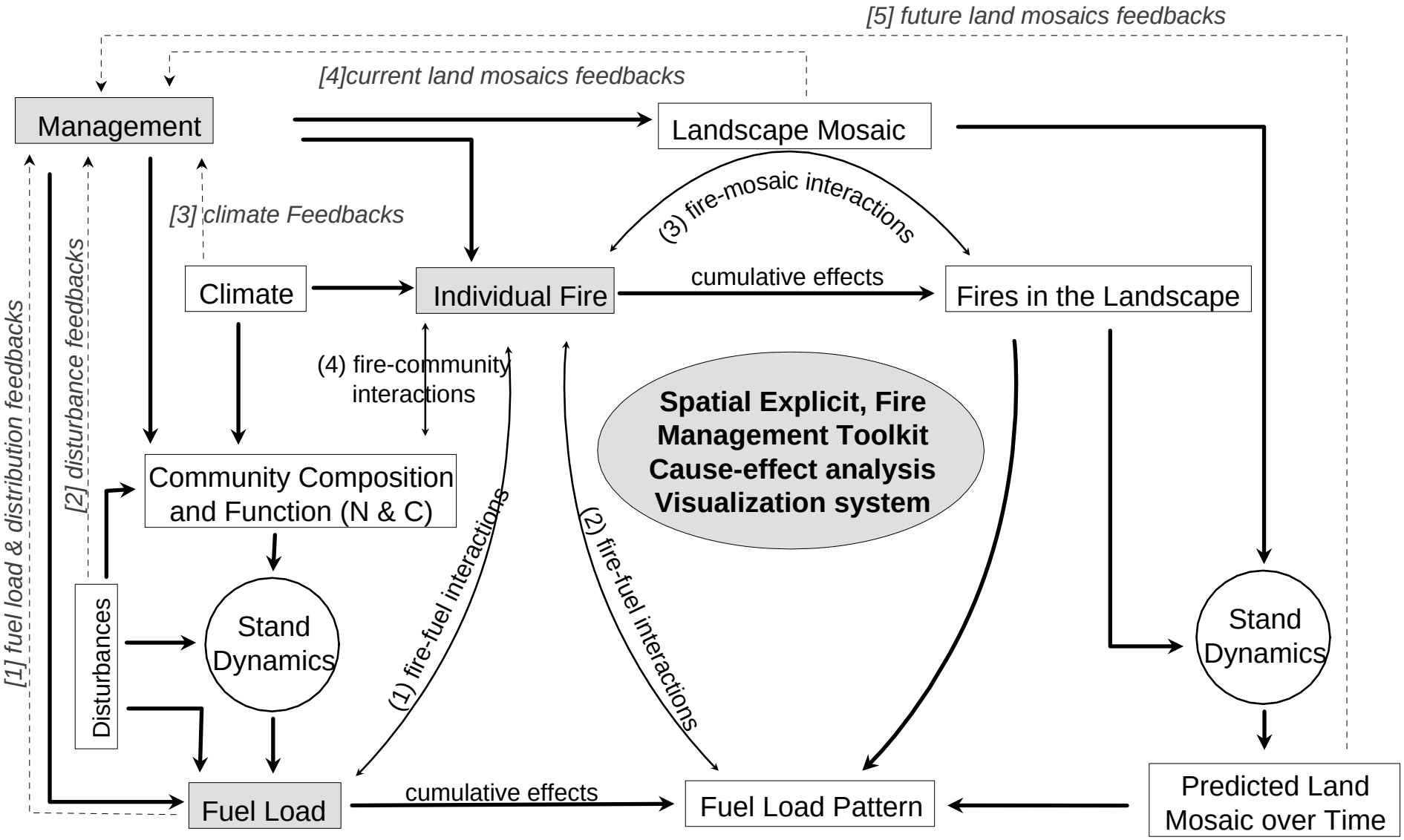


FIGURE 37.1

A histogram showing the number of tree ring studies (Skinner and Chang 1996) by median fire return interval. Only one study found a median return interval greater than 50 years.

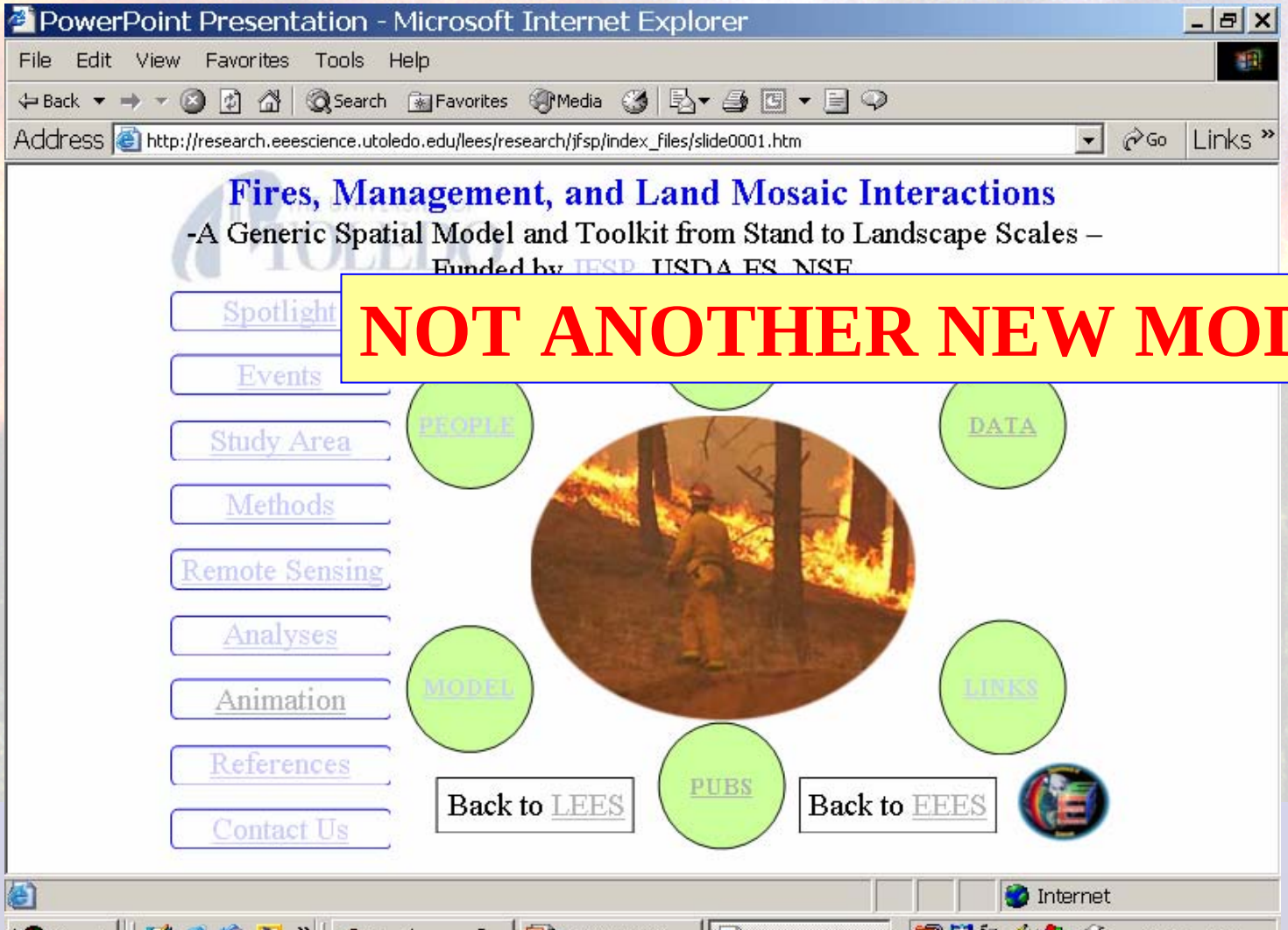
The Wilderness Society 2003

The Conceptual Framework



Goal

Developing a spatially explicit, PC Windows-based generic model accomplished by computer visualizations



APPROACH

(1) Annual NPP & fuel loading is estimated using field survey, PnET-II and a modified LandNEP model

(2) Outputs from PnET & RS provide the inputs for FARSITE

(3) Nearby FIA plots were used for stand composition & structure

(4) FVS is used to calculate stand dynamics

(5) VNS2 (Visual Natural Studio 2) for animation

(6) Outputs are in the form of images & data for Web posting

Estimating Fuel Loading Under Various Disturbance Regimes and Vegetation Types

Soung-Ryoul Ryu, John A. Rademacher, Jiquan Chen, Daolan Zheng and Thomas R. Crow

Why Fuel Loading?

- Altered fuel loading patterns
  - Fire prevention
  - Fire suppression
  - Timber harvesting
  - Pest management
- Climate change
  - Affect the intensity and frequency of fire through changing fuel quality and quantity

Climate Change

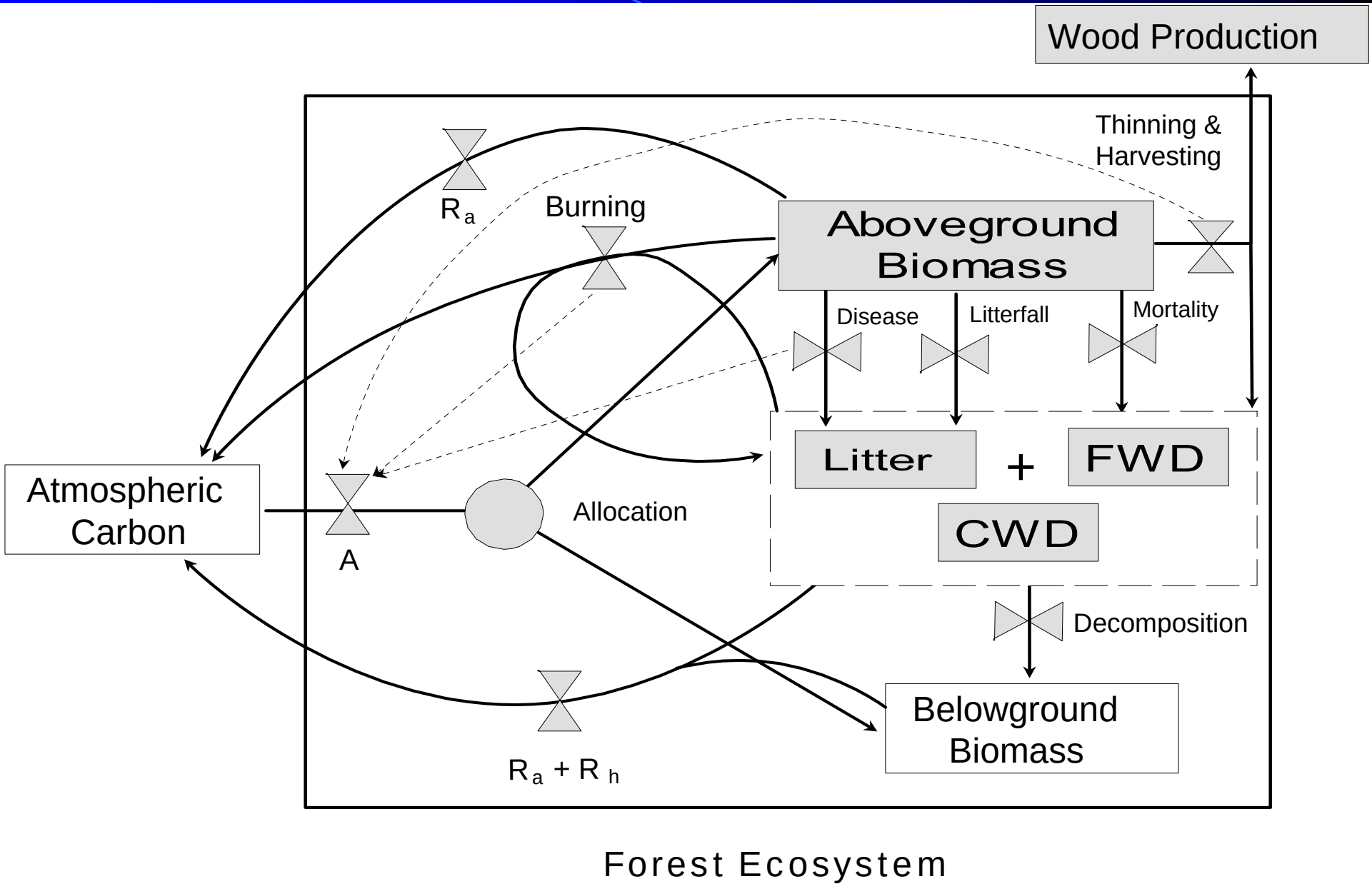
- Forest structure change
- Disturbance frequency
- Habitat changes
- Fine fuel mainly control fire ignition and spreading (<2.5cm in diameters)

Study Objectives

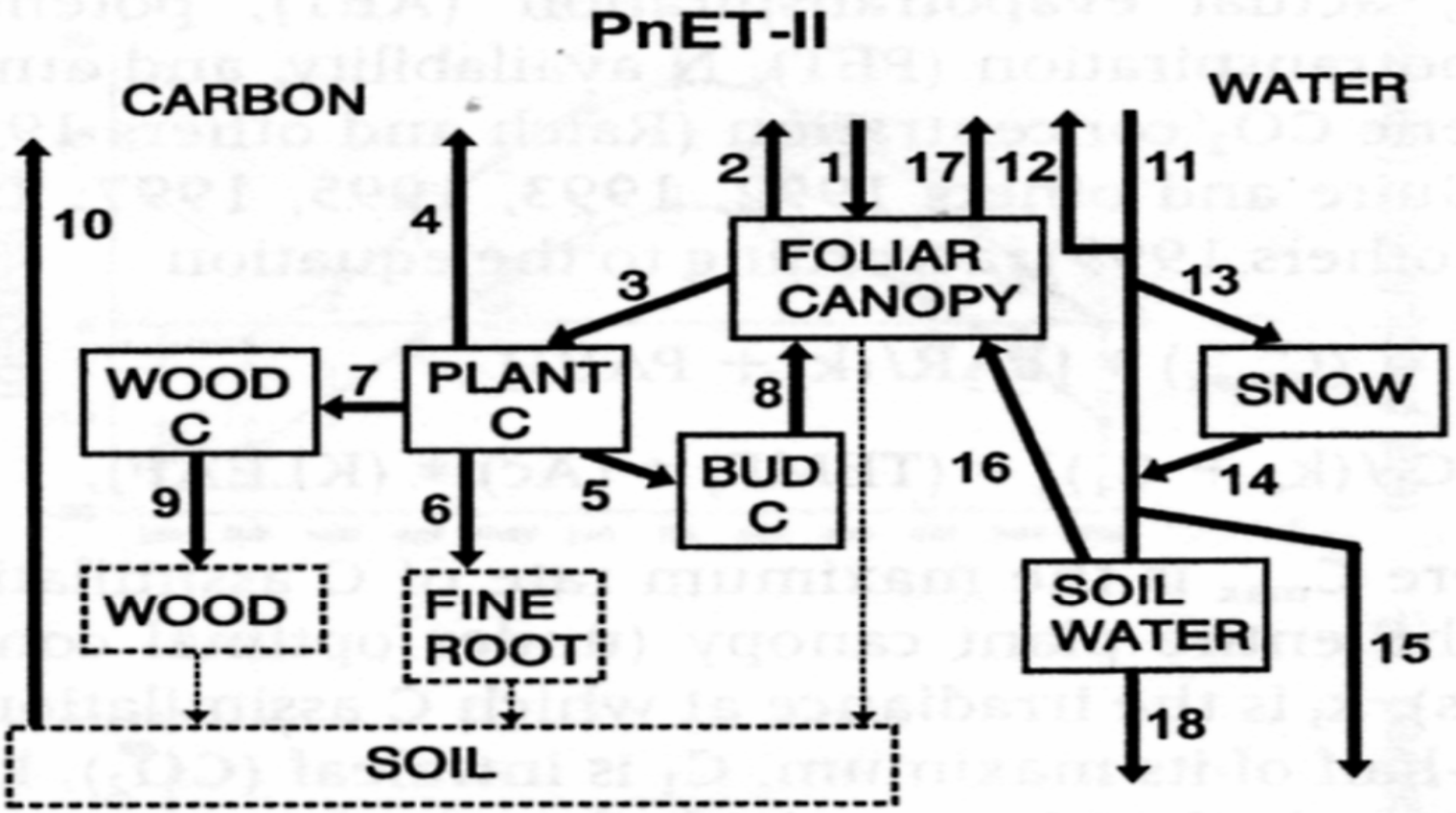
To evaluate the effect of various disturbance regimes and alternative forest ecosystem types on the fuel loading through modeling.

- Possibility develop a simple model
- Estimate the effect of various vegetation and disturbance regimes on fuel loading
  - Alternative productivity, decomposition, disease and mortality, and fire frequency

Model Description



Maximum Net Primary Production (NPP)



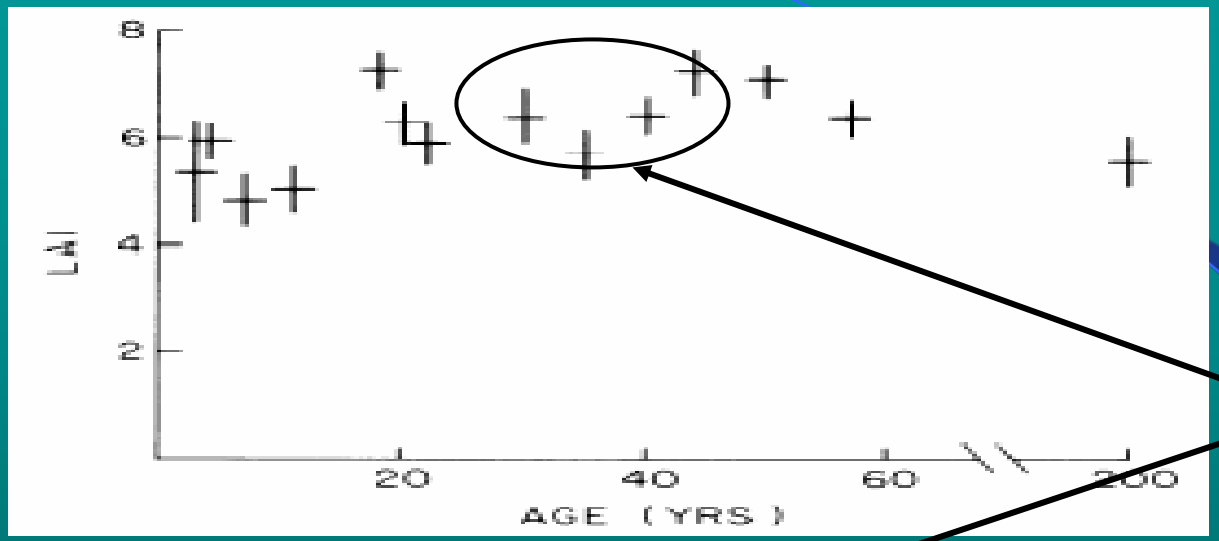
1. Gross Photosynthesis
2. Foliar Respiration
3. Transfer to Mobile C
4. Growth and Maintenance Respiration

PnET Fluxes

5. Allocation to Buds
6. Allocation to Fine Roots
7. Allocation to Wood Carbon
8. Foliar Production
9. Wood Production
10. Soil Respiration

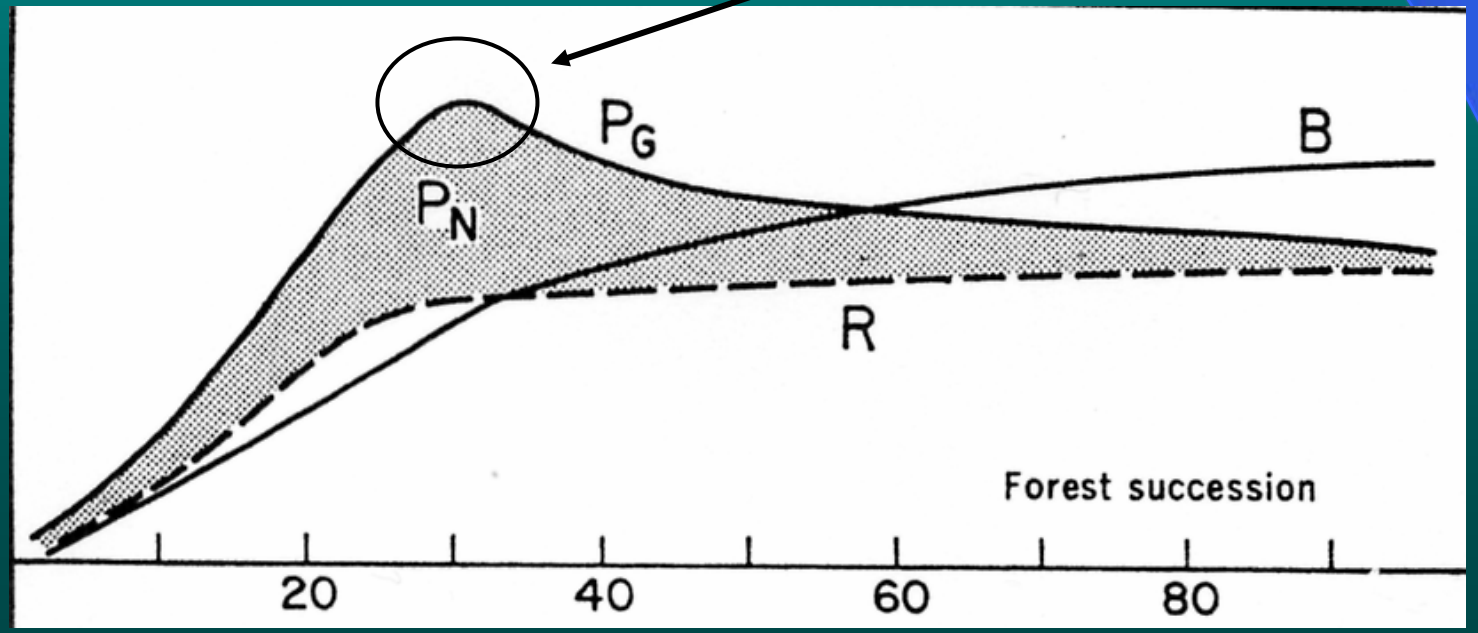
11. Precipitation
12. Interception
13. Snow / Rain Partition
14. Snowmelt
15. Fast Flow
16. Uptake
17. Transpiration
18. Drainage

Net Primary Production



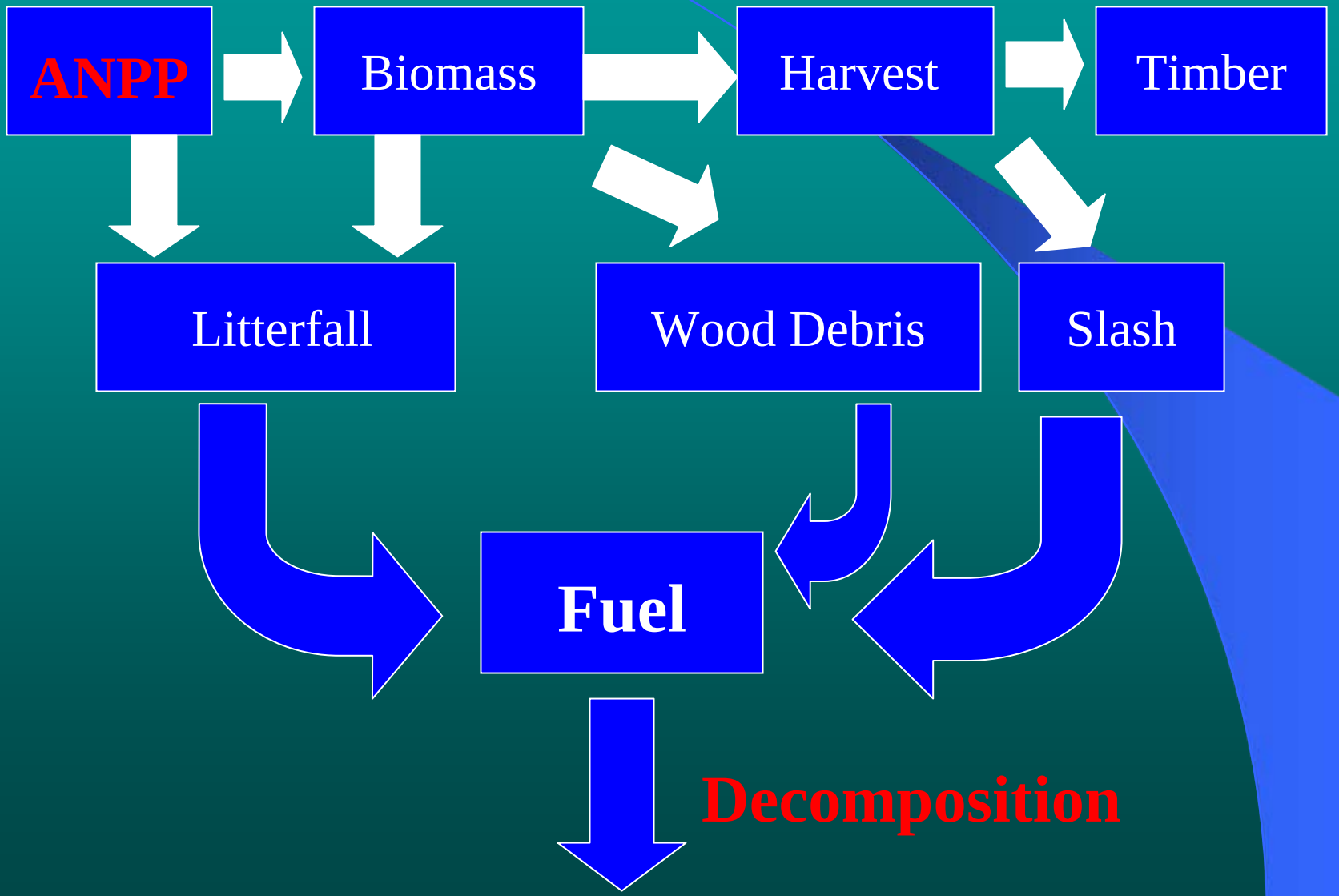
Aber 1979

Canopy Closing

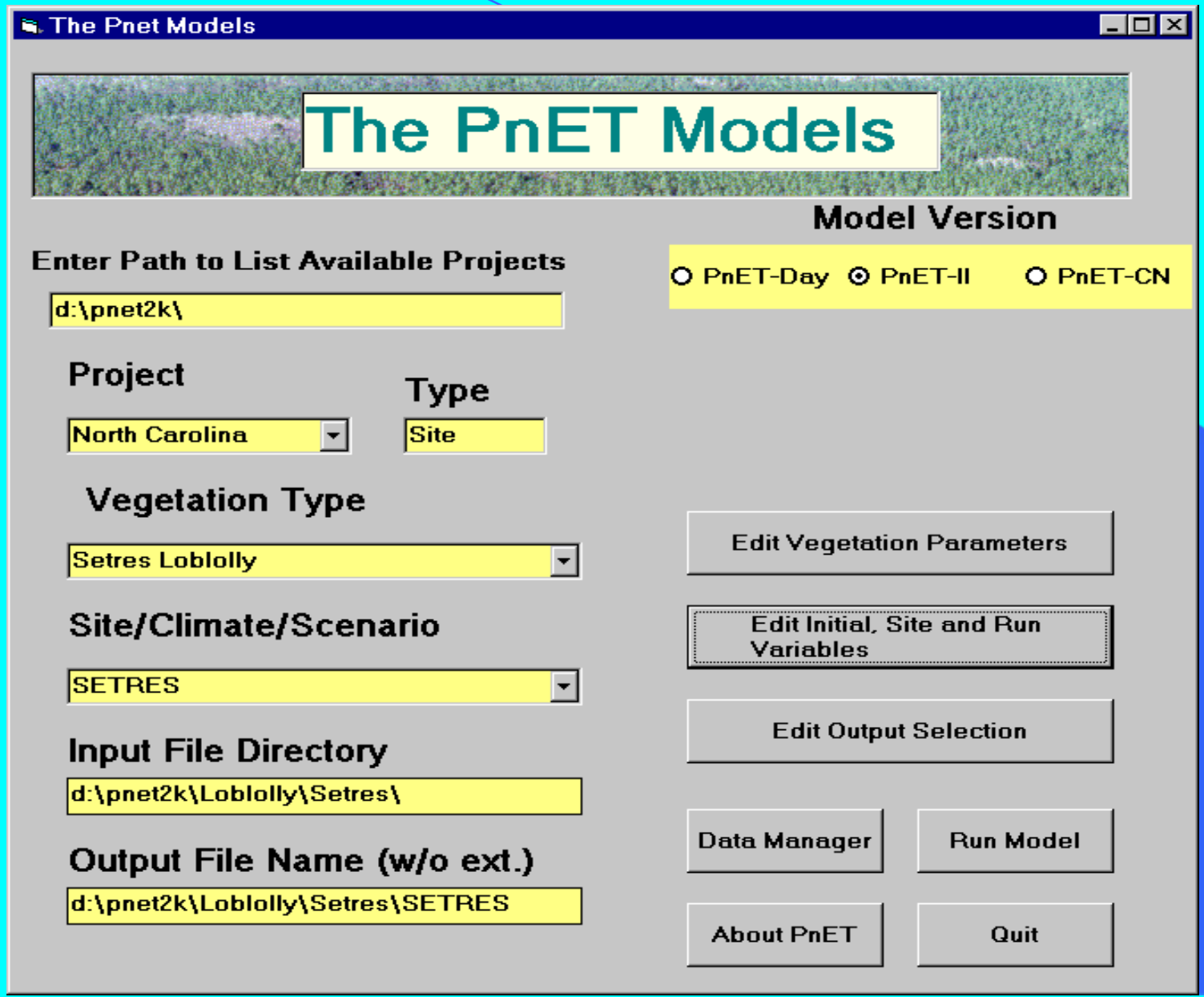


Odum 1969

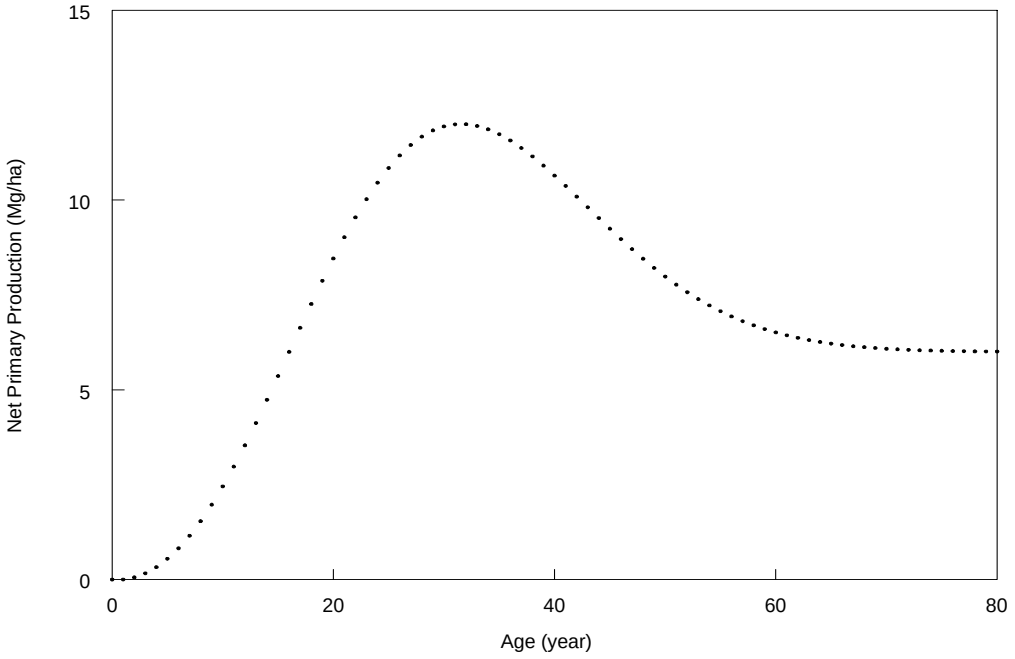
Model Scheme

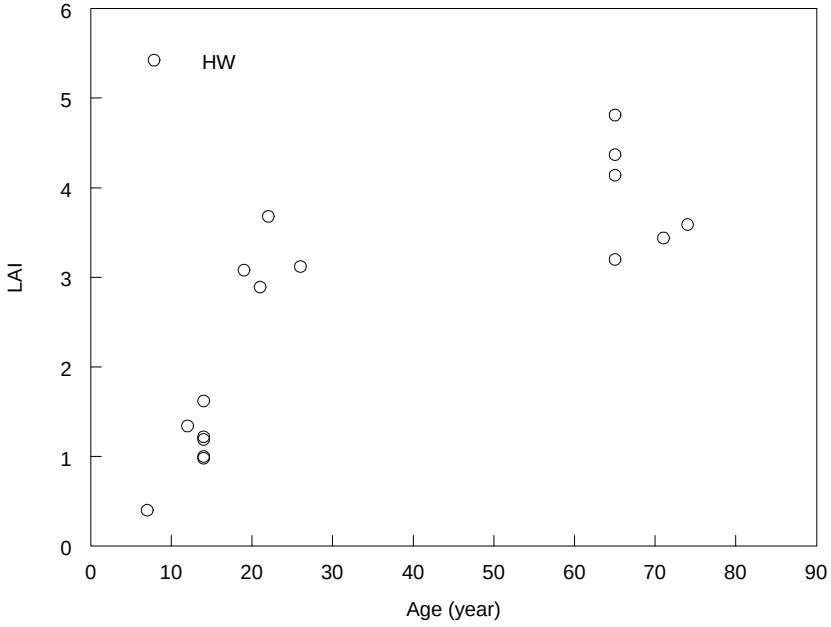


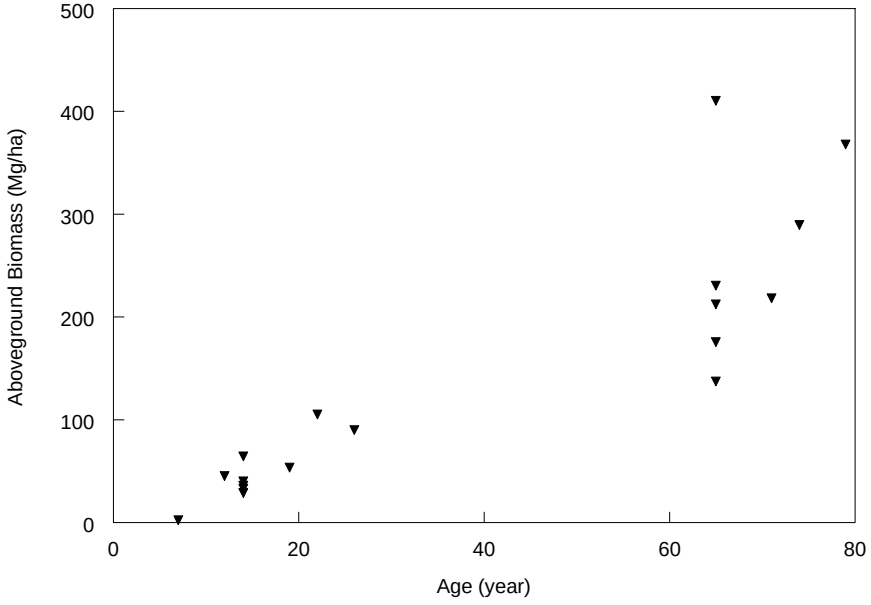
PnET Model Demonstration



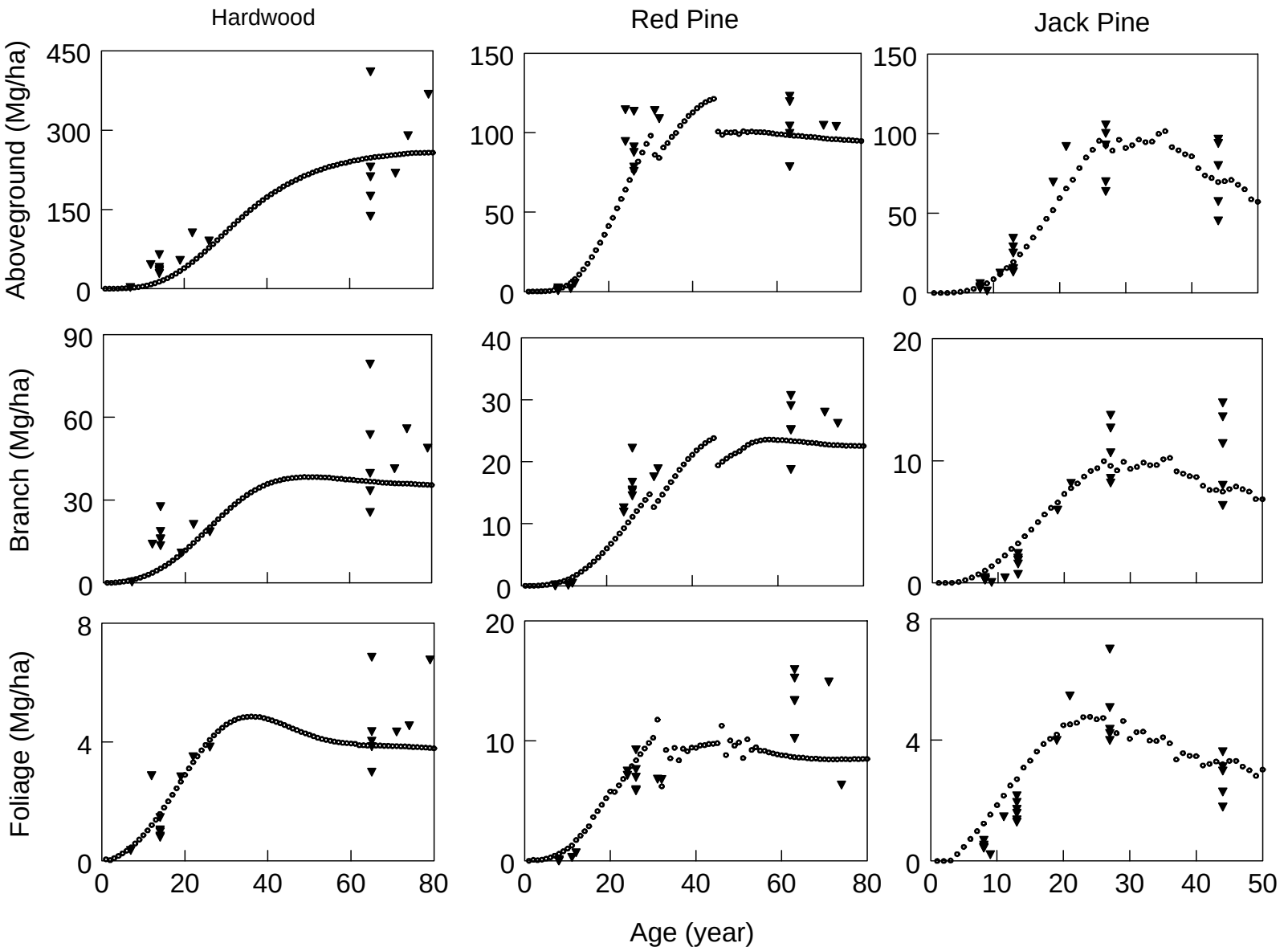
Changes in NPP with stand dynamics



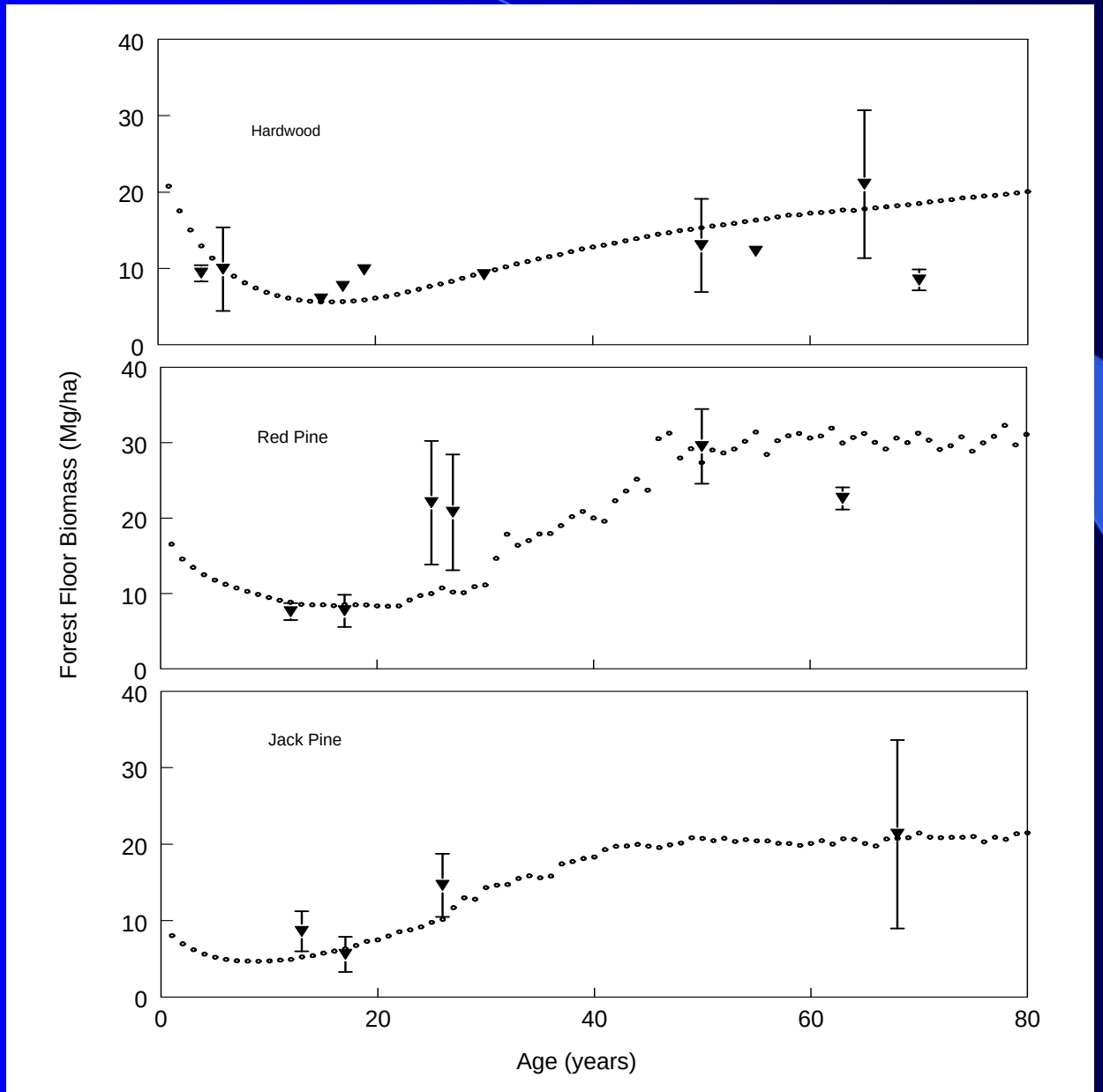




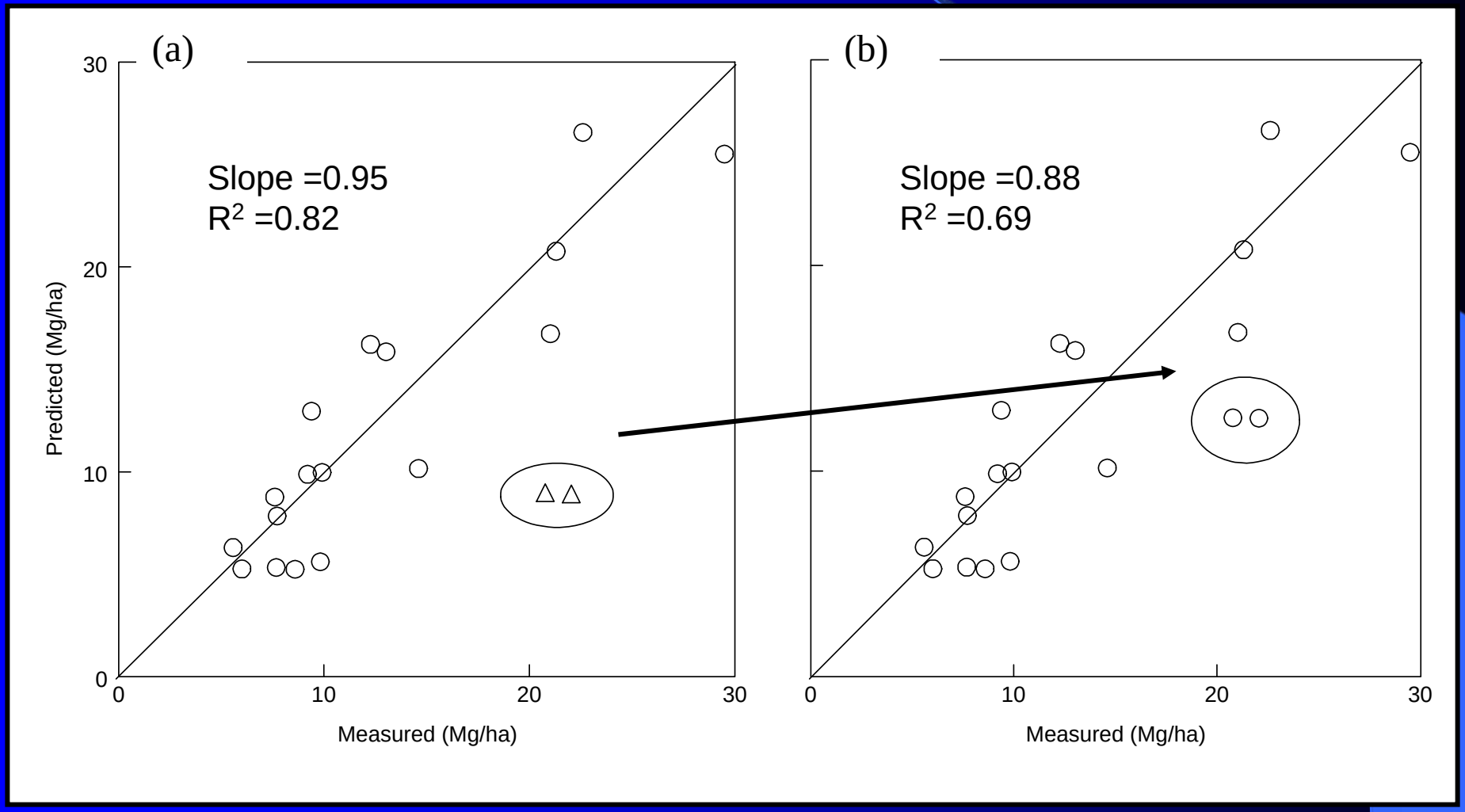
Aboveground tree, branch, and foliage biomass at various ages and model prediction for three ecosystem types.



Predicted forest floor fine fuel (●) and measured forest floor fine fuel (▼). Error bar indicates one standard deviation.



The relationship between predicted and mean measured forest floor biomass. (a) when two outliers in red pine (empty triangles) were excluded, and (b) when thinning applied at age 25.



Sensitivity Analysis

Variables	Standard Value	Tested		Sensitivity of Model	
		Value	% Change	% Change	SI
Maximum NPP (Mg/ha/yr)	12	10.8	-10%	-5.00	50.02
		13.2	10%	4.63	46.29
Litter Decay	0.475	0.428	-10%	3.20	-32.03
		0.523	10%	-2.53	-25.26
FWD Decay	0.124	0.112	-10%	6.03	-60.32
		0.136	10%	-5.30	-53.04
Possibility of Disease	0.1	0.09	-10%	0.43	-4.32
		0.11	10%	0.21	2.06
Maximum Mortality Rate	0.01	0.009	-10%	0.18	-1.77
		0.011	10%	0.04	0.39
Fire	PFI = 0.1 MFD = 0.2 MAD = 0.05	PFI = 0.09 MFD=0.22 MAD = 0.055	-10%	-0.20	2.04
		PFI = 0.11 MFD=0.18 MAD=0.045	10%	0.28	2.77

Scenarios I

Scenarios	PD	MD	FF
CLN	C	L	N
CLH	C	L	H
CLL	C	L	L
CHN	C	H	N
CHH	C	H	H
CHL	C	H	L
HLN	H	L	N
HLH	H	L	H
HLL	H	L	L
HHN	H	H	N
HHH	H	H	H
HHL	H	H	L

Disturbance Types	Productivity and Decay (PD)					
	Current (C)			High (H)		
Forest Types	Maximum NPP	Decay Rate		Maximum NPP	Decay Rate	
		Litter	FWD		Litter	FWD
Hardwood	12.0	0.475	0.124	12.6	0.499	0.130
Red Pine	10.5	0.413	0.049	11.0	0.434	0.051
Jack Pine	10.5	0.413	0.049	11.0	0.434	0.051

Disturbance Types	Disease and Mortality (DM)			
	Low (L)		High (H)	
Forest Types	Possibility of Disease	Mortality	Possibility of Disease	Mortality
Hardwood	0	0.005	0.1	0.01
Red Pine	0	0.005	0.1	0.01
Jack Pine	0	0.05	0.1	0.055

Disturbance Types	Fire Frequency (FF)								
	No Fire (N)			High Frequency (H)			Low Frequency (L)		
Forest Types	FIP	MFD	MAD	FIP	MFD	MAD	FIP	MFD	MAD
Hardwood	0	0	0	0.1	0.2	0.05	0.01	0.8	0.8
Red Pine	0	0	0	0.1	0.2	0.05	0.01	0.8	0.8
Jack Pine	0	0	0	0.1	0.2	0.05	0.01	0.8	0.8

Model Assumptions 1

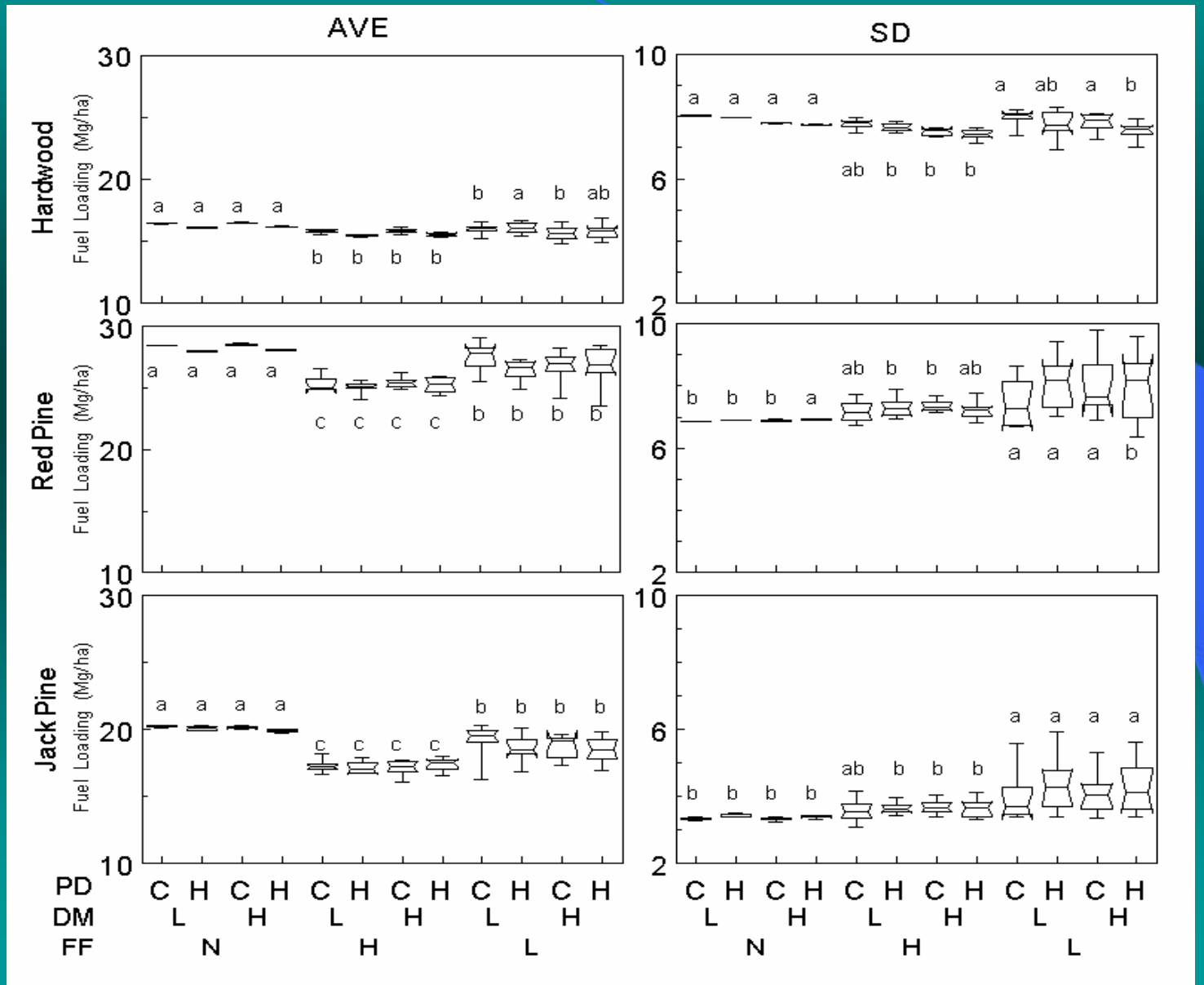
- Fire ignition and damage was calculated with random function
  - Fire ignition, fuel combustion, and aboveground biomass damage
  - We assumed that the ecosystem productivity returned to the 5 years prior to the fire occurrence with each 10% biomass reduction.

- Disease decreases the amount of live foliage resulting in the proportional NPP decrease.

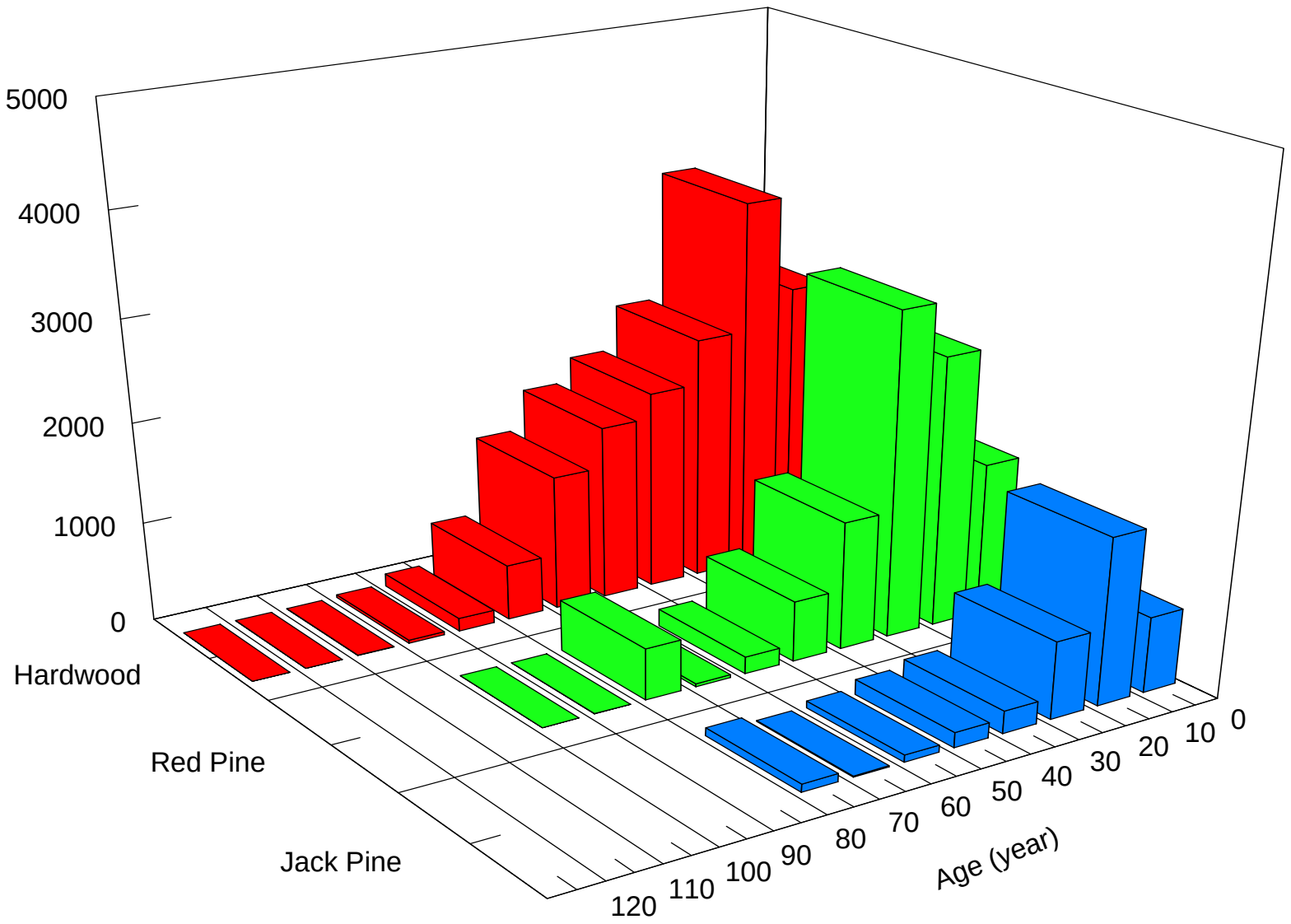
Model Assumptions 2

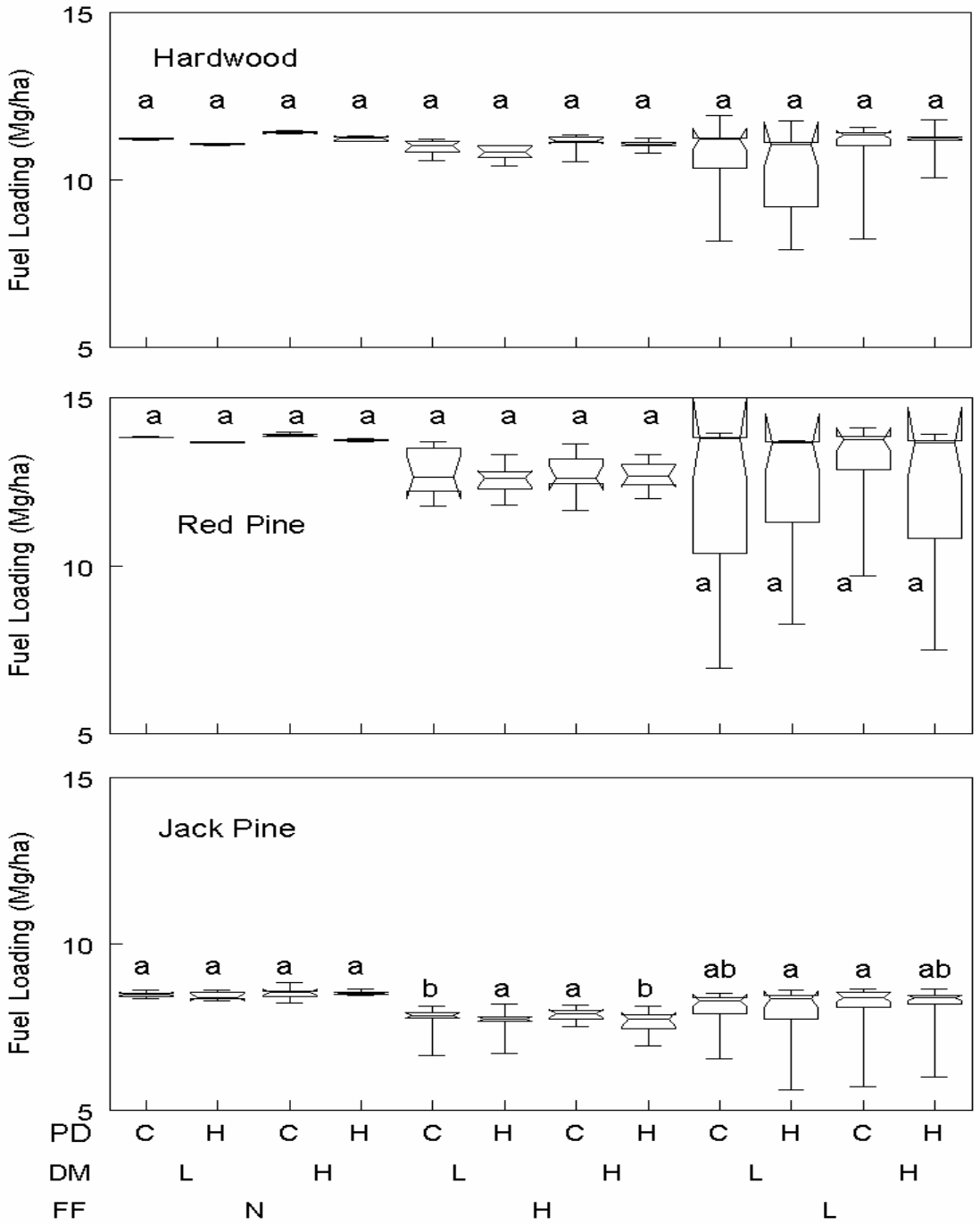
- Harvesting method
  - Clearcutting method removes all stems and leaves branches and foliage on the ground.
  - Clearcutting method decreases 10% of the NPP for 10 years after harvesting
  - Thinning was applied only for the red pine age 30 and 45 and every thinning removes 20% of biomass
  - Thinning also harvests stem and converts branch and foliage to ground fuel.
  - Thinning decrease the NPP 10% after harvests and recovers productivity 2% every year following harvest.
  - After thinning, there is a 10% increase in carbon allocated to foliage lasting for 5 years.

Fuel loading under alternative disturbance regimes (mean & STD. Letters on the box-whisker plot indicate the significance effect of fire frequency on fuel loading (α=0.05).



Age distribution of Vegetation in CNF





Fuel loading under current age structure for three ecosystem types with alternative disturbance scenario. Each scenario was simulated ten times and averaged fuel laoding was used for the calculation. Each run had five harvest cycles. Letters on the box-whisker plot indicate the significance effect of fire frequency on fuel loading (α=0.05).

Results of the analysis of variance test on estimated fuel loading in the CNF under alternative disturbance regimes.

Ecosystem Types			Hardwood		Red Pine		Jack Pine	
The Effect of Fire Frequency			Productivity and Decomposition (PD)					
			C	H	C	H	C	H
Disease and Mortality (DM)	L	AVE	0.2274	0.1261	0.1153	0.0935	0.0055	0.0645
	H	AVE	0.2219	0.6142	0.0675	0.1146	0.0808	0.0075
The Effect of DM			Productivity and Decomposition (PD)					
			C	H	C	H	C	H
Fire Frequency	N	AVE	<0.0001	<0.0001	<0.0001	<0.0001	0.5072	0.0419
	H	AVE	0.1246	0.0038	0.9925	0.5589	0.3968	0.8711
	L	AVE	0.5383	0.0017	0.2905	0.9079	0.7732	0.5062
The Effect of PD			Disease and Mortality					
			L	H	L	H	L	H
Fire Frequency	N	AVE	<0.0001	<0.0001	<0.0001	<0.0001	0.3768	0.8871
	H	AVE	0.0899	0.4601	0.4995	0.8044	0.7224	0.1003
	L	AVE	0.4038	0.2811	0.8452	0.3033	0.7092	0.9354

Conclusions

- We showed that possibility of simple model to predict the fuel loading under various ecosystem conditions
- Fire frequency had the largest effect on the fuel loading at the scenario testing
- Scenario showed that alternative PD and DM generally influenced fuel loading only under no fire condition.

Conclusions

- However, when we projected the same disturbance regimes, each ecosystems responded to the disturbance regime differently.
  - Only jack pine ecosystem showed significant response to the fire frequency.
  - Red pine showed highest variability to the fire frequency
  - Hardwood forest showed significant difference to the alternative disease and mortality condition under high productivity and decay condition.

Study Sites

- Interior Alaska (AK)
- H.J. Andrews Experimental Forest, Oregon (OR)
- Southern Sierra Nevada Mountains (CA)
- Montane Conifer Forest in southern Arizona (AZ)
- Missouri ozorks (MO)
- Pine/Oak Barrens in Wisconsin (WI)
- Cascade Range, Washington (WS)
- Hubbard Brook Experimental Forest, New Hampshire (NH)
- Southern coastal plains in South Carolina (SC)

Data for JFSP

Data needed for simulations are in the form of map for each Variable with exception of roads and streams.

Land/Cover: Land cover types developed from various satellite sensors.

Elevation: In meter from the DEM.

Slope: In degree or in percent.

Aspect: Expressed in positive degrees from 0 to 360, measured clockwise from the north. Cells with value of –1 indicates flat areas.

Stand-age: In year.

NDVI: Normalized difference vegetation Index (-1 to 1).

NPP: Net primary production in gC/ m^2/yr.

Stream: Vector file.

Road: Vector file.

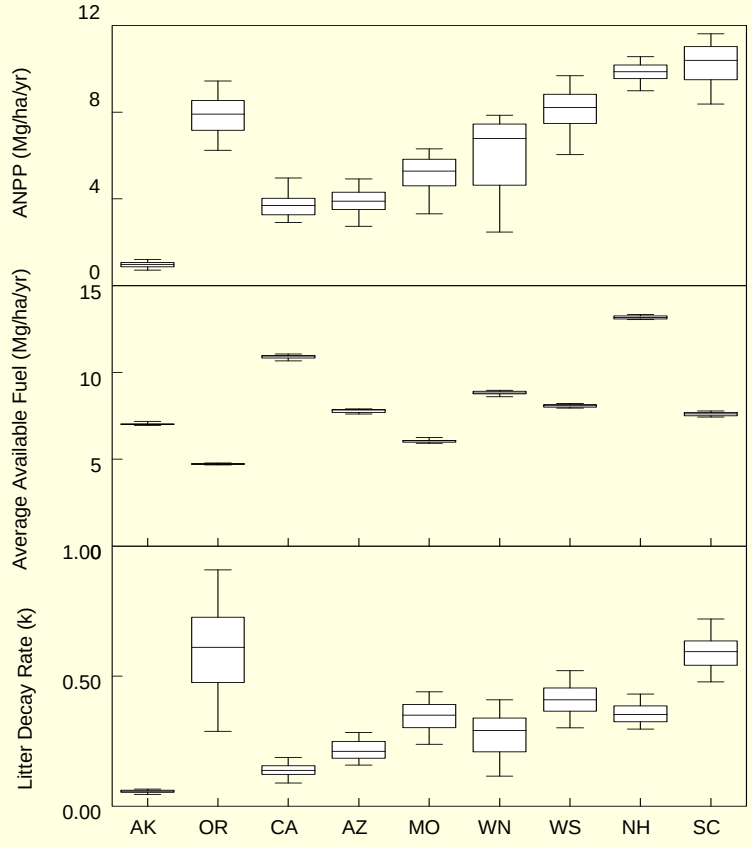
Soil: Water holding capacity in cm, moisture in Mpa, Nitrogen in kg/ha.

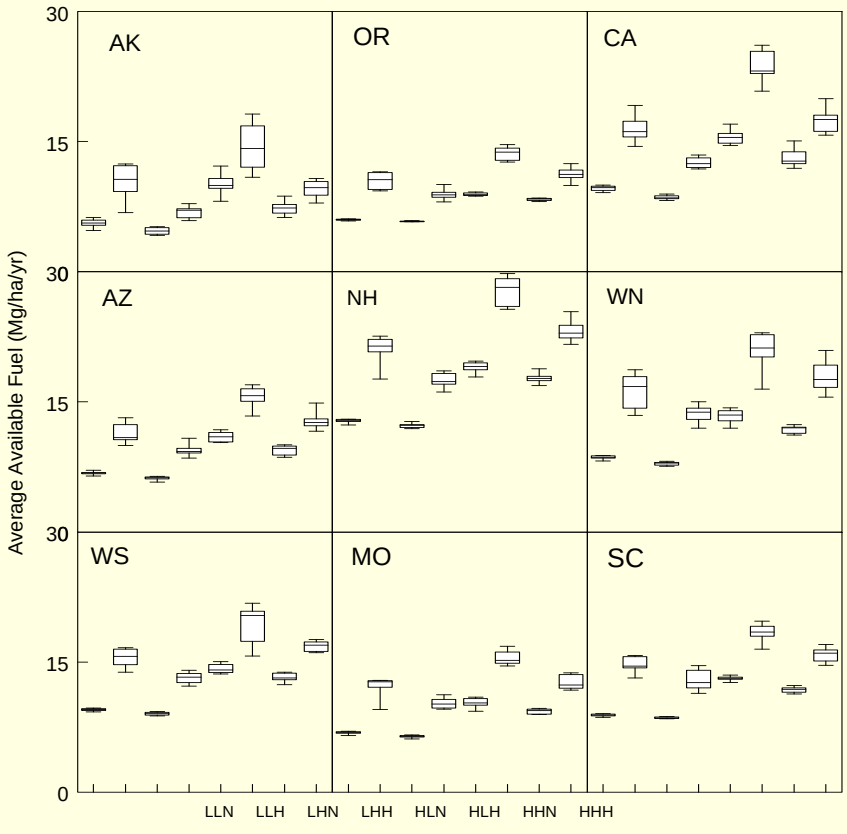
Temperature: Monthly transient data from 1961 to 1990 in °C.

Precipitation: Monthly transient data from 1961 to 1990 in mm.

Results

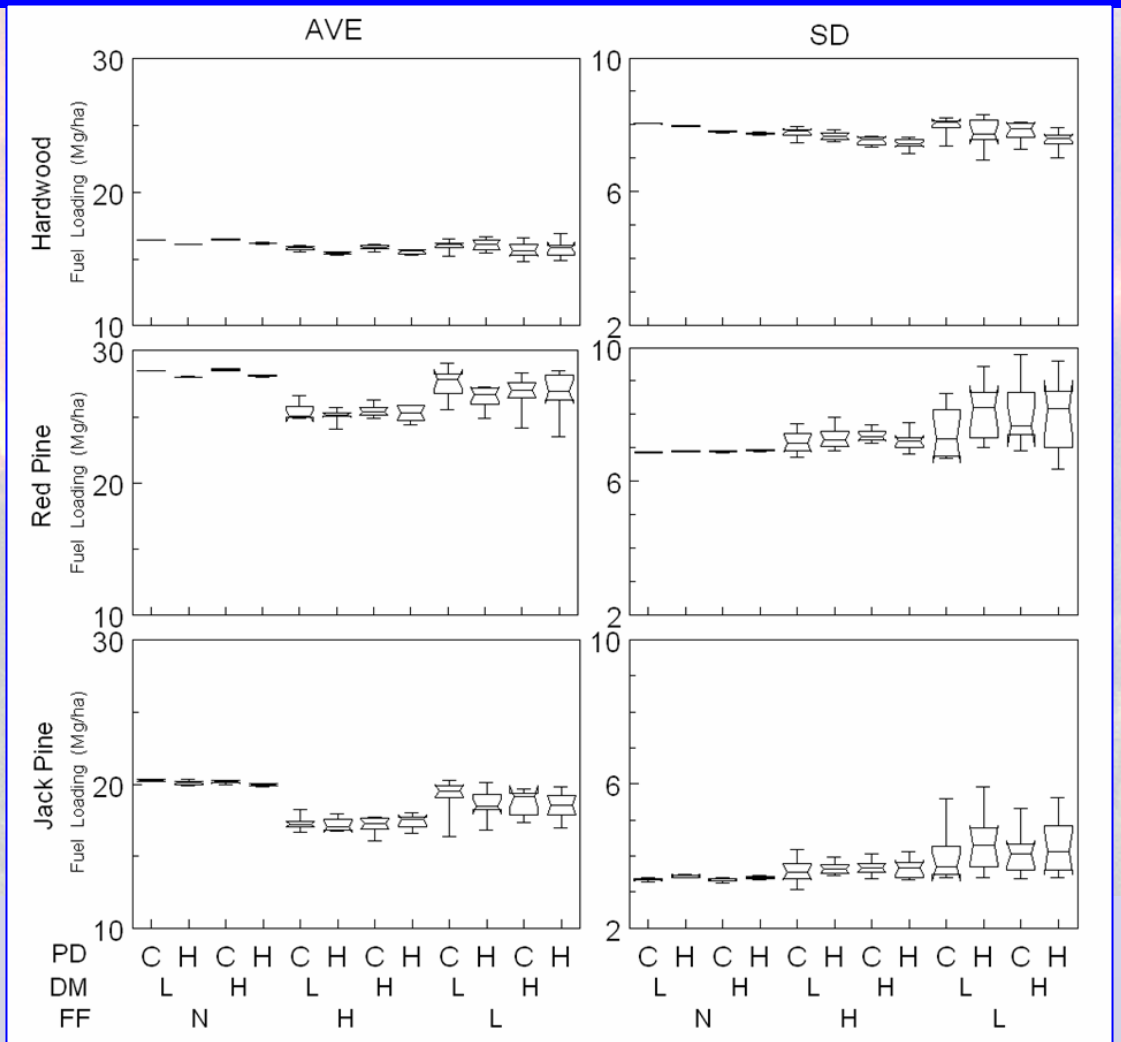
We first conducted fuel analysis and prediction among the 9 study sites representing different fire regimes across the U.S. (Ryu et al., *in press*)





Results

We also simulated the effects of various disturbance regimes(alternative productivity, mortality, and fire frequency) on fuel loading in dominant ecosystems in northern Wisconsin landscape (Ryu et al, *in review*).



Examining fire spread patterns across a managed forest-land mosaic in northern Wisconsin, USA using a modeling approach

Jacob LaCroix, Daolan Zheng, Soung-Ryoul Ryu and Jiquan Chen

Introduction

- Chequamegon National Forest, WI
- With FARSITE model
- Look at fire spread across landscape using standard fuel modules
- Support research to other efforts of fire team, basic questions of fire spread

Objectives

- Examine 4 factors that influence the rate of fire spread on a landscape
- Interrelated at the landscape level

4 Factors to Investigate:

- Influence/strength of fire behavior
  - Can we make simplifying predictions for FML, FLI, HPA on ROS
- Demonstrate patch differences
  - Is the fire behaving differently in each patch?
- Landscape Structure
  - Are burned areas different for fires started in 12 different locations?
- Influence/strength of 3 weather factors
  - Wind, Rain, Temperature, influence on area of fire spread

Methods

- Gather data from FARSITE simulation at CNF, using 2001 landscape and 2002, weather from the MHW met-station
- Place fires on the landscape in up to 12 different locations, for 15 and 27 days long, 24 hour burning period, same weather and starting moistures in the fuels in all cases
  - Except last weather investigation
- For a modeler using Andersons (1982) fuels which FARSITE was designed to use without adjustment

Background Information

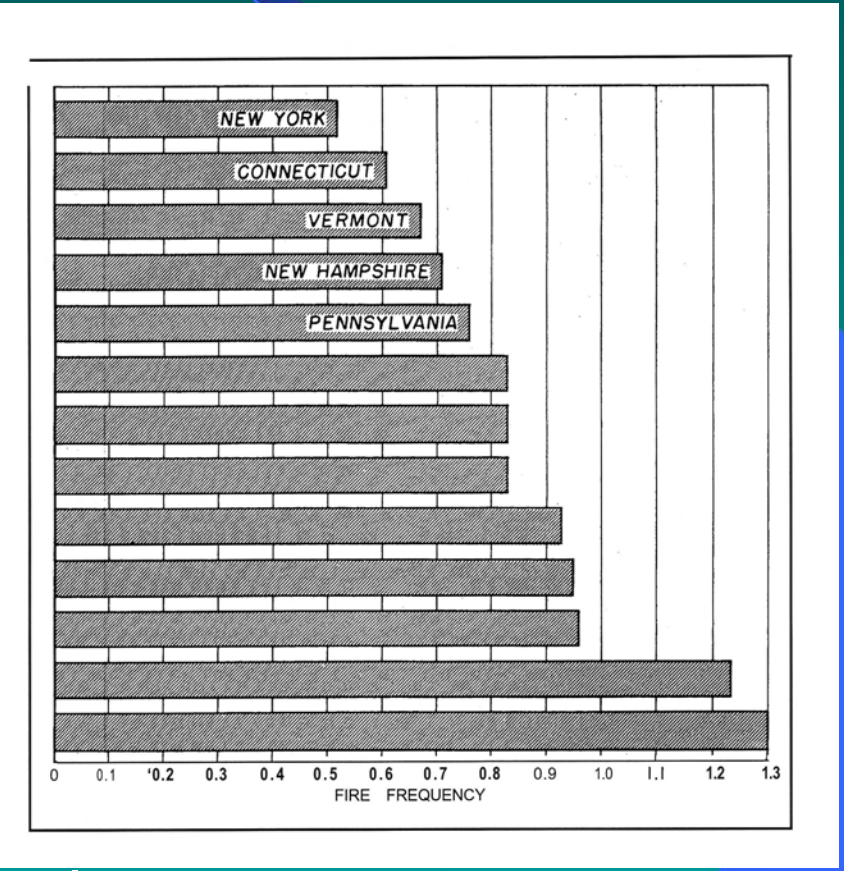
1. Standard Fuels - Anderson 1982
2. Fuel Loading, CWD- Brown et al 1982
3. Fire Behavior Chart- Andrews and Rothermel 1982

http://www.nps.gov/fire/greatplains/campground03.htm

Fire Frequency Report

Lindenmuth et al 1953

1. Northeastern states reported fires
2. Fire frequency calculated as the ratio of # of fires that occur to the # expected according to measured fire danger
3. In one example 8,948/9,745 frequency = 0.92
4. In 1953 learning the expected became a goal and keeping the ratio below 1.0
5. Today we would say that keeping it at 1.0 should be the goal



Nationally Recognized Fuel Models

Table 1.— Description of fuel models used in fire behavior as documented by Albini (1976)

Fuel model	Typical fuel complex	Fuel loading				Fuel bed depth	Moisture of extinction dead fuels
		1 hour	10 hours	100 hours	Live		
		Tons/acre				*Feet*	*Percent*
	Grass and grass-dominated						
1	Short grass (1 foot)	0.74	0.00	0.00	0.00	1.0	12
2	Timber (grass and understory)	2.00	1.00	.50	.50	1.0	15
3	Tall grass (2.5 feet)	3.01	.00	.00	.00	2.5	25
	Chaparral and shrub fields						
4	Chaparral (6 feet)	5.01	4.01	2.00	5.01	6.0	20
5	Brush (2 feet)	1.00	.50	.00	2.00	2.0	20
6	Dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25
7	Southern rough	1.13	1.87	1.50	.37	2.5	40
	Timber litter						
8	Closed timber litter	1.50	1.00	2.50	0.00	0.2	30
9	Hardwood litter	2.92	.41	.15	.00	.2	25
10	Timber (litter and understory)	3.01	2.00	5.01	2.00	1.0	25
	Slash						
11	Light logging slash	1.50	4.51	5.51	0.00	1.0	15
12	Medium logging slash	4.01	14.03	16.53	.00	2.3	20
13	Heavy logging slash	7.01	23.04	28.05	.00	3 0	25

Biomass and Fuel Loading

Brown et al 1982

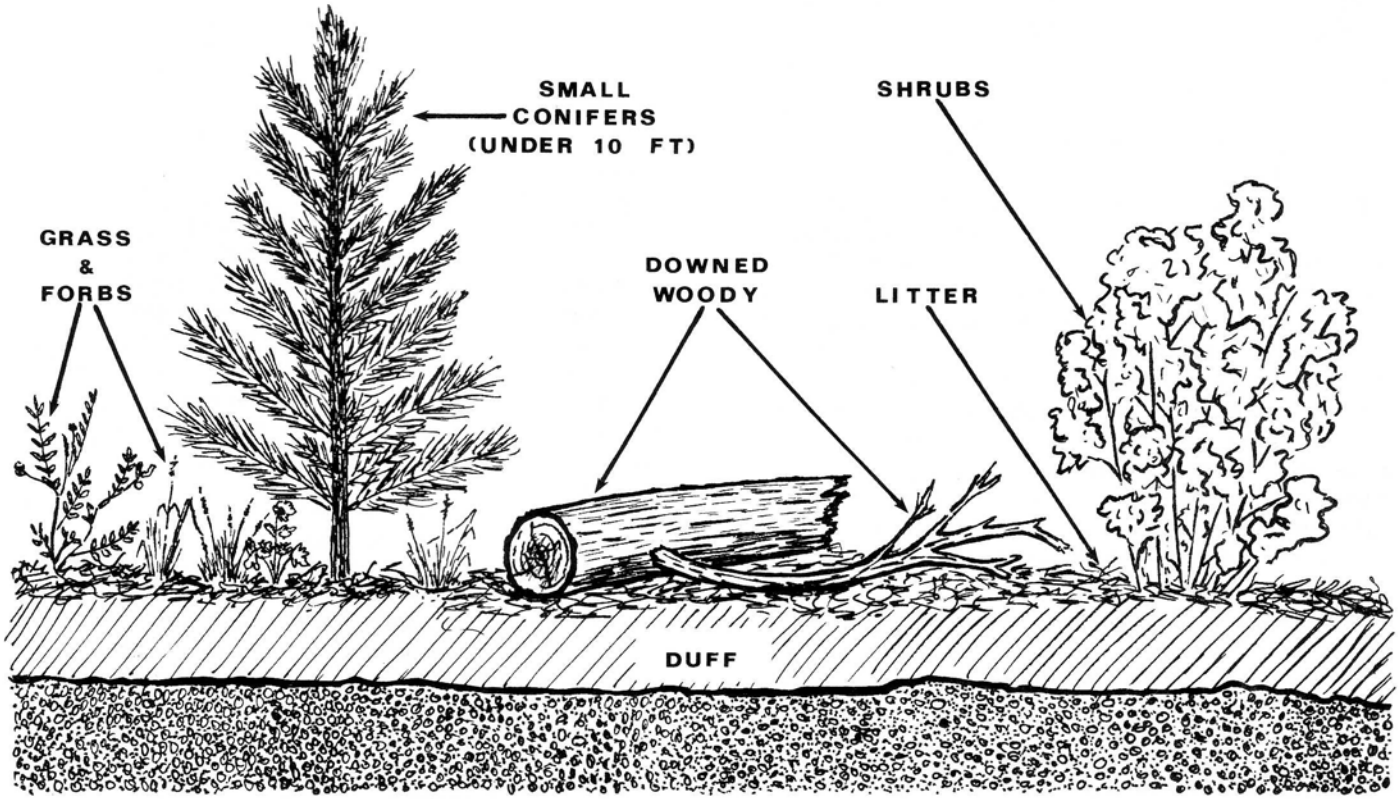
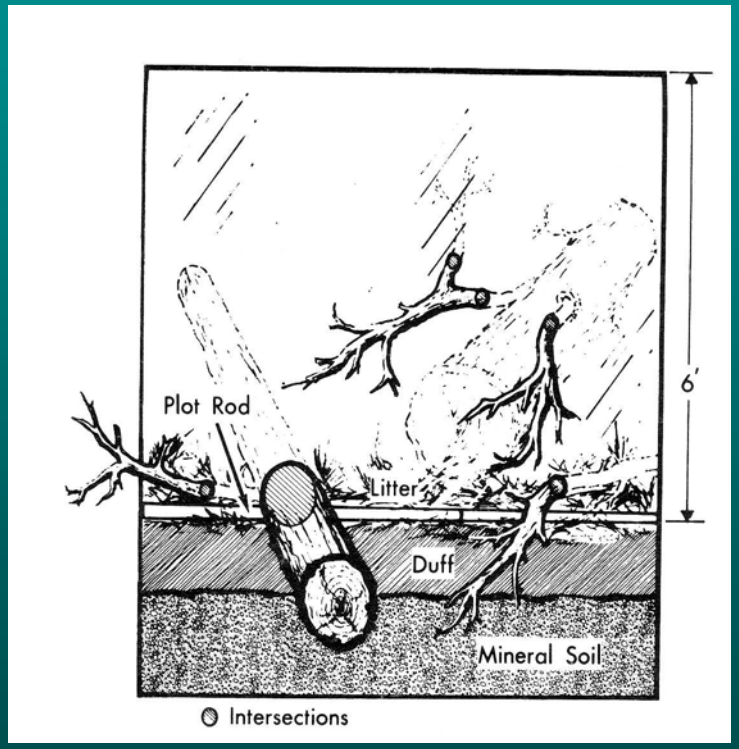


Figure 1.—Vegetative components included in procedures for estimating biomass and fuel loading.

Downed Woody Material

Brown et al 1982



For fuel loading, the sampling plane is defined by the plot rod.

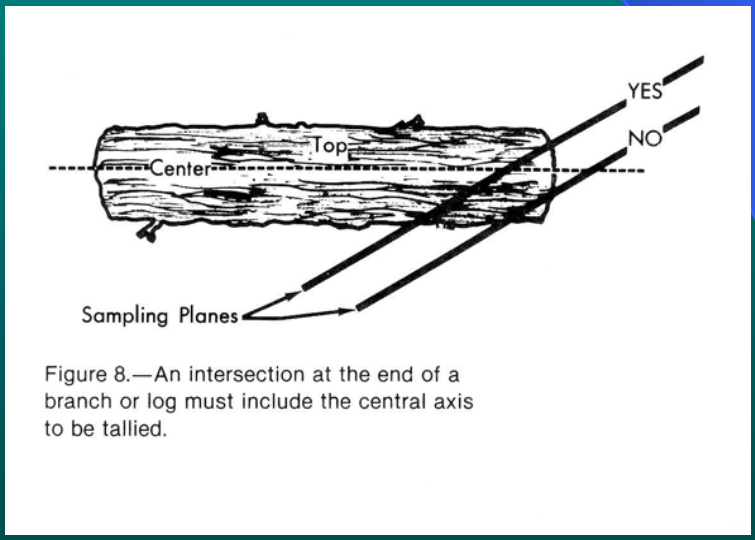


Figure 8.—An intersection at the end of a branch or log must include the central axis to be tallied.

Fire Behavior Chart

Andrews and Rothermel 1982

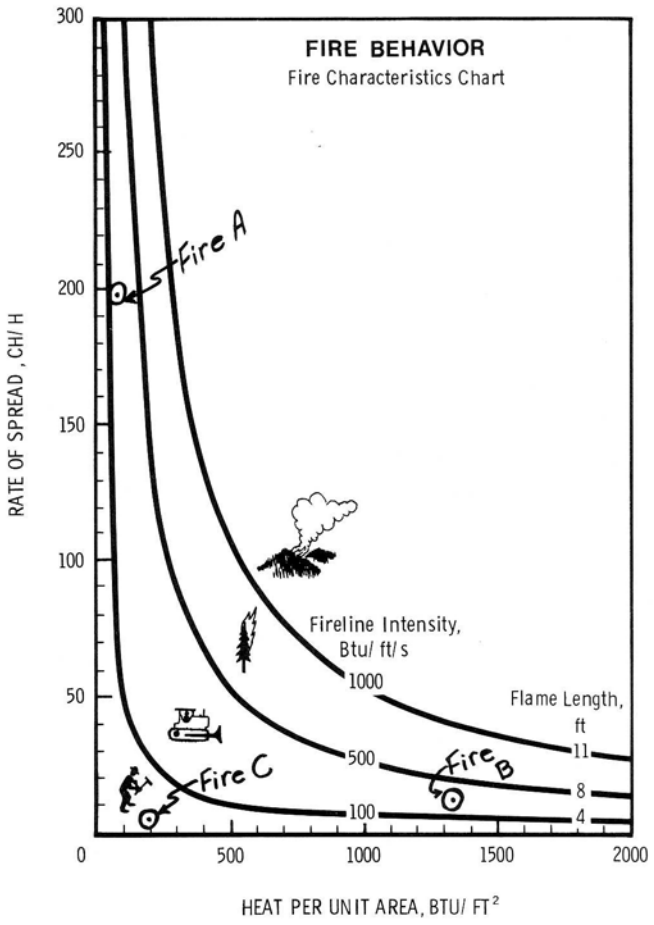


Figure 3.—Fire behavior predictions from table 2 plotted on a fire behavior chart.

Table 2.—Fire behavior predictions for specific fuel, moisture, wind, and slope conditions

Descriptors	Fire A	Fire B	Fire C
Fuel and environmental conditions:			
Fuel model	1	10	8
Dead fuel moisture, percent	5	5	5
Live fuel moisture, percent	100	100	100
Midflame windspeed, mi/h	7	7	7
Slope, percent	10	10	10
Fire behavior predictions:			
Rate of spread, chains/h	197	14	4
Heat per unit area, Btu/ft²	92	1,330	200
Fireline intensity, Btu/ft/s	333	344	13
Flame length, ft	7	7	1

A = grass (Anderson 1982)

B = timber litter and understory with heavy deadfall

C = short needle litter

1. Rate of spread 2. Heat per unit area
3. Flame Length 4. Fireline intensity

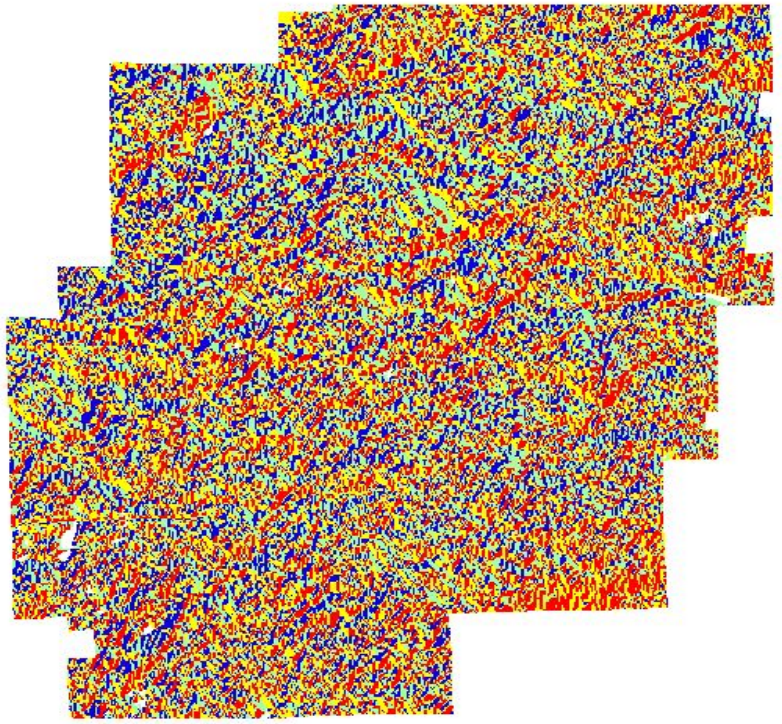
Spread calculations - Rothermel 1972

Methods 4

- To determine the relative influences of 3 weather characteristics on the rate of spread of fire to see if we can make simpler models
- Separate out the affects of each component on area of fire in FARSITE first
  - 3x3x3=27 landscape conditions
- Use Path Coefficient Analysis, to create a model and a table of direct and indirect affects for each variable, Wind, Rain and Temperature, on area of spread.
- Brainstorm, ideas about other statistical test to accomplish this, e.g. General Linear Model (GLM), ANOVA, others?

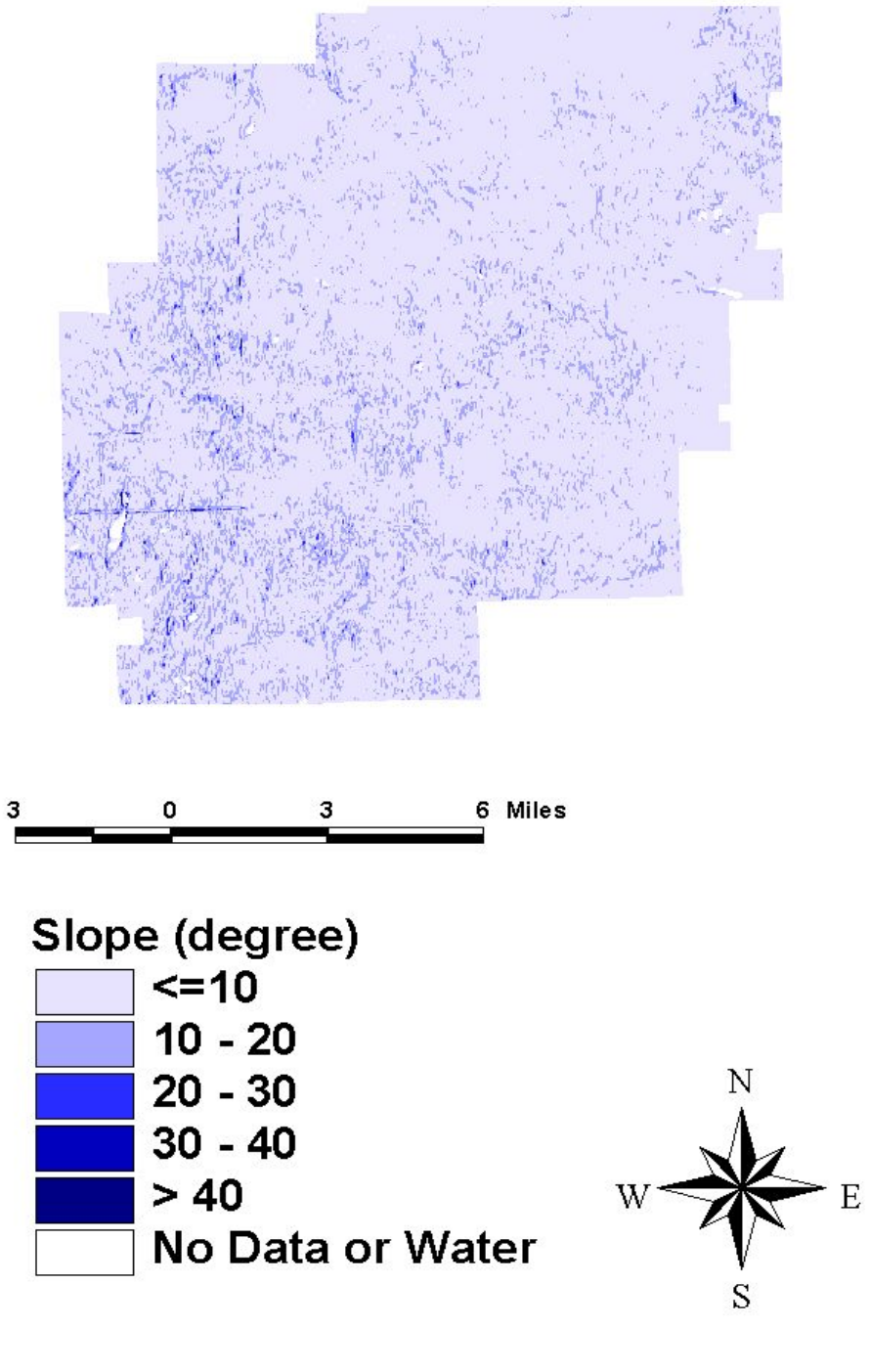
FARSITE Input

Aspect



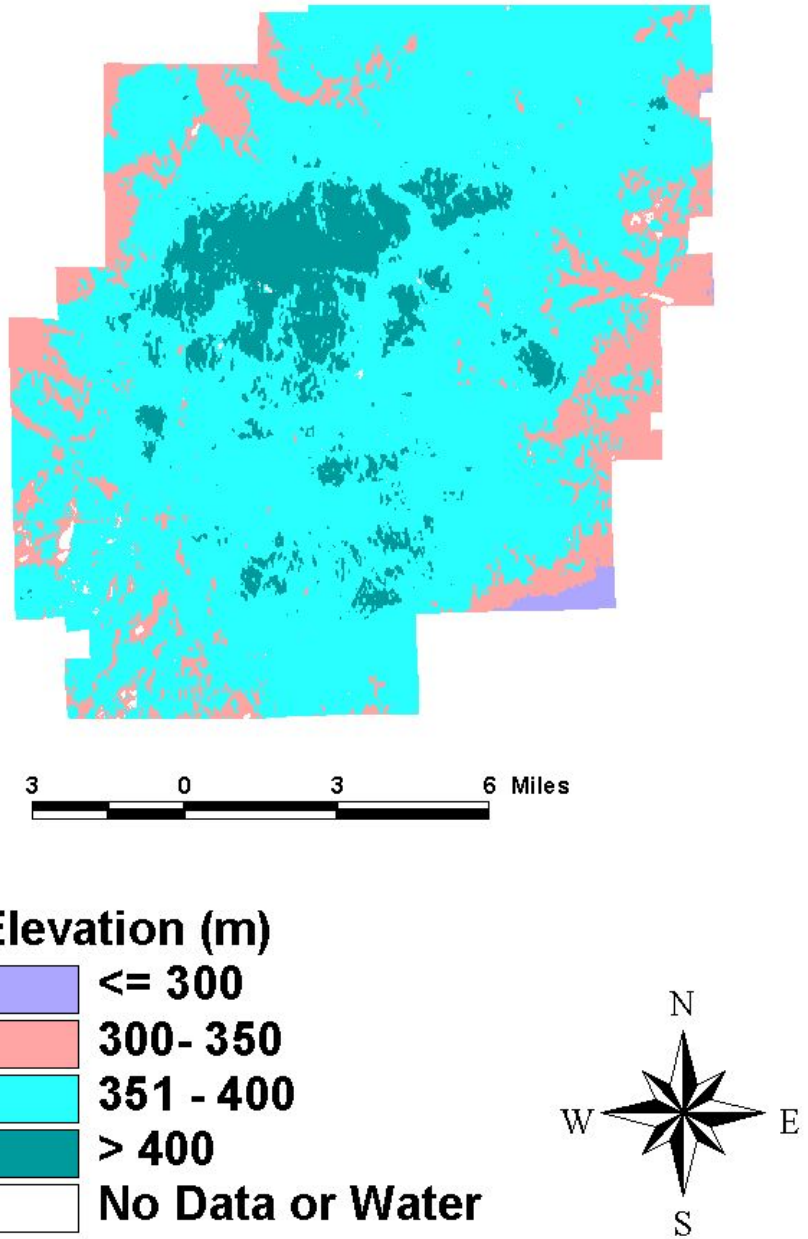
FARSITE Input

Slope



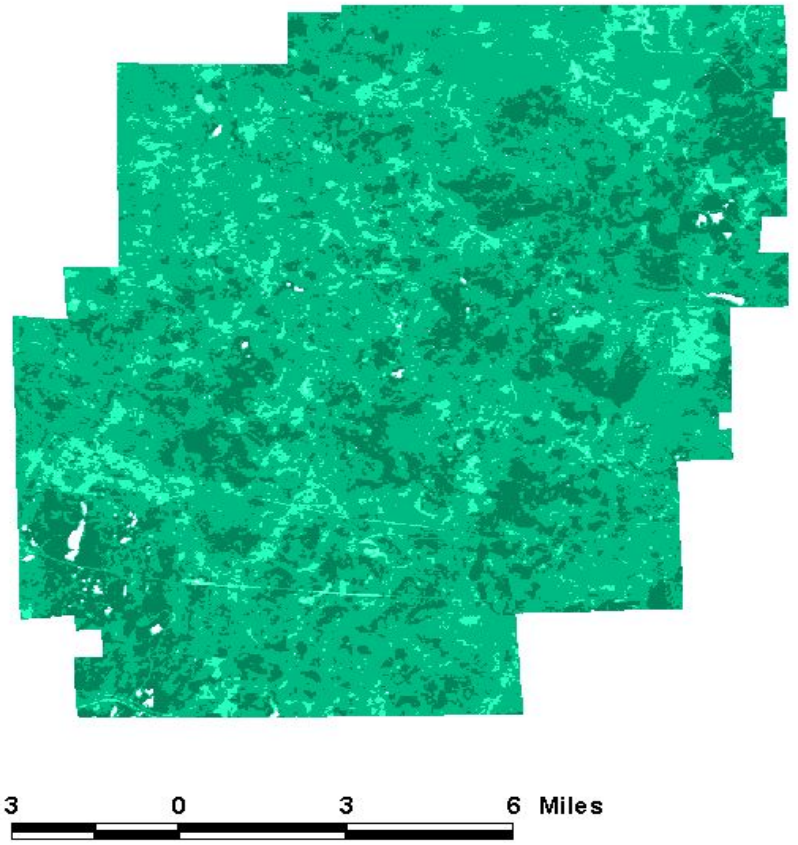
FARSITE Input

Elevation



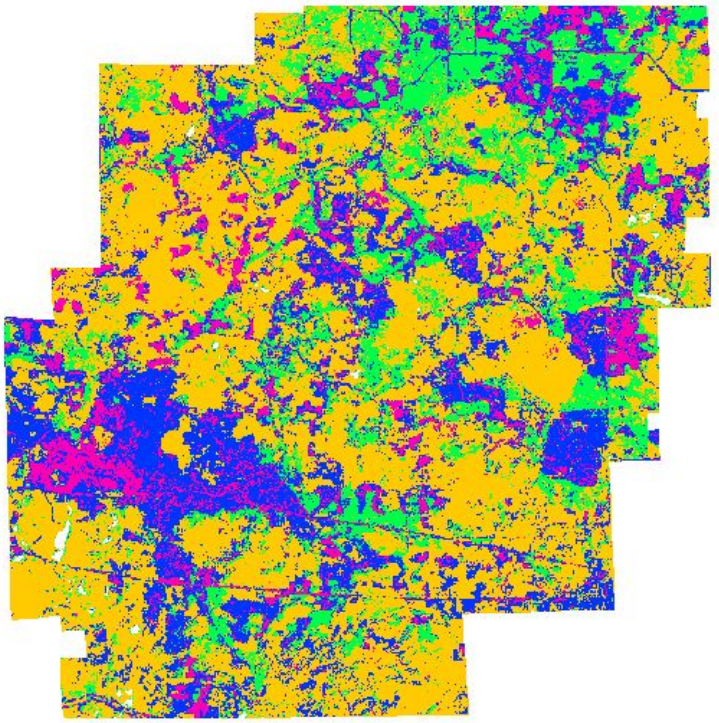
FARSITE Input

Canopy



FARSITE Input

Fuel Type



Fire in S. portion of the Washburn

JP slightly burn
JP medium burn
MH slightly burn
MH medium burn
MHC slightly burn
MHC medium burn
NFS slightly burn
NFS medium burn
RP slightly burn
RP medium burn
NFBG

Day1	Slightly burn	16.401	ha
	Medium burn	5.177	ha
	Completely burn	3.959	ha

LaCroix et al., *to be submitted*

Weather Variables

- Use historic data from Ashland, WI to find ranges that are logical for Hi and Lo Wind, Rain, and Temperatures from the past 100 years
- http://mcc.sws.uiuc.edu/Precip/WI/470349_psum.html
- Change the ASCII file inputs in FARSITE
  - run simulations 27x12=324

Preliminary Results

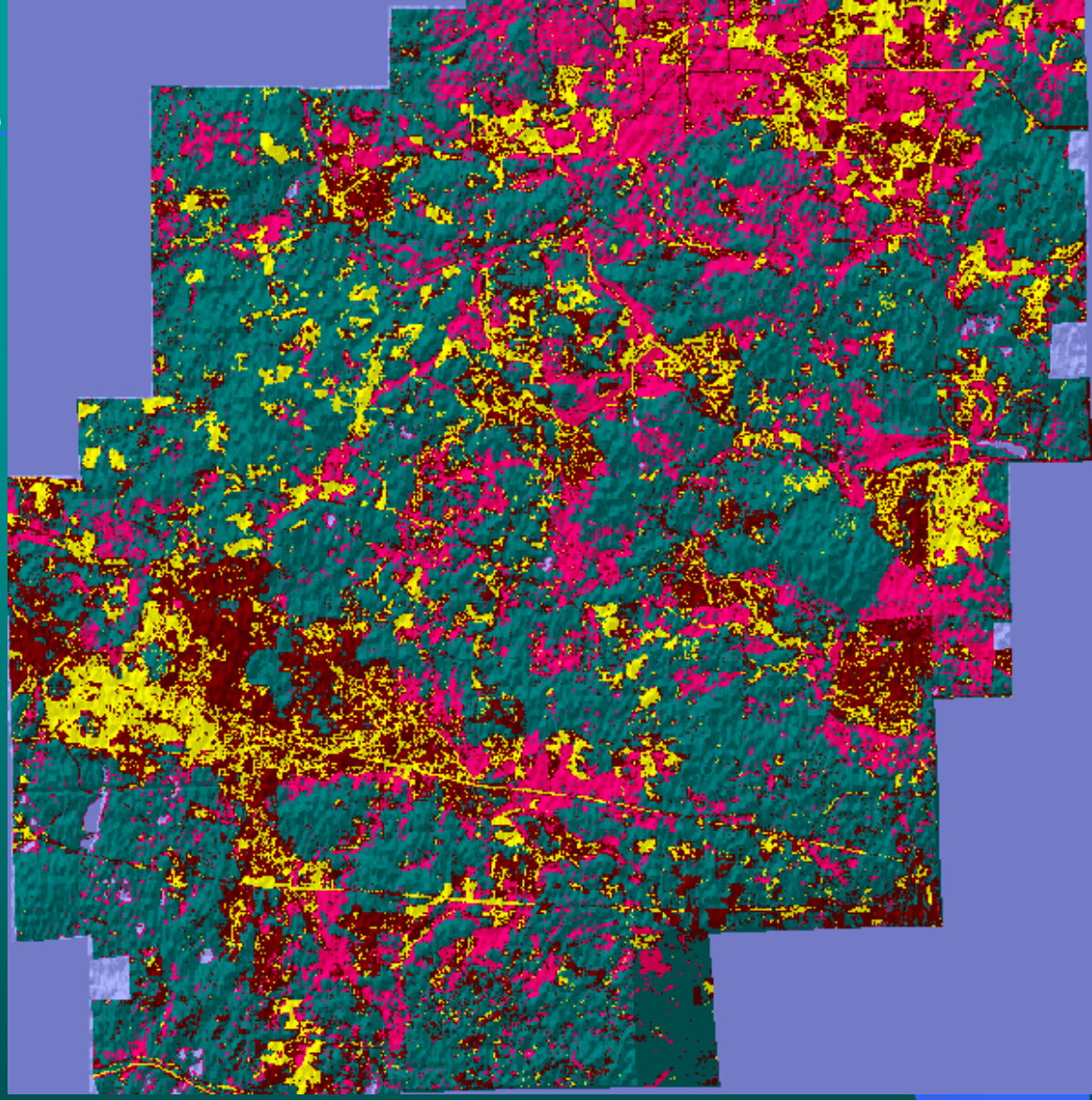
- Running the model suggests differences in area in with different weather factors

FARSITE Outputs

- Show the 2001 landscape
- With Fire in HPA
- With Fire in ROS
- With Fire in FLI
- With Fire in FML

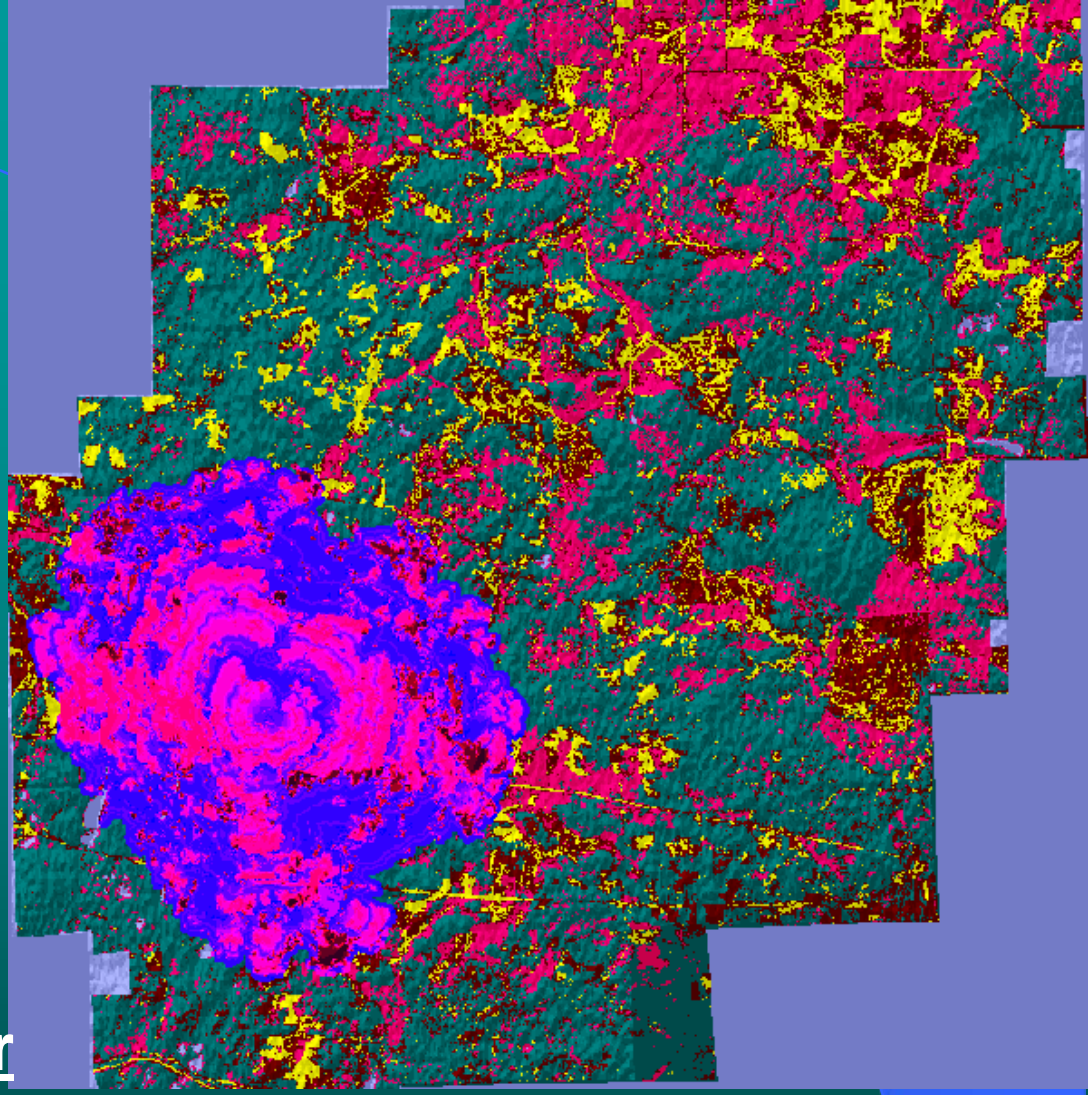
Chequamegon
National Forest Landscape
with the 4 fuel types in
different colors.

Brown = brush.
Green = closed timber
litter: no under-story,
closed canopy,
pine needle and leaf duff.
Red = timber litter and
Under story: hardwood
leaves, young trees.
Yellow = light logging
slash.



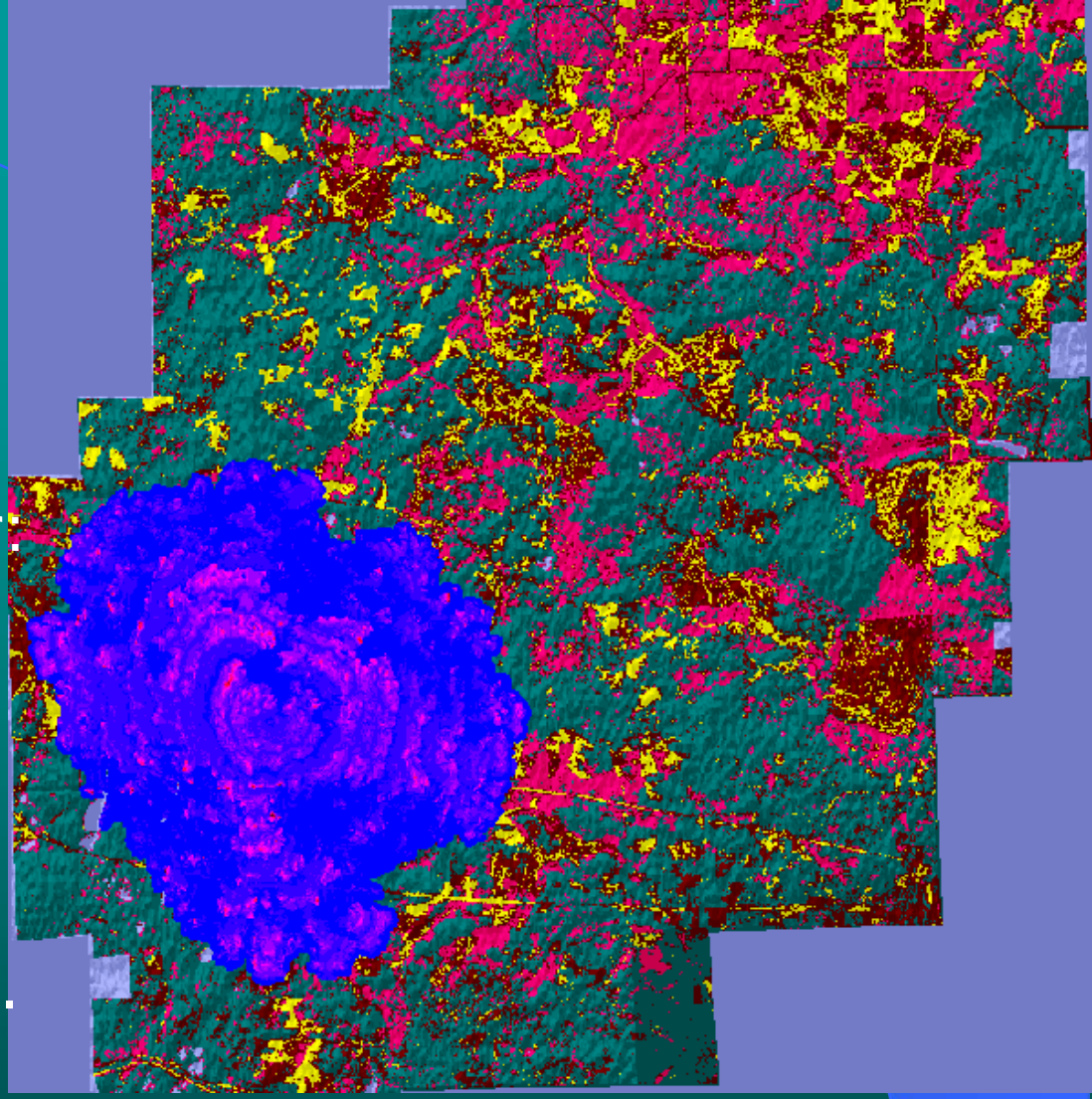
CNF Landscape
with the 4 fuel types in different colors.

Brown = brush.
Green = closed timber litter: pine needle and leaf duff, closed canopy.
Red = timber litter and under story, hardwood leaves, young trees.
Yellow = light logging slash.
Also, the fire is placed on the landscape with **Heat per Area** represented. Blue = Cool heat.
Red = Medium heat. Black = High heat.



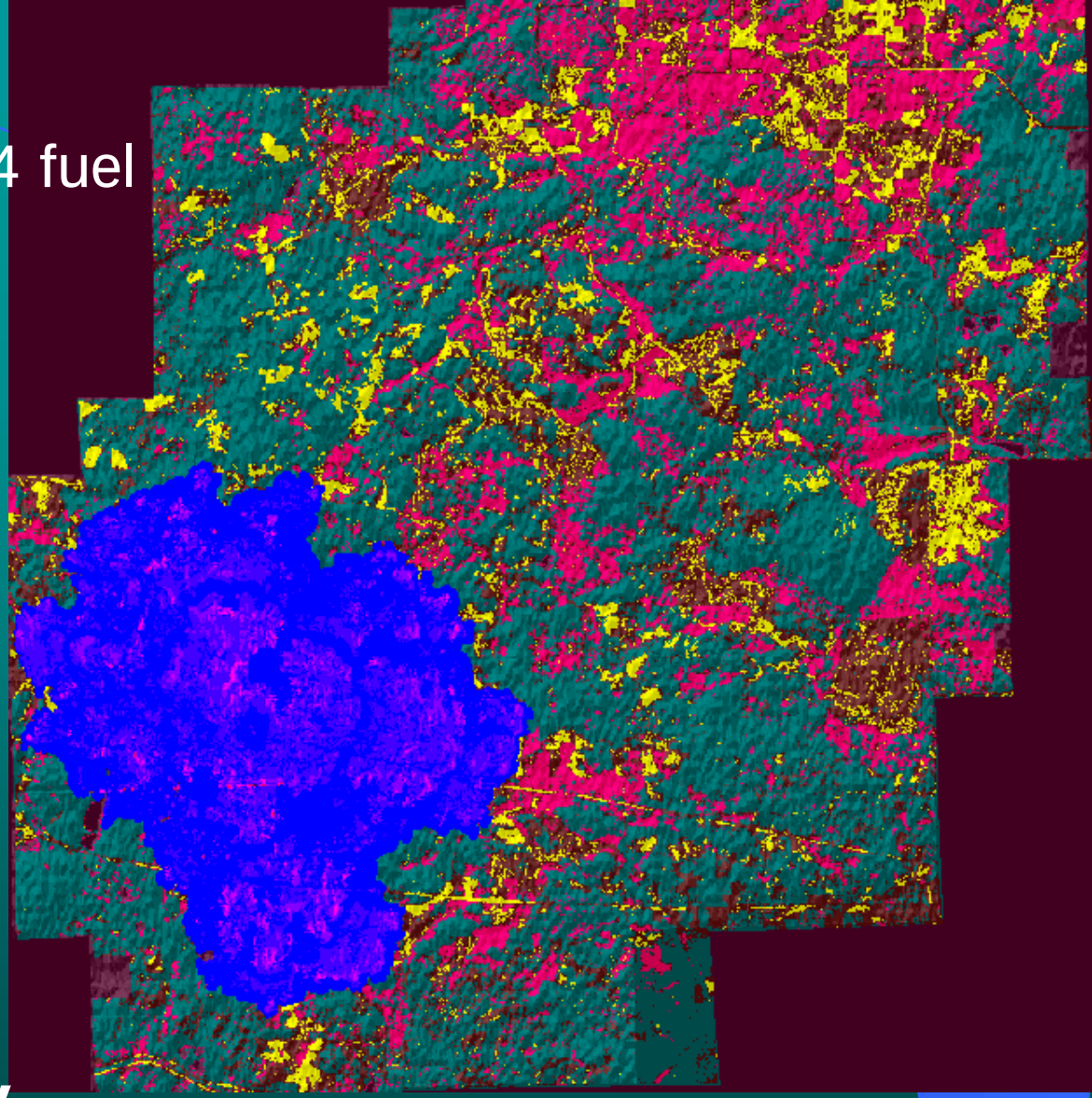
CNF Landscape
with the 4 fuel types in different colors.

Brown = brush.
Green = closed timber litter: pine needle and leaf duff, closed canopy.
Red = timber litter and under story: hardwood leaves and young trees.
Yellow = light logging slash.
Also, the fire is placed on the landscape with **Rate of Spread** represented.
Blue = Slow rate. Red = Medium rate.



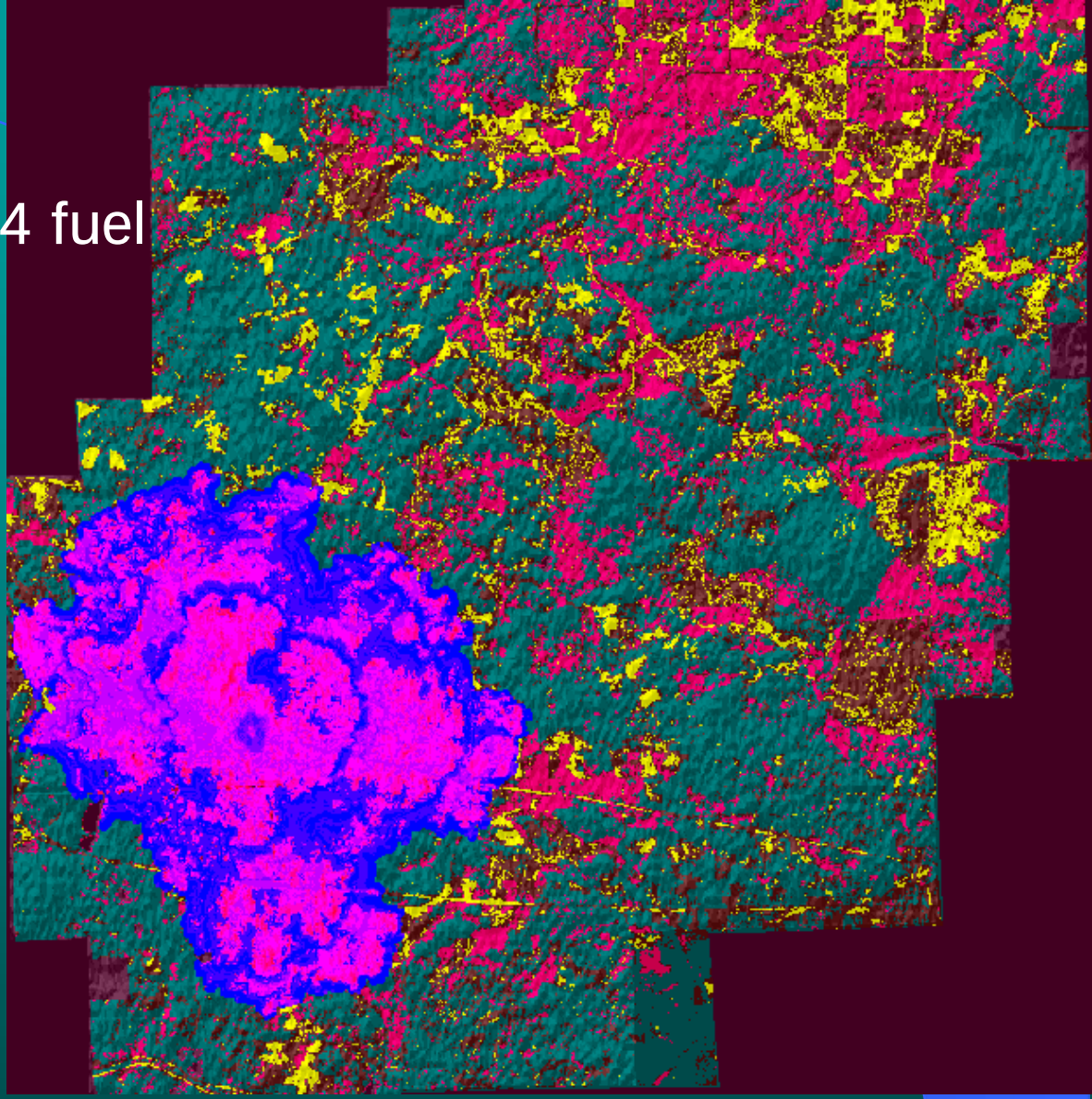
CNF Landscape with the 4 fuel types in different colors.

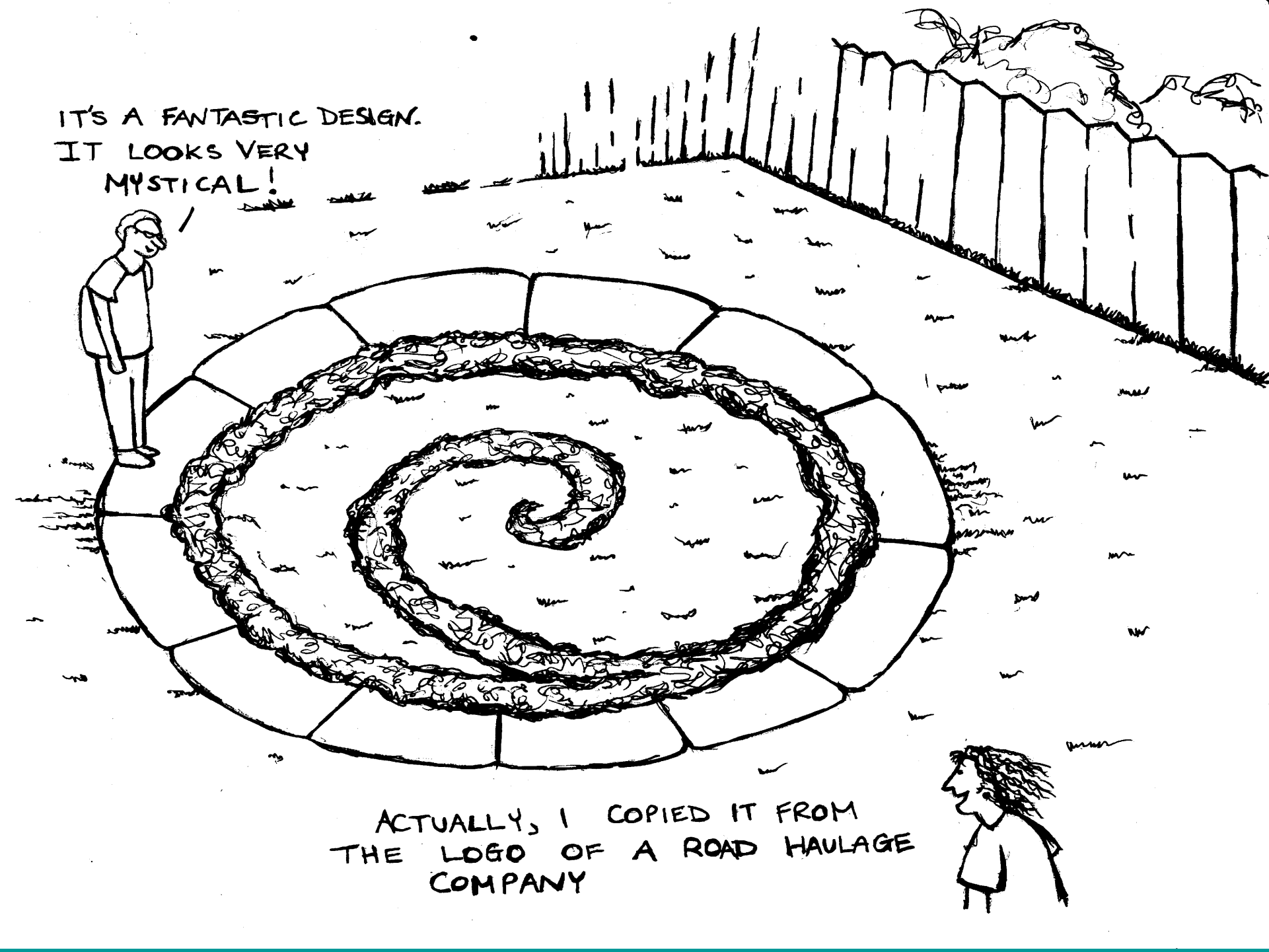
Brown = brush.
Green = closed timber litter: pine needle and leaf duff, closed canopy.
Red = timber litter and under story: hardwood leaves and young trees.
Yellow = light logging slash. Also, the fire is placed on the landscape with **Fire Line Intensity** represented. Blue = Slow rate. Red = Medium rate.

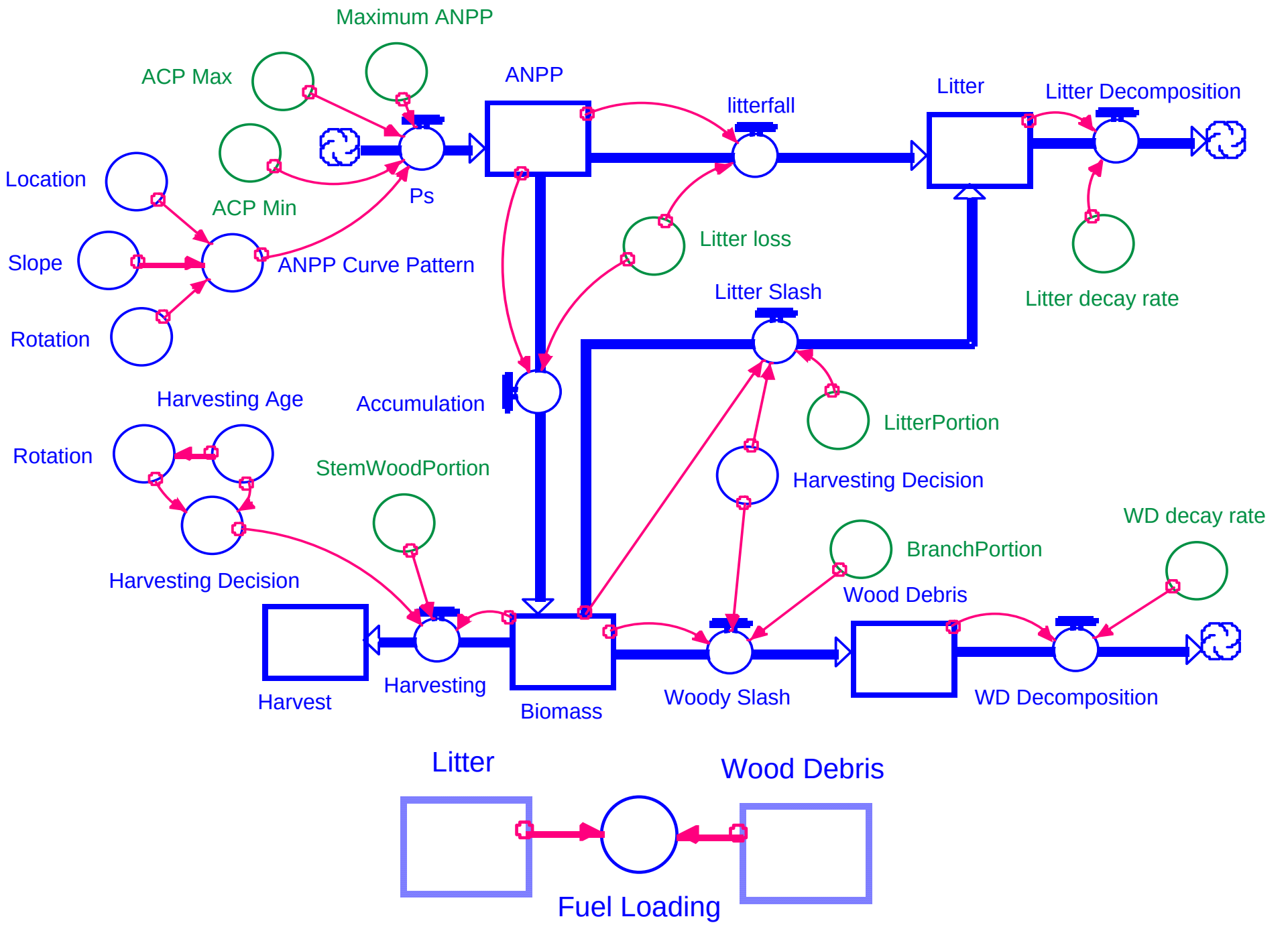


CNF Landscape with the 4 fuel types in different colors.

Brown = brush.
Green = closed timber litter: pine needle and leaf duff, closed canopy.
Red = timber litter and under story: hardwood leaves and young trees.
Yellow = light logging slash. Also, the fire is placed on the landscape with **Flame Length** represented. Blue = Slow rate. Red = Medium rate.




IT'S A FANTASTIC DESIGN. IT LOOKS VERY MYSTICAL!
ACTUALLY, I COPIED IT FROM THE LOGO OF A ROAD HAULAGE COMPANY


Maximum ANPP
ACP Max
ANPP
litterfall
Litter
Litter Decomposition
Location
ACP Min
Ps
Litter loss
Litter decay rate
Slope
ANPP Curve Pattern
Litter Slash
Rotation
Harvesting Age
Accumulation
LitterPortion
Rotation
StemWoodPortion
Harvesting Decision
WD decay rate
BranchPortion
Harvesting Decision
Wood Debris
Harvest
Harvesting
Biomass
Woody Slash
WD Decomposition
Litter
Wood Debris
Fuel Loading

CALIFORNIA
Example

Task: Visualization system for stand and fuel dynamics, & fires in the landscape

Scales included in this study

- Spatial scales
  - Stand
  - Landscape
  - Region
- Temporal scale
  - Around 50-200 Years when visualize the forest dynamics

Objectives

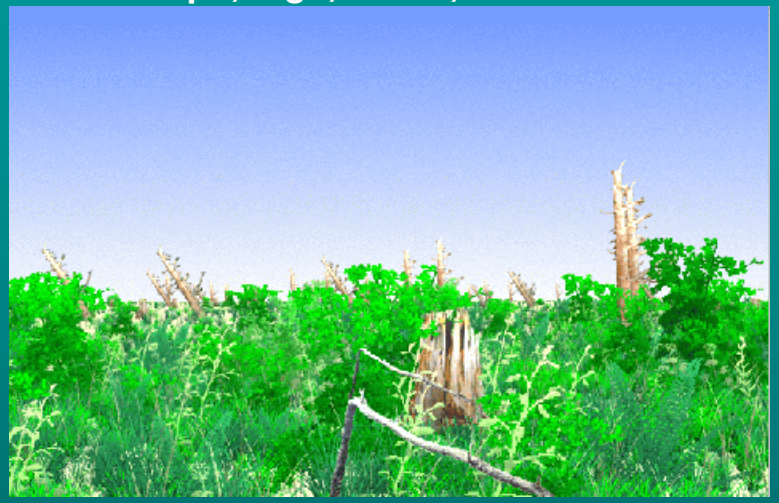
- Visualization of forest dynamics at multiple scales
- Visualization of management alternatives
- Visualization of forests at various scales

Data needed for visualization

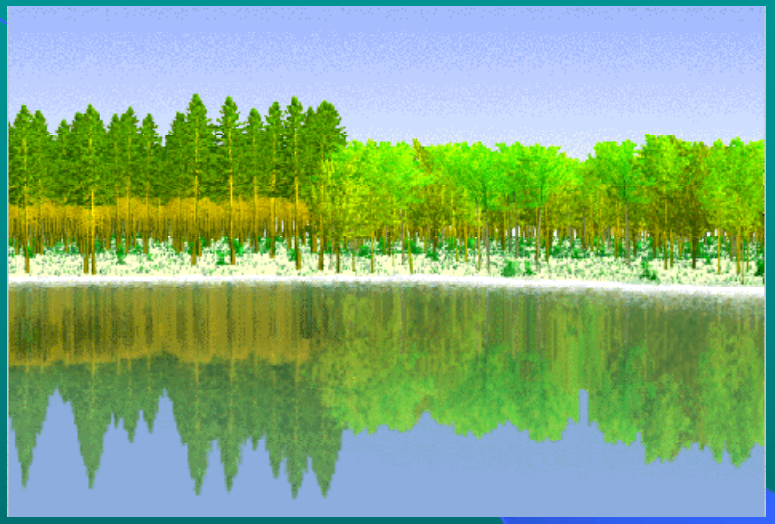
- Digital Elevation Map (DEM)
- Landcover (GIS coverage, optional)
- Tree Images
- Tree Height
- Tree Density
- Species Composition

Examples of visualization capability

a) Other objects such as snags, stumps, logs, herbs, shrubs

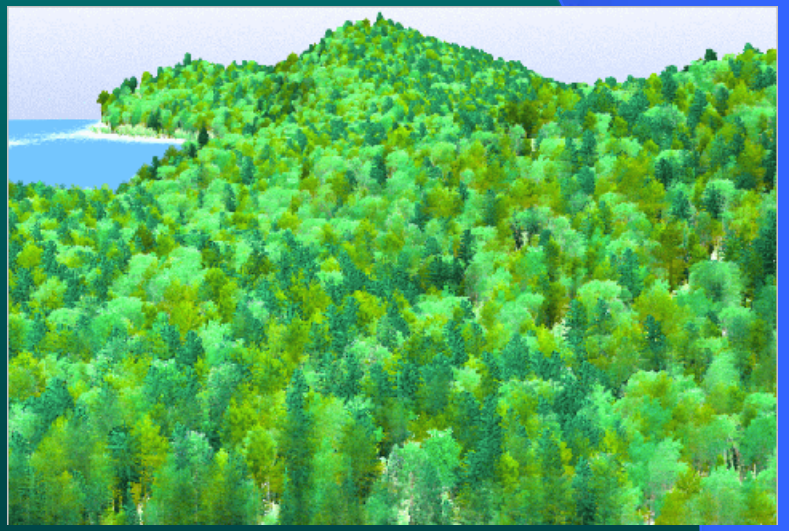


b) Lake (water body)



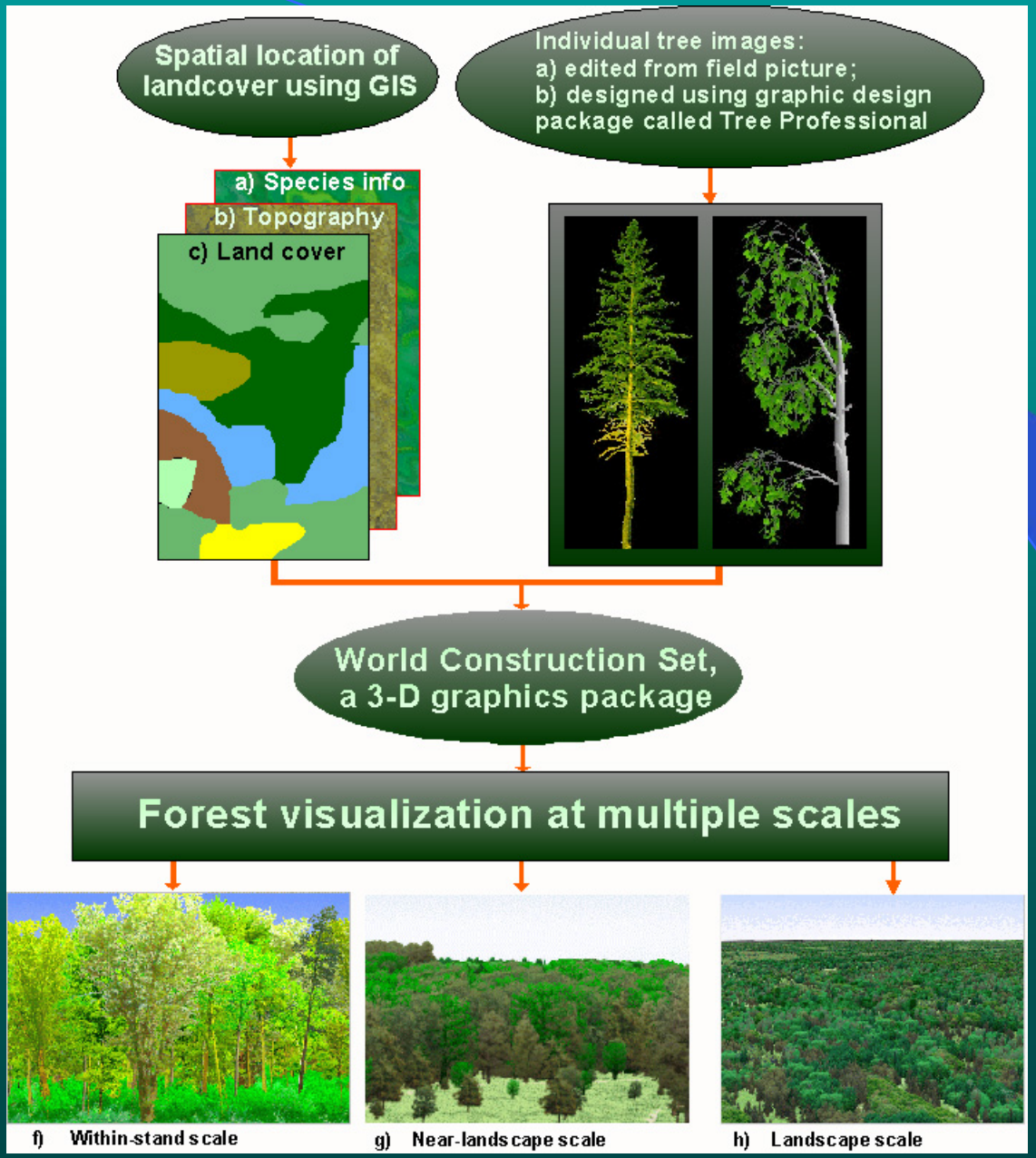
c) Road

d) Topographic visualization

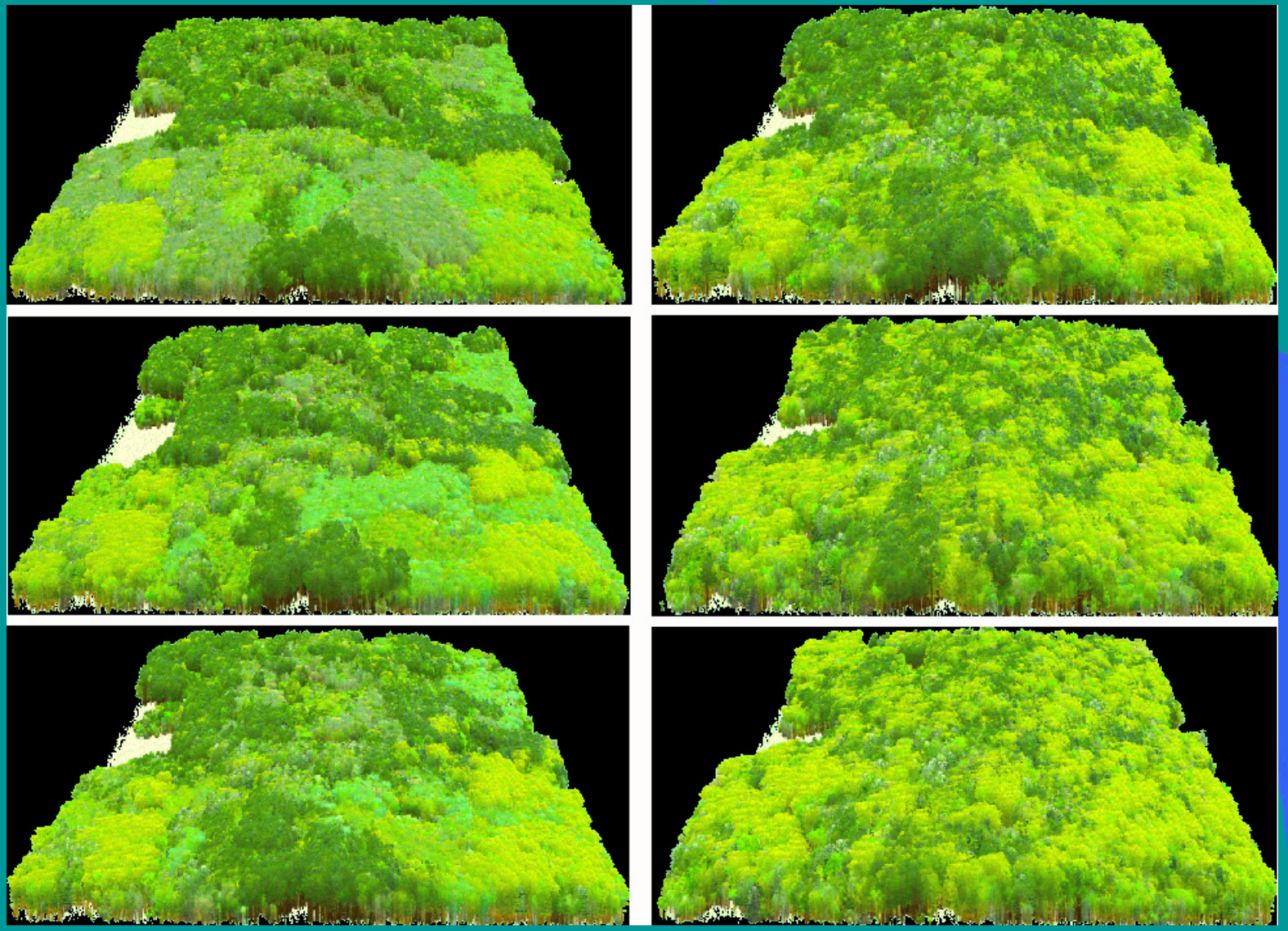


Various trees designed on computer or taken from the field for forest visualization

The Approach of Forest Visualization at Multiple Scales

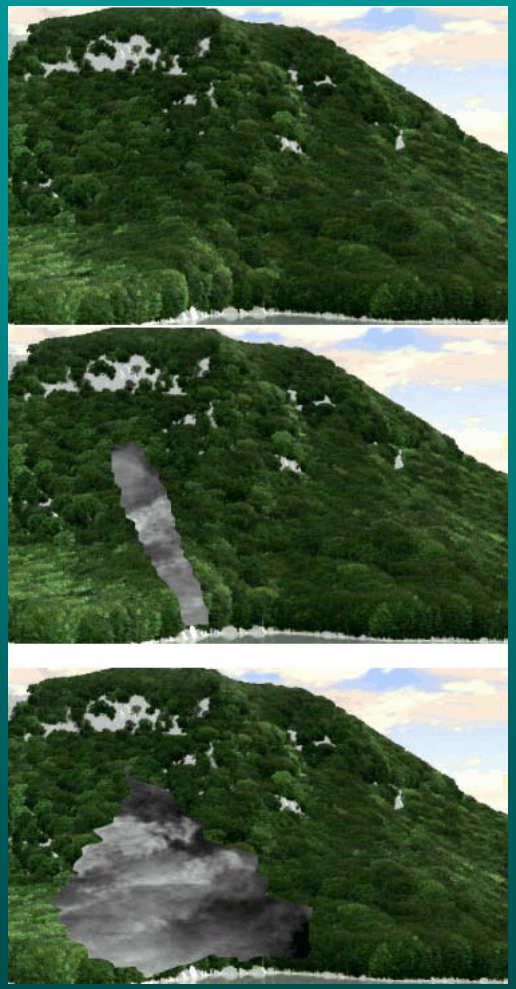


The temporal changes of forest landscape from modeling output with fire effect (a through f, in a vertical sequences)



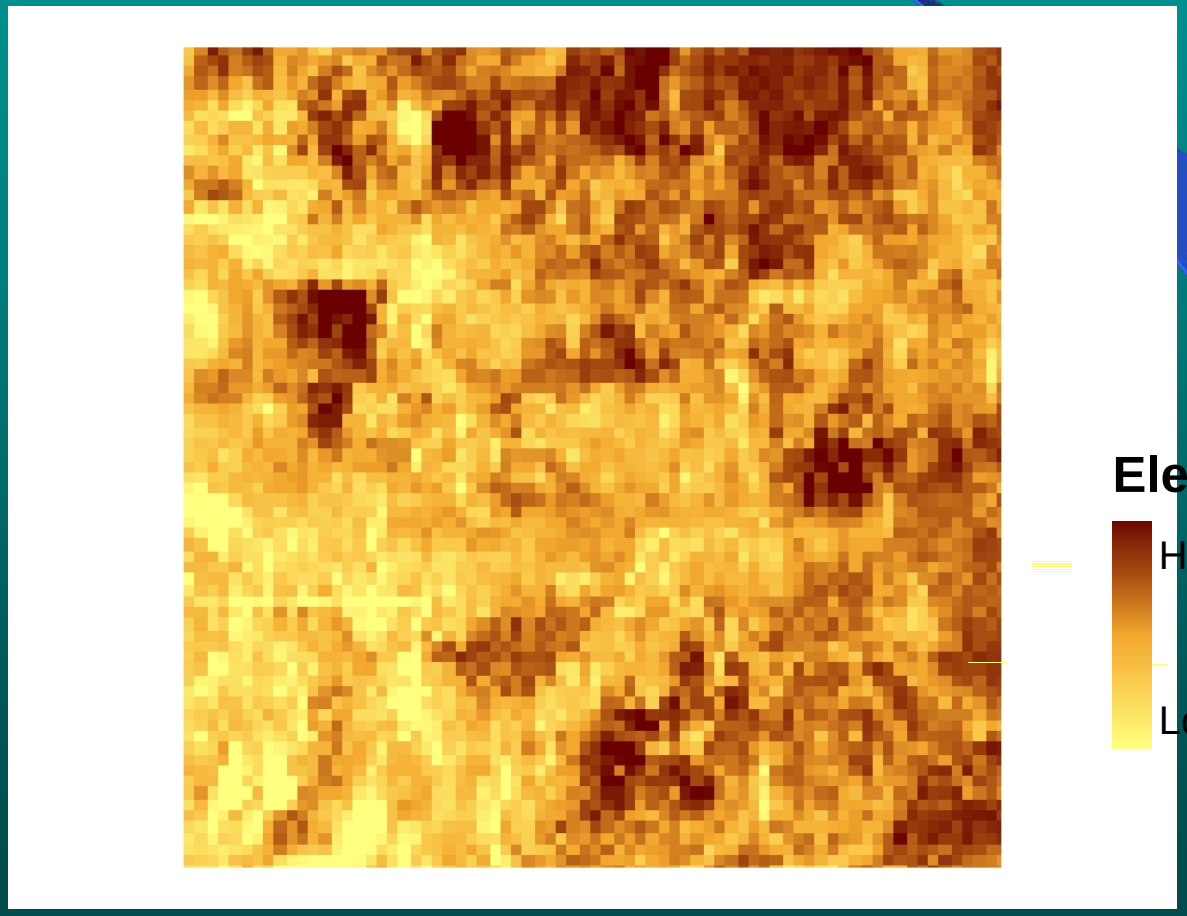
Visualization of Landscape Change During 200 Year Period with the Effects of Fire and Wind

Fires, Management, and Land Mosaic Interactions

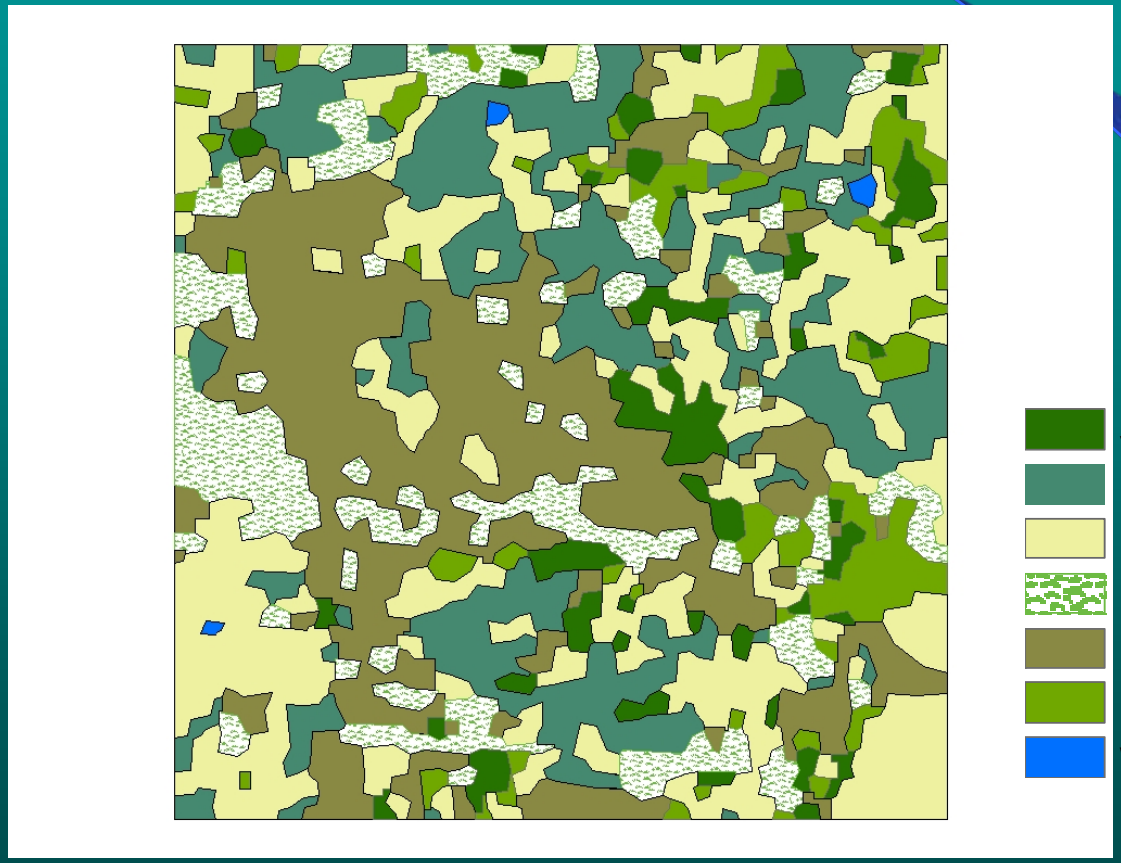


Please wait to watch the movie. Be patient, the movie can be slow

Digital Elevation Map of a part of Chequamegon National Forest

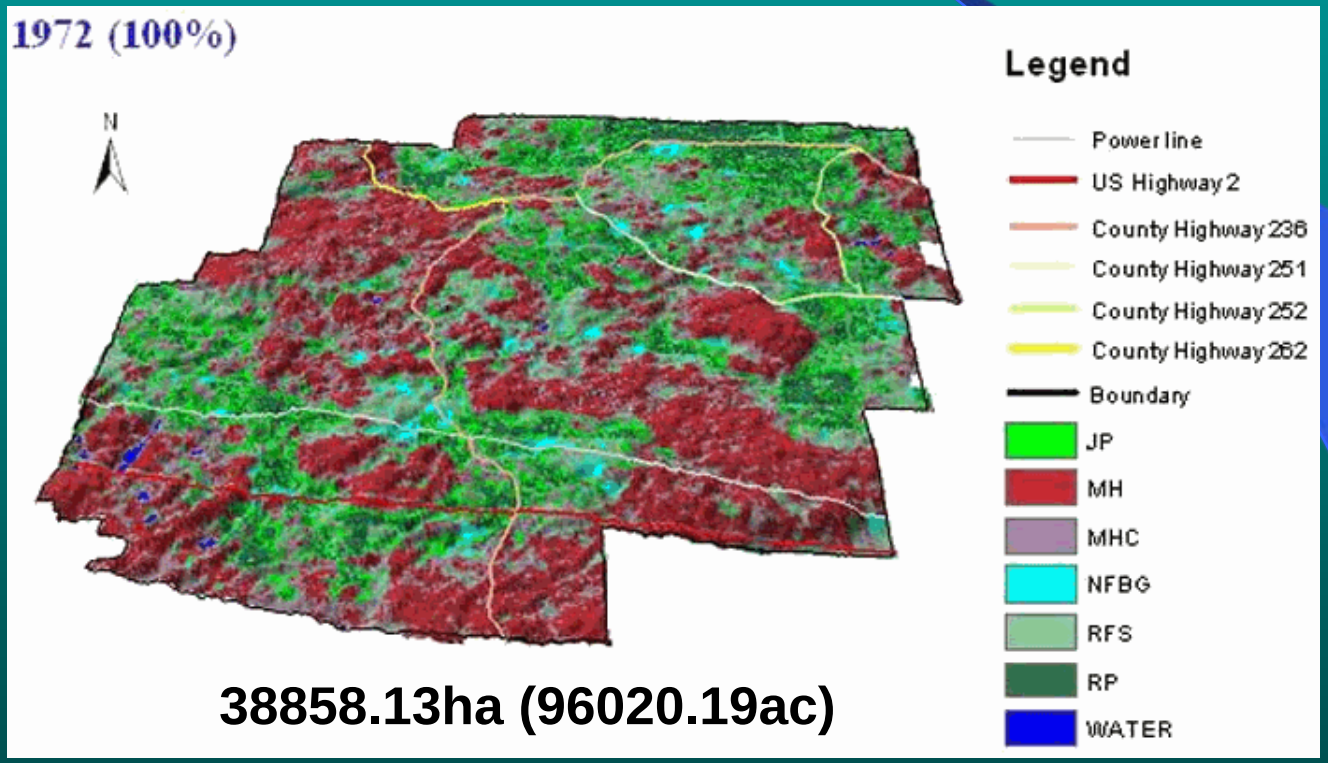


Landcover in a part of Chequamegon national forest



8670.61ha (21425.48ac)

Visualization of Temporal Landscape Change from 1972 to 2001

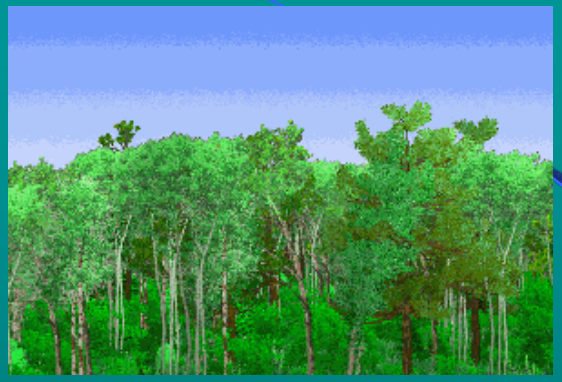


38858.13ha (96020.19ac)

Visualization of 50 Years of Red Pine Forest Growth at Stand Scale

Visual Comparison of Different Cutting Methods at Stand Scale

Walking through the Original Forest

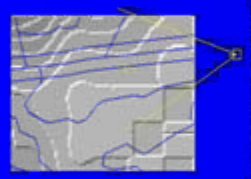


Walking through the Residual Cut Forest

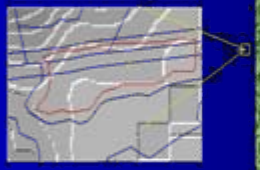
Walking through the Clear Cut Forest

Visualization of Different Cutting Strategies

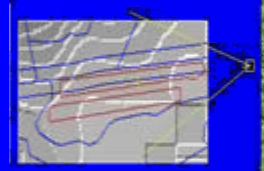
Original Forest

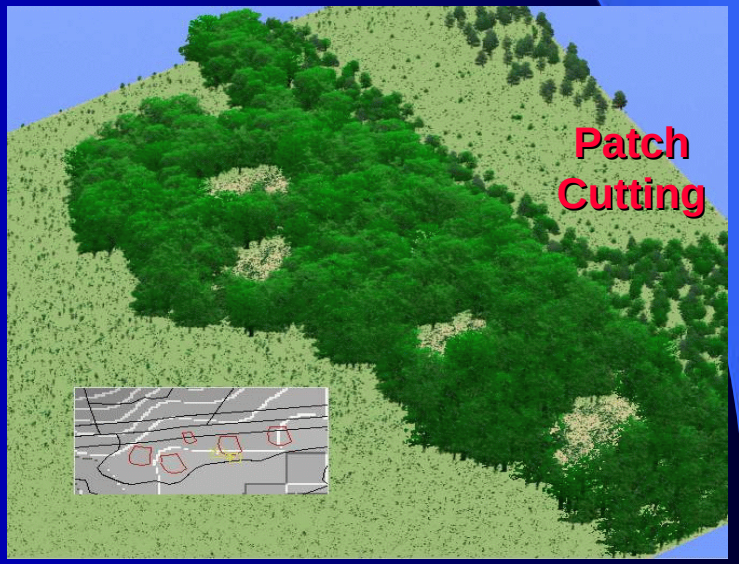


Clear Cutting

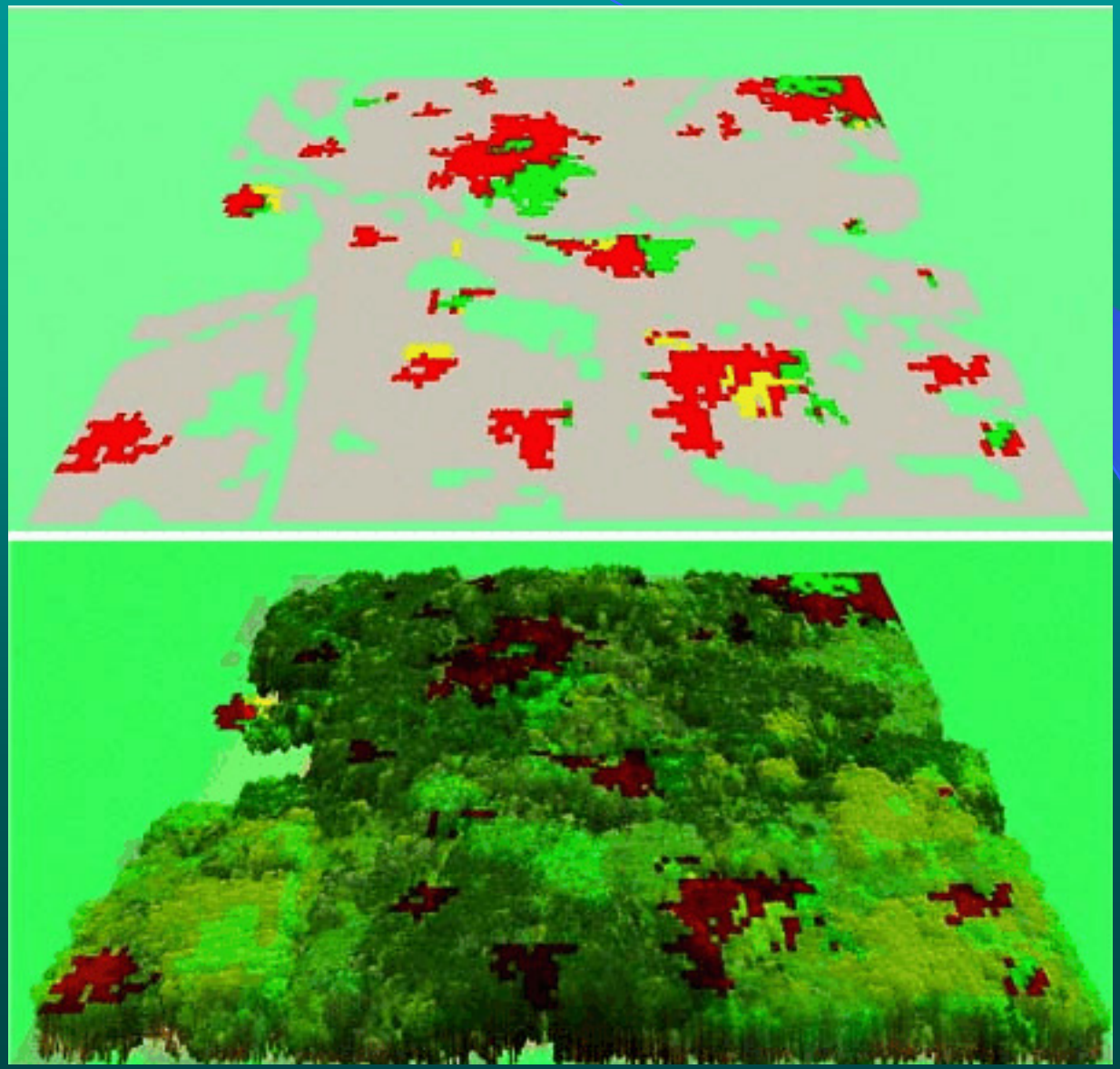


Strip Cutting

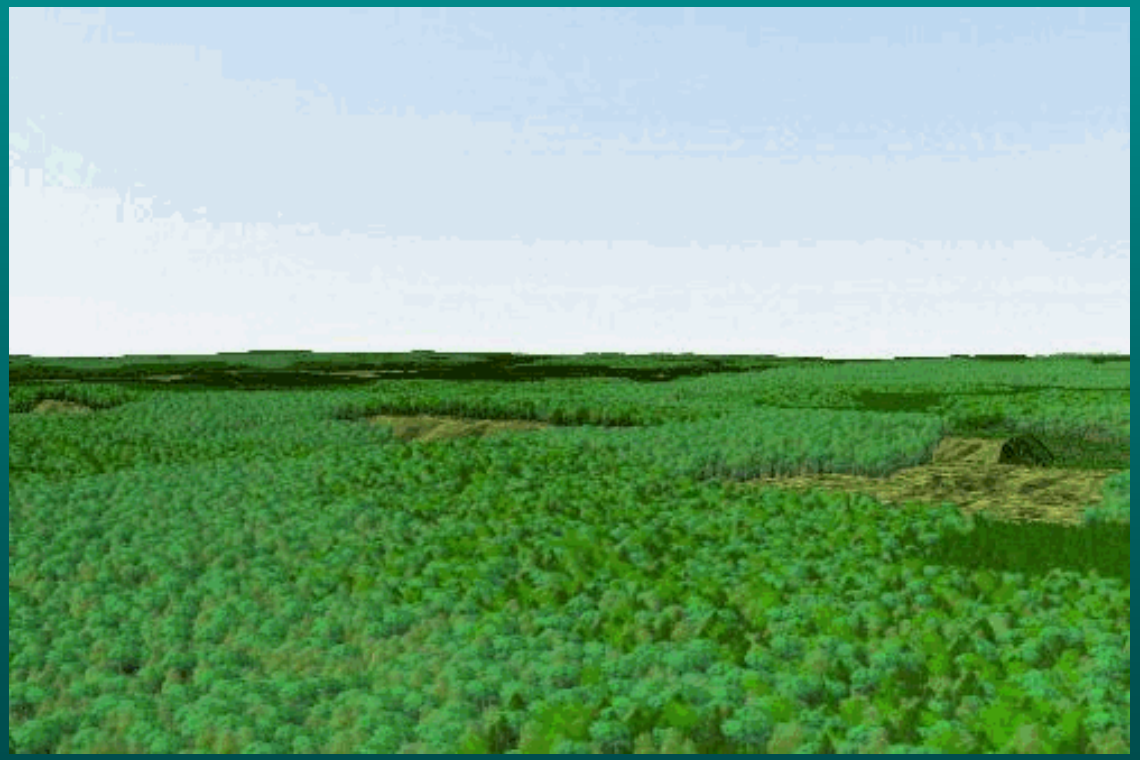




Visualization of Landscape Change under Land Management and Fire Effects



Fly-through over a part of Chequamegon National Forest at 500 m altitude



Regeneration Forest

Mature Hardwood

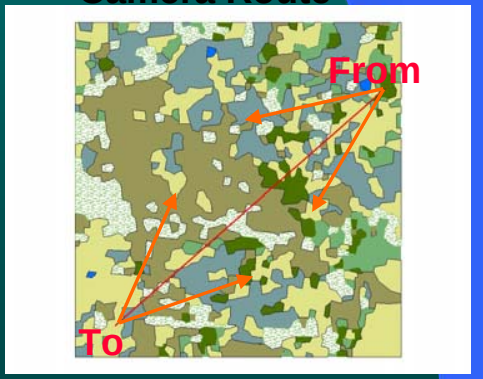
Mature Hardwood & Conifer

Jack Pine

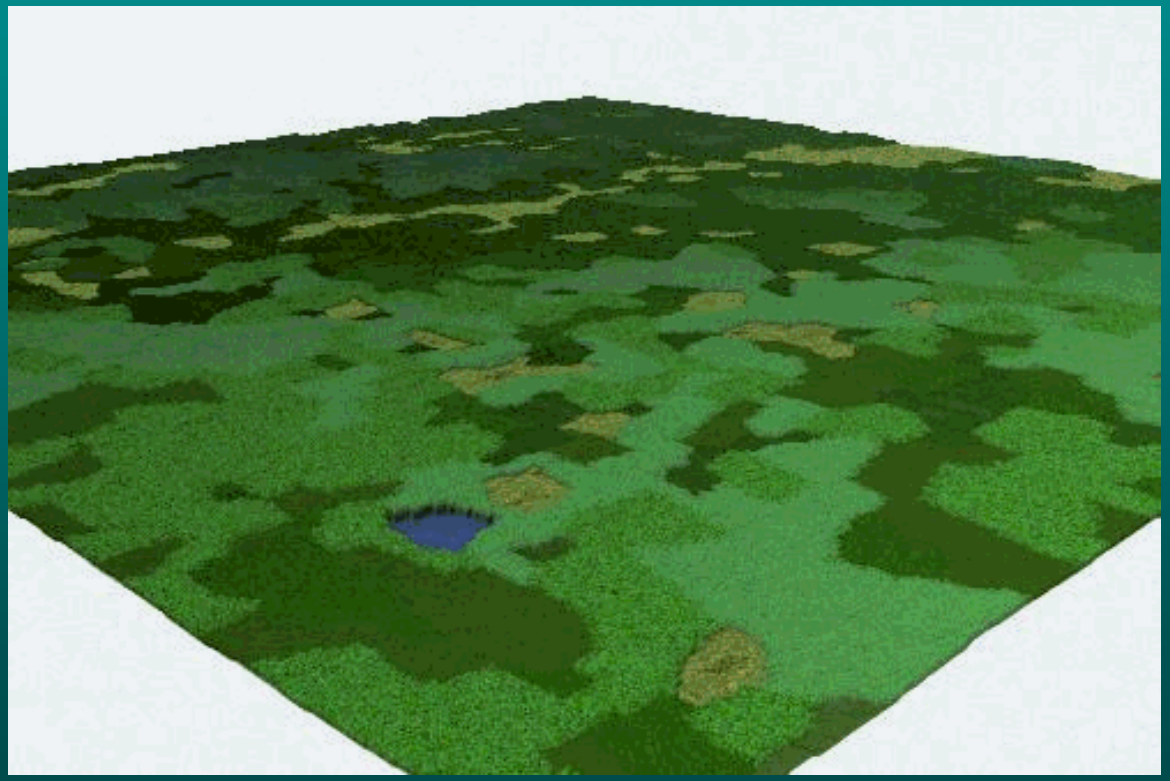
Non-forested

Red Pine

Camera Route



Fly-through over a part of Chequamegon National Forest starting at 2000 m altitude and then descending to 600m



Regeneration Forest

Mature Hardwood

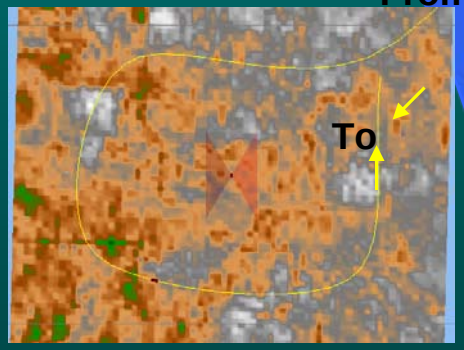
Mature Hardwood & Conifer

Jack Pine

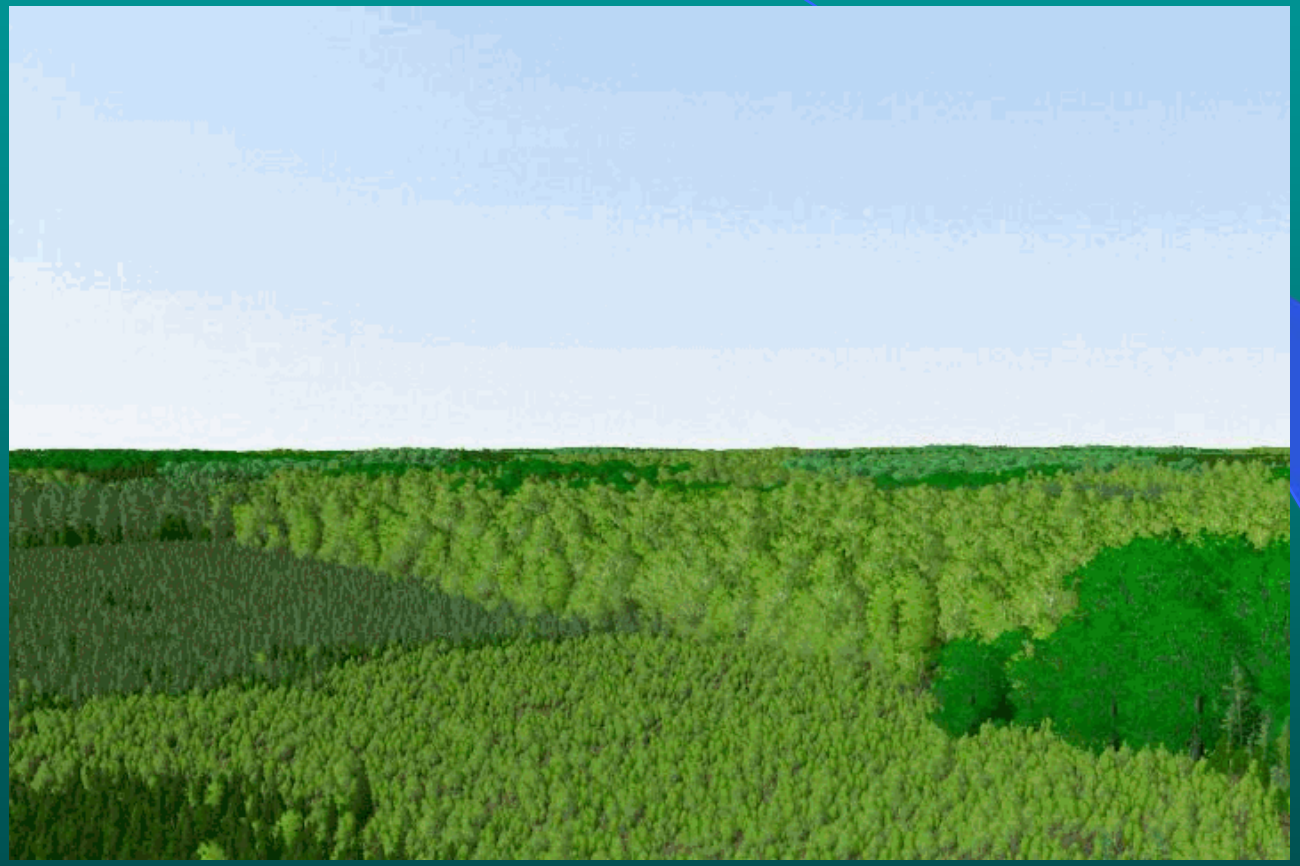
Non-forested

Red Pine

Camera Route



Fly-through Chequamegon National Forest at 500 ft above the terrain

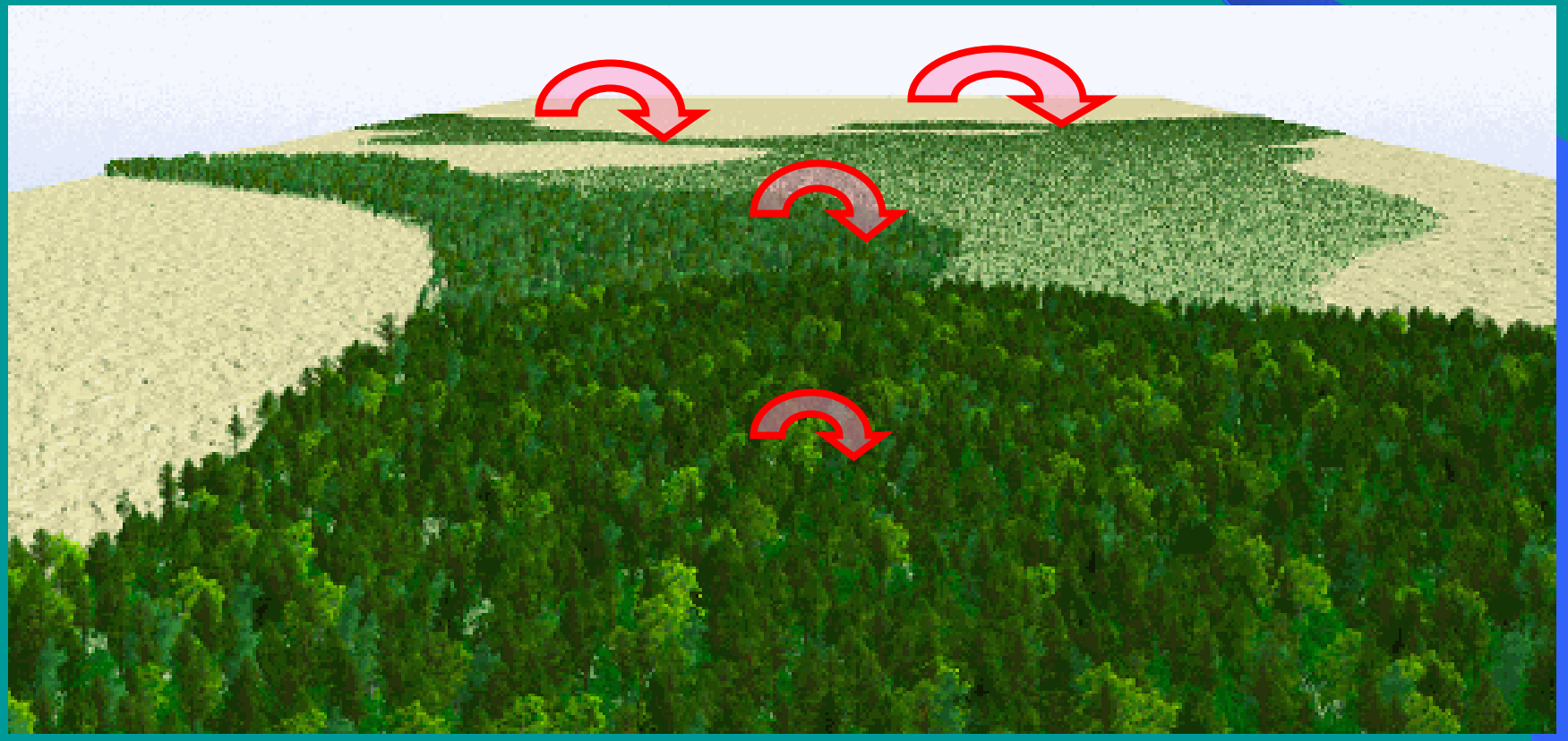


38858.13ha (96020.19ac)

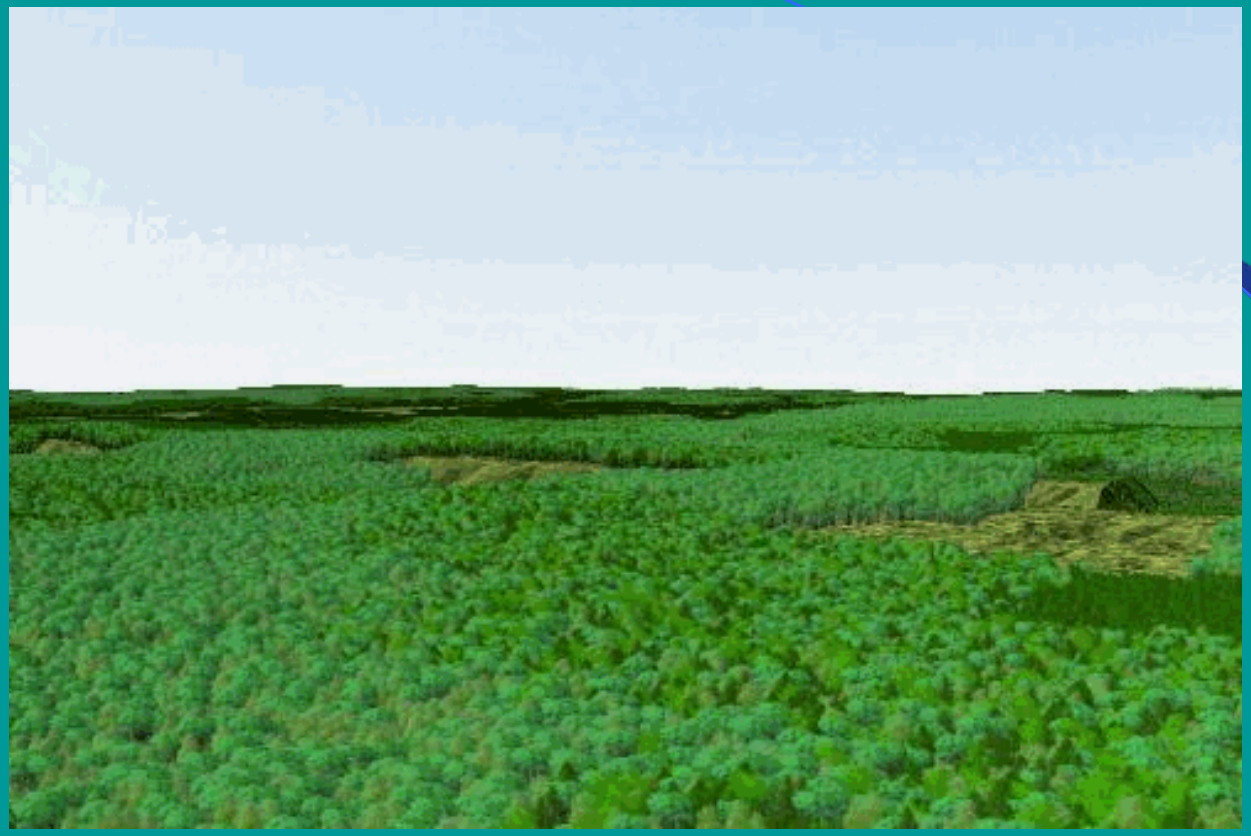
Visualization of 60 Years of Forest Growth

Note: Using four patches of forest; the growth rates are different with different cutting strategies

(Wang et al., *in review*)



Fly-through over a part of Chequamegon National Forest at 500 m altitude



Regeneration Forest

Mature Hardwood

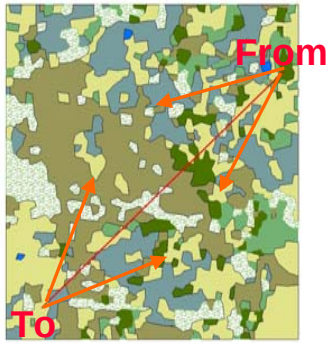
Mature Hardwood & Conifer

Jack Pine

Non-forested

Red Pine

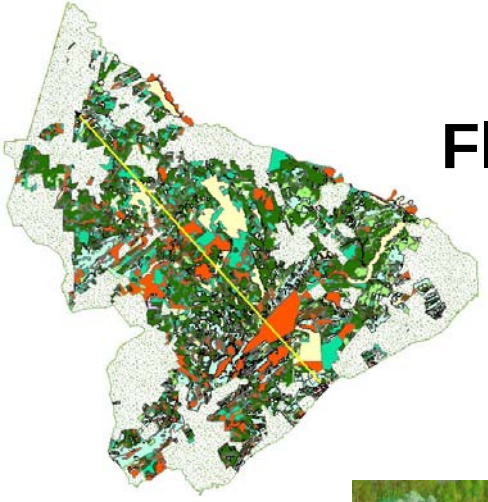
Camera Route



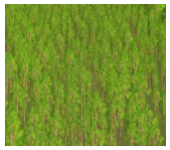
Please wait to watch the movie. Be patient, the movie can be slow

Wang et al, *in review*

Fly-through Francis Marion National Forest at 100 m altitude



Beech-Magnolia



Cypress-Tupelo

Loblolly Pine

Loblolly-Longleaf pine

Longleaf Pine

Please wait to watch the movie. Be patient, the movie can be slow

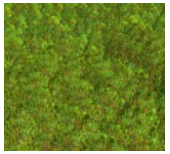
Mixed Hardwood

Oak

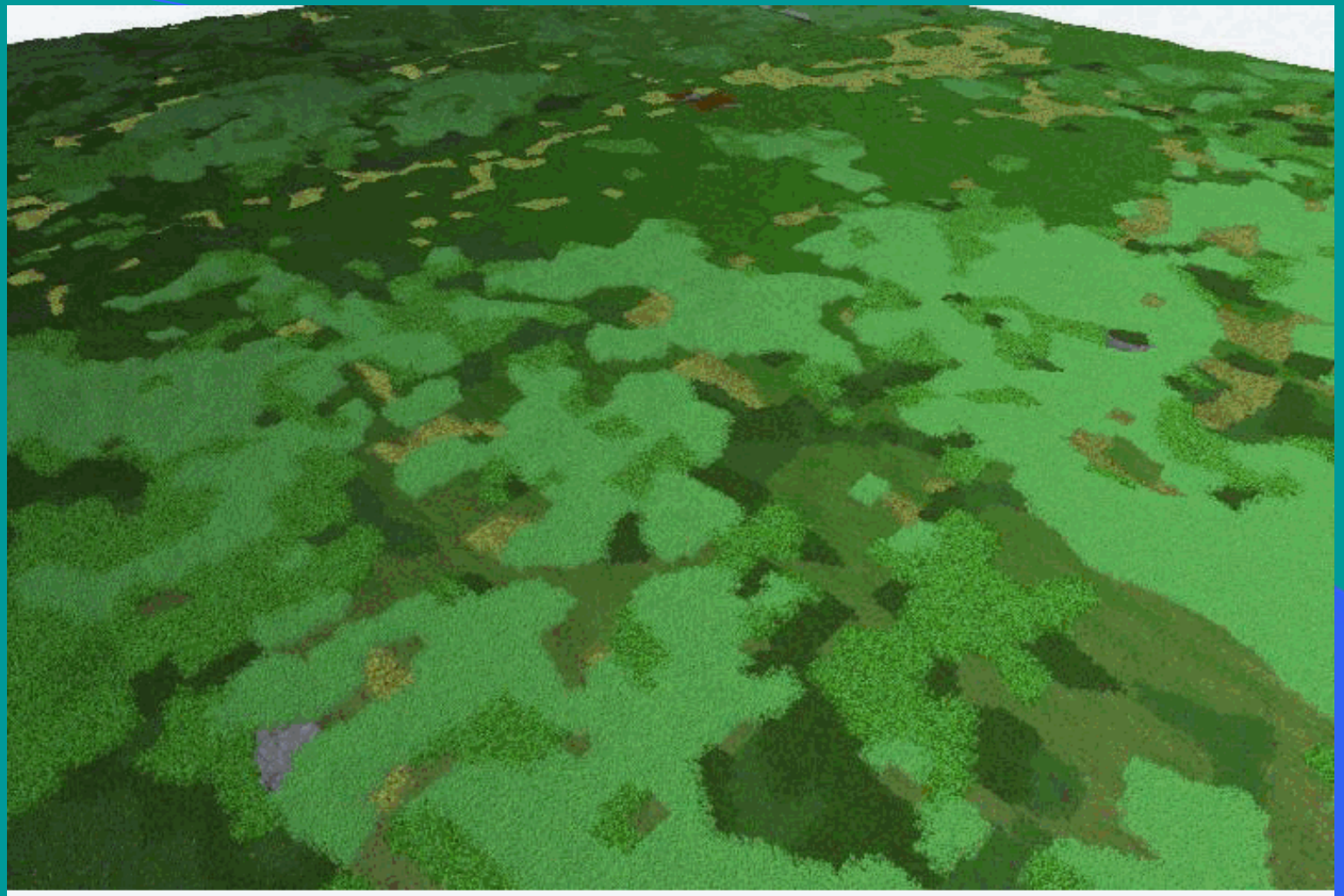
Oak-Hickory

Other Pine

Pine-Hardwood



Unknown



JP slightly burn

JP medium burn

MH slightly burn

MH medium burn

MHC slightly burn

MHC medium burn

NFS slightly burn

NFS medium burn

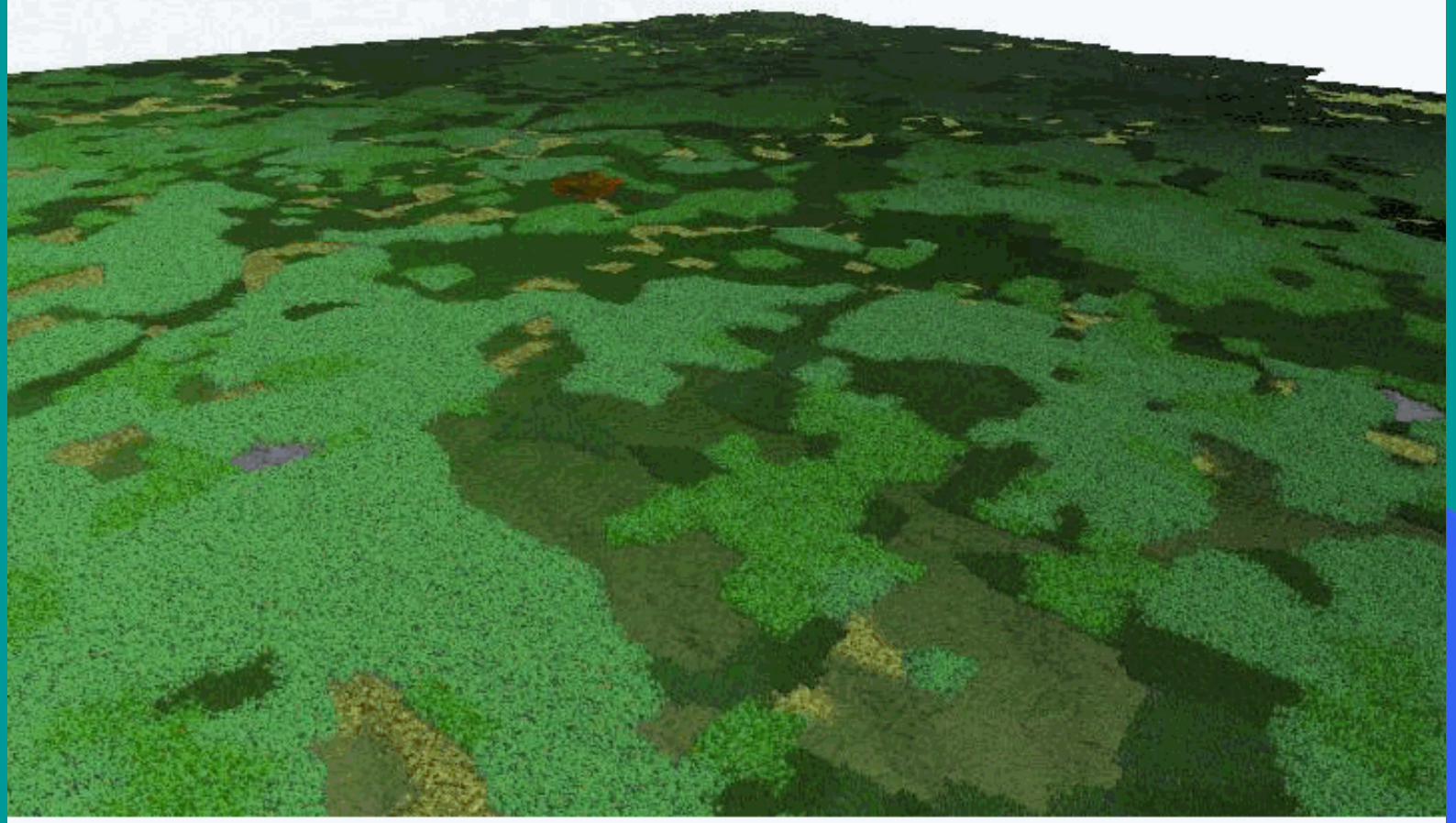
RP slightly burn

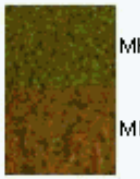
RP medium burn

NFBG

Day1	Slightly burn	16.401	ha
	Medium burn	5.177	ha
	Completely burn	3.959	ha

Fire in N. portion of the Washburn





Day1	Slightly burn	3.955	ha
	Medium burn	2.062	ha
	Completely burn	8.684	ha

Discussion & Conclusion

- Visualizations at multi-scale could be helpful for assisting multi-scale forest management.
- Small-scale visualizations will require greater accuracy of data, such as tree height and tree density in order not to be misleading.
- Classification system will greatly affect the visualization performance. The more detailed classification input the closer the visualization to the real world.
- Landscape visualization is quantitative ecological information based technique that could be applied from stand succession to landscape transformation and regional planning.
- Visualization is economical and efficient in terms of visually comparing different management strategies, landscape planning scenarios etc.

Thank you! For more information, please

(1) Visit our WebPage at:
http://research.eeescience.utoledo.edu/lees/research/jfsp/

(2) Email PIs (jiquan.chen@utoledo.edu, 419-530-2664)

(3) Request for a free copy of the CD

(4) Demo at the desk in the hallway

(5) Visit us in Toledo, Charleston, or Washington D.C.

Question?