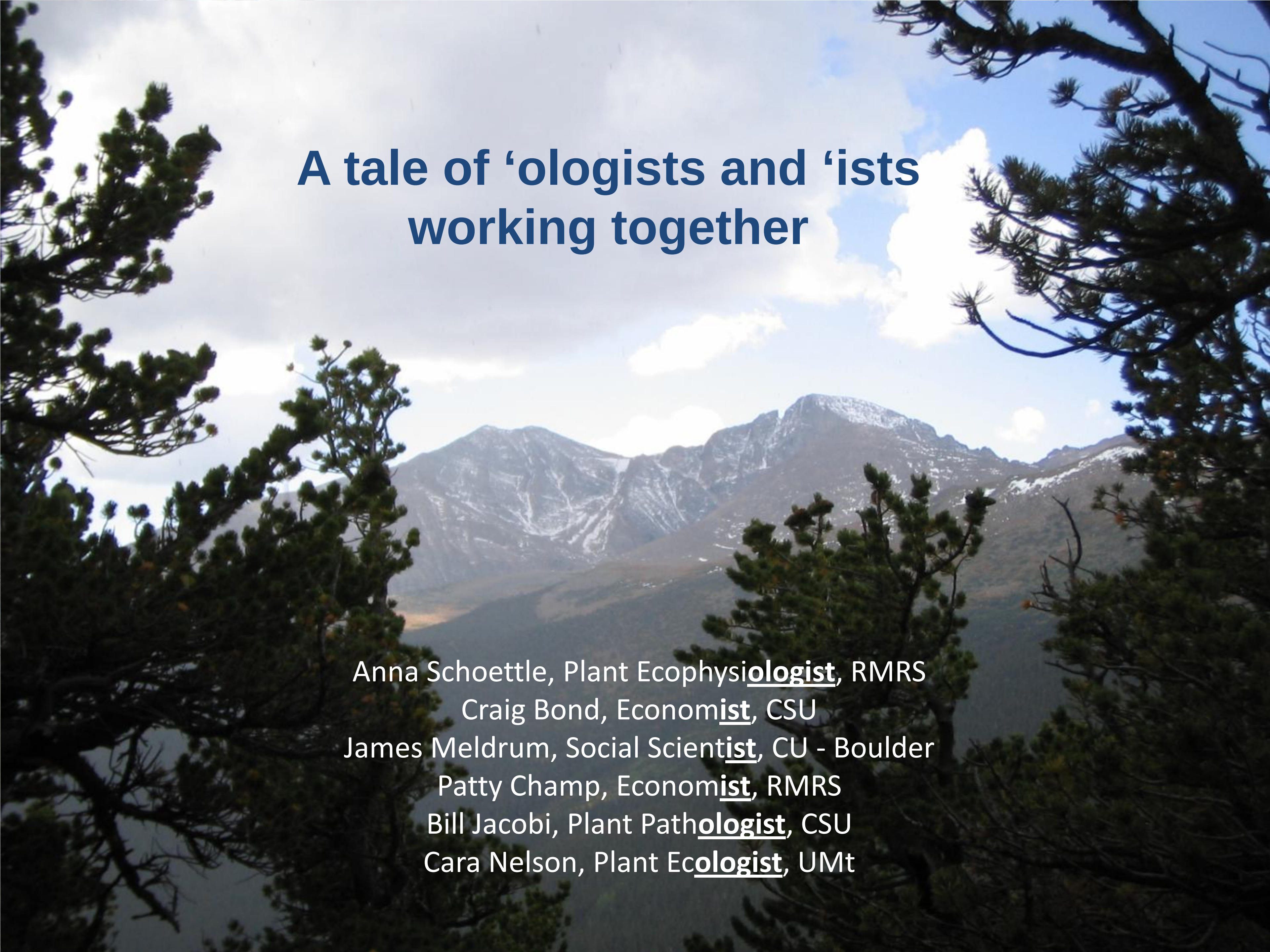
Efficient Management of White Pine Blister Rust in High Elevation Ecosystems: A Dynamic Modeling Approach

Dr. Craig A. Bond
Colorado State University

Presented to the 2011 PREISM Workshop
May 17, 2011



A tale of 'ologists and 'ists working together

Anna Schoettle, Plant Ecophysi**ologist**, RMRS
Craig Bond, Econom**ist**, CSU
James Meldrum, Social Scient**ist**, CU - Boulder
Patty Champ, Econom**ist**, RMRS
Bill Jacobi, Plant Path**ologist**, CSU
Cara Nelson, Plant Ec**ologist**, UMt

The Model Ecosystem

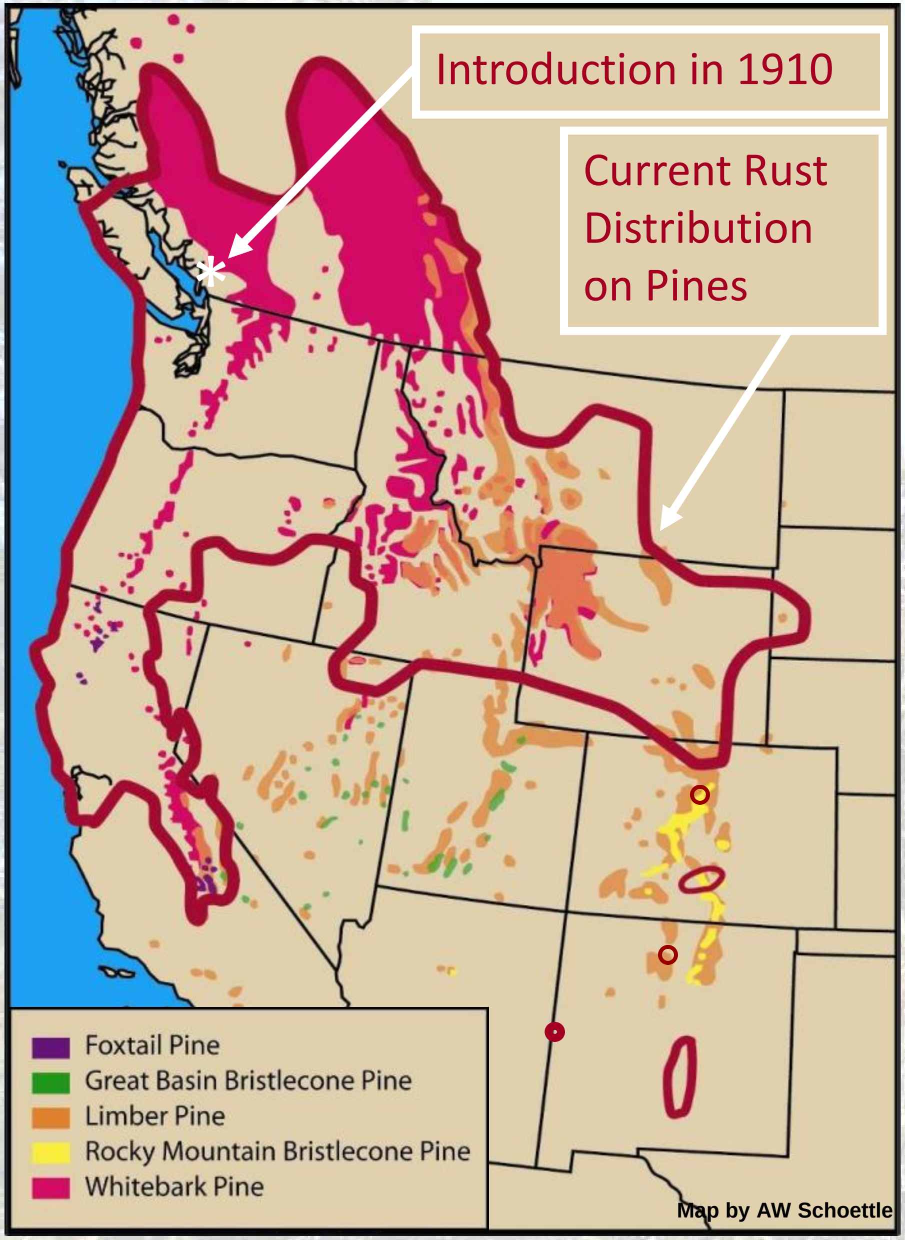
High elevation white pines + non-native pathogen
on traditionally unmanaged landscapes

Pine ecosystems at treeline
Non-timber species
- RM bristlecone pine
- GB bristlecone pine
- Limber pine
- Whitebark pine
- Foxtail pine

Non-native invasive
- White pine blister rust

People
- Preferences
- Economics

White Pine Blister Rust



Non-native *Cronartium ribicola* causes the lethal disease white pine blister rust on white pines

Despite efforts to control the disease, it continues to spread

There are still ecosystems where WPBR has not yet invaded.

There is no reason to assume the remaining ecosystems will escape infection.

Other NA white pines = western white pine, eastern white pine, SW white pine, sugar pine

WPBR kills white pine trees of all ages

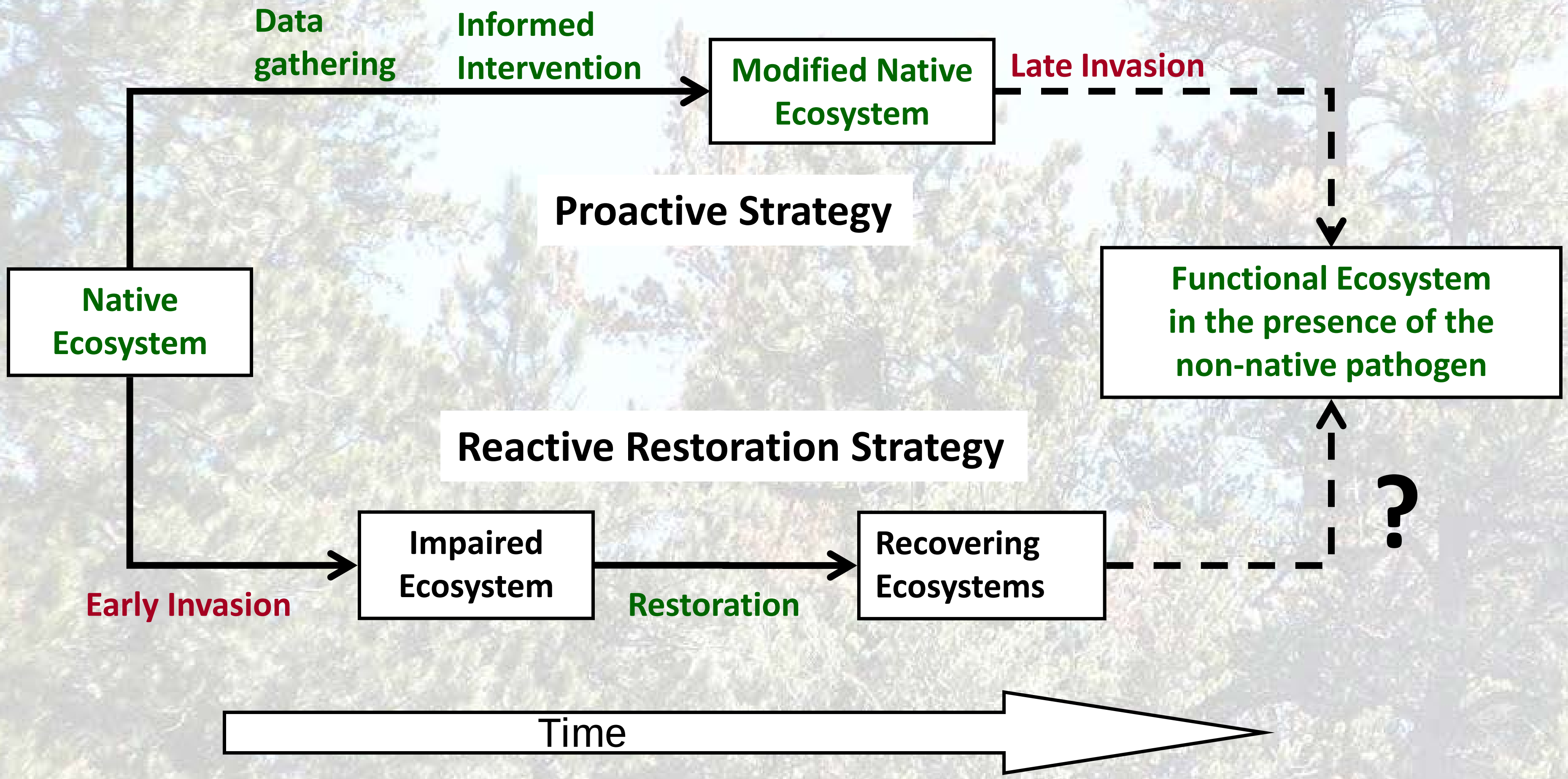
Impairs recovery processes

Pines have very low resistance to the disease

Management is required to sustain pine populations and ecosystem function

Do it now or do it later?

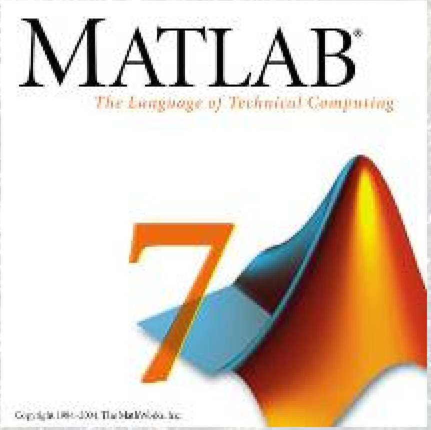
Ecological efficacy? Social acceptance? Economic trade-offs?



(Schoettle and Sniezko 2007)

Project Objectives

- Estimate intergenerational social costs of WPBR using nonmarket valuation techniques
- Construct basic model of WPBR epidemiology
- Continue research and development of management strategies
- Develop dynamic programming management model
- Evaluate and prescribe management practices under alternative conditions



Key Outcomes

- Valuation of non-market benefits associated with white pine ecosystems
- Decision tool to help make better management decisions under a range of circumstances
  - Should managers intervene?
  - If so, how?

Presentation Outline

- Population Modeling Effort
- Epidemiology Effort
- Cost Data Effort
- Non-Market Valuation Effort
- Dynamic Modeling Effort

Population Modeling

A. Schoettle, R. Sniezko

Key questions to evaluate population sustainability over multiple generations with and without management

In the presence of *Cronartium ribicola*:
How does rust infection probability affect population dynamics?

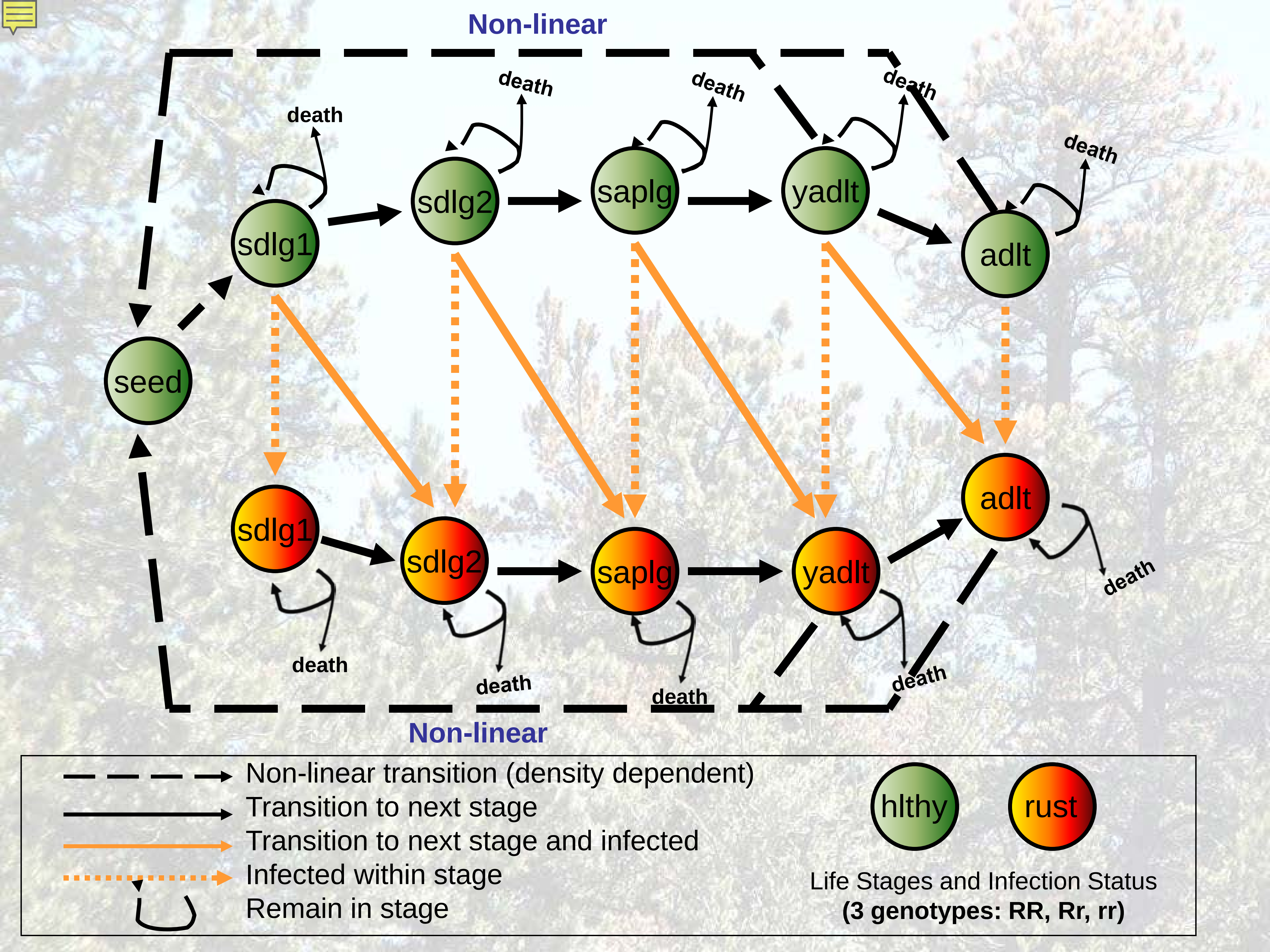
What is the effect of regeneration capacity?

What is the effect of competition?

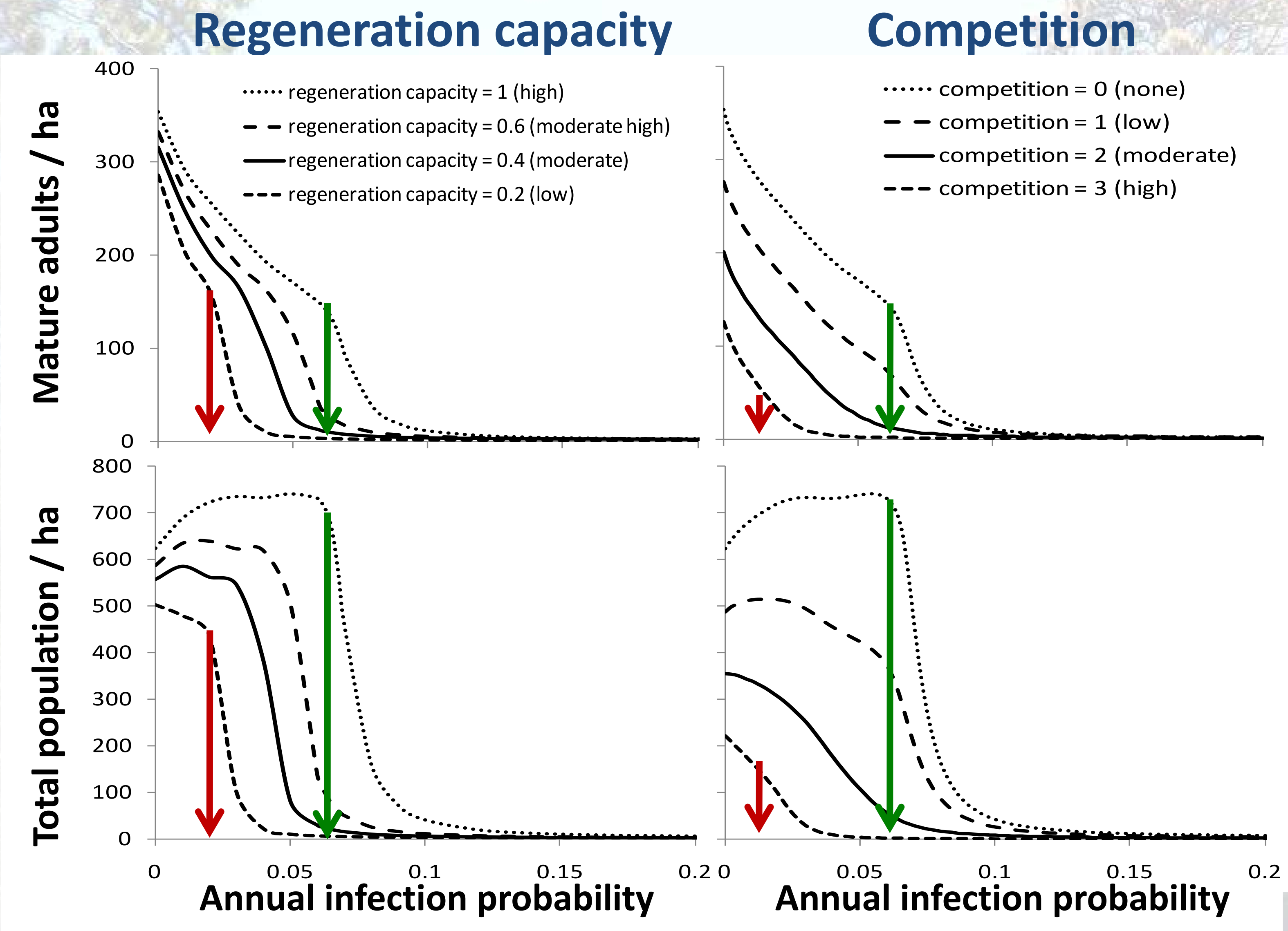
What frequency of resistance to WPBR is enough to sustain a population?

How can management promote sustained populations and increased resistance?

Stage Structured Population Genetic Infection Matrix Model


Non-linear
death
death
death
death
death
sdlg1
sdlg2
saplg
yadlt
adlt
seed
sdlg1
sdlg2
saplg
yadlt
adlt
death
death
death
death
death
Non-linear
Non-linear transition (density dependent)
Transition to next stage
Transition to next stage and infected
Infected within stage
Remain in stage
hlthy
rust
Life Stages and Infection Status
(3 genotypes: RR, Rr, rr)

Initial conditions - Competition and Regeneration Capacity

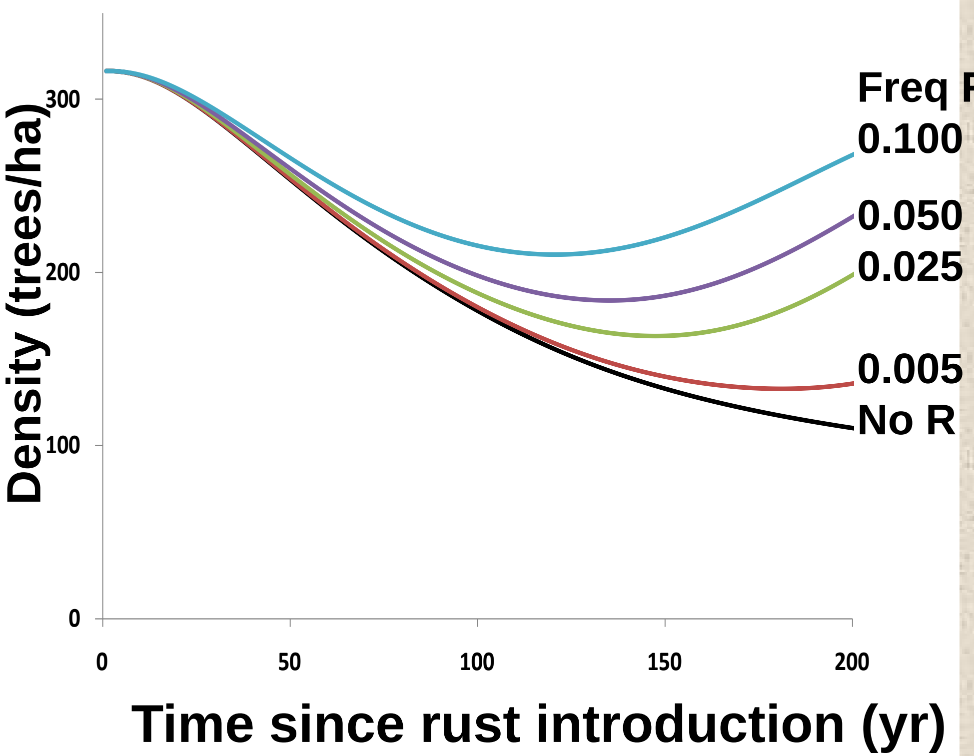


Stands with greater regeneration capacity can tolerate greater infection probabilities

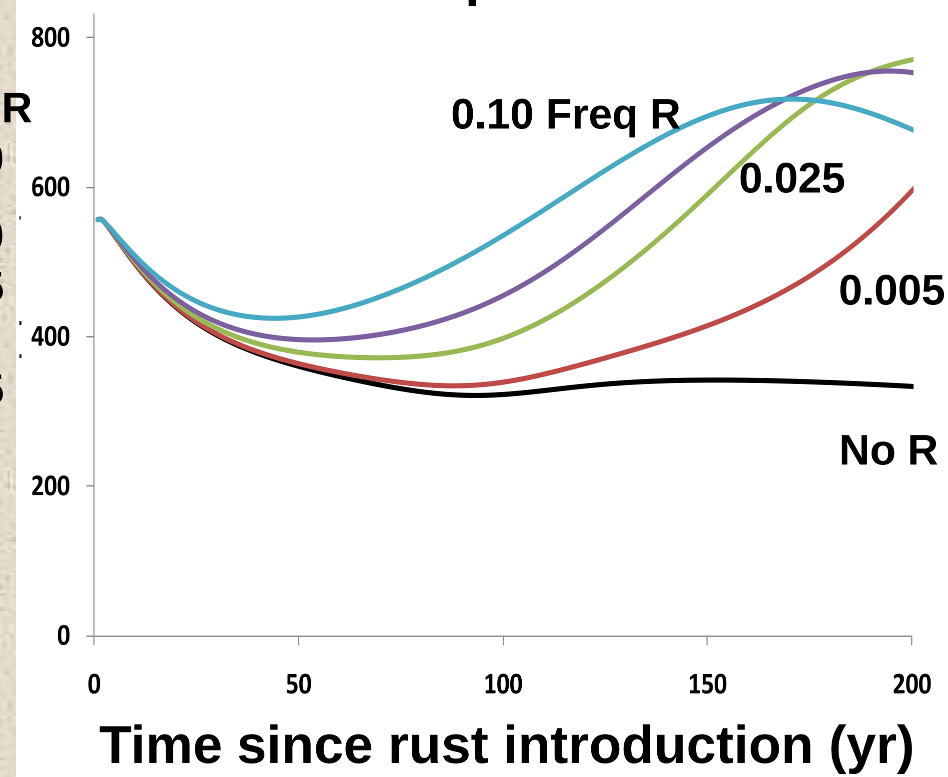
Initial Conditions - Frequency of Resistance in Population

More resistance → faster rebound
Significant dip in density in first 50-150 years in all cases

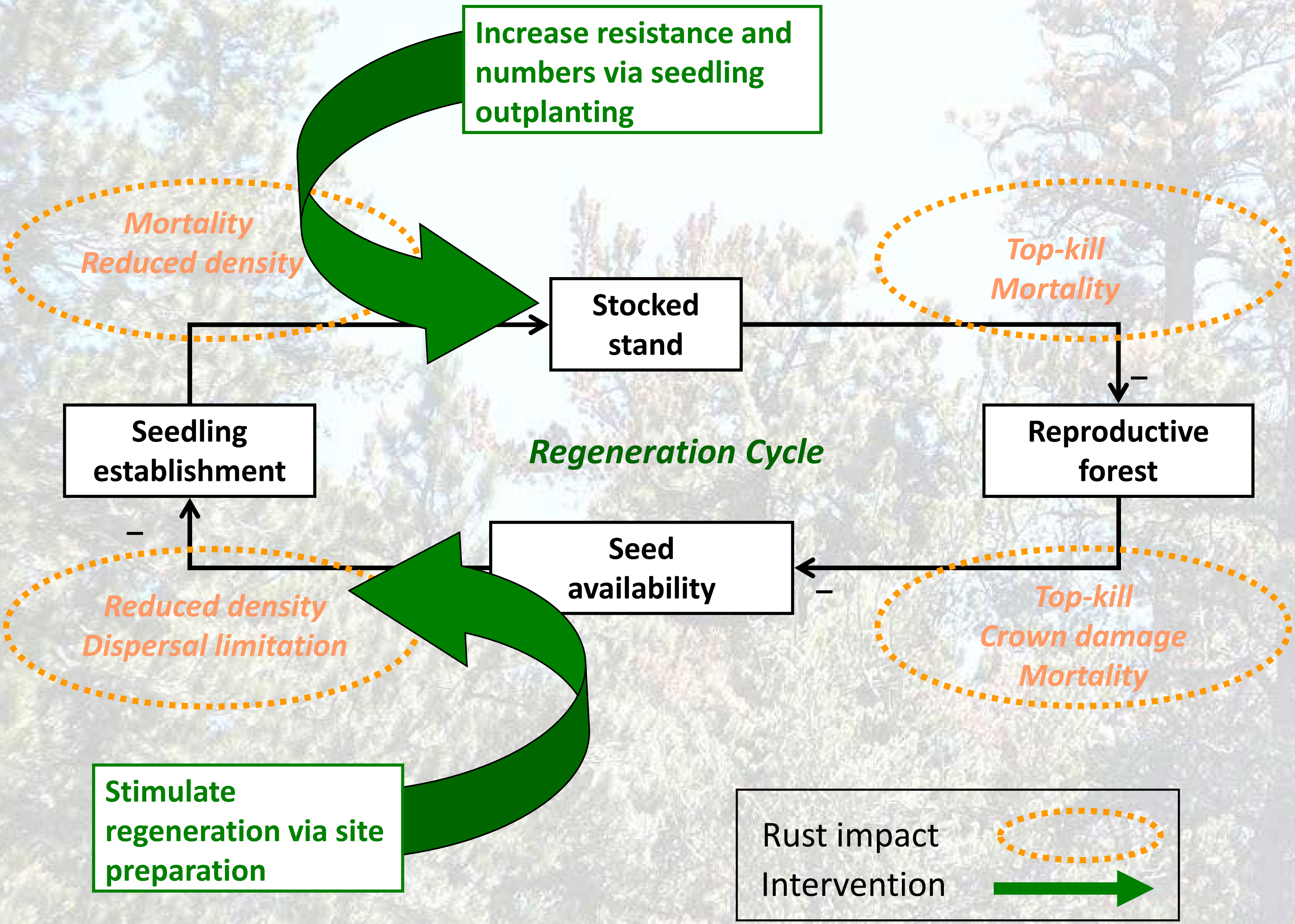
Mature adults



Total Population



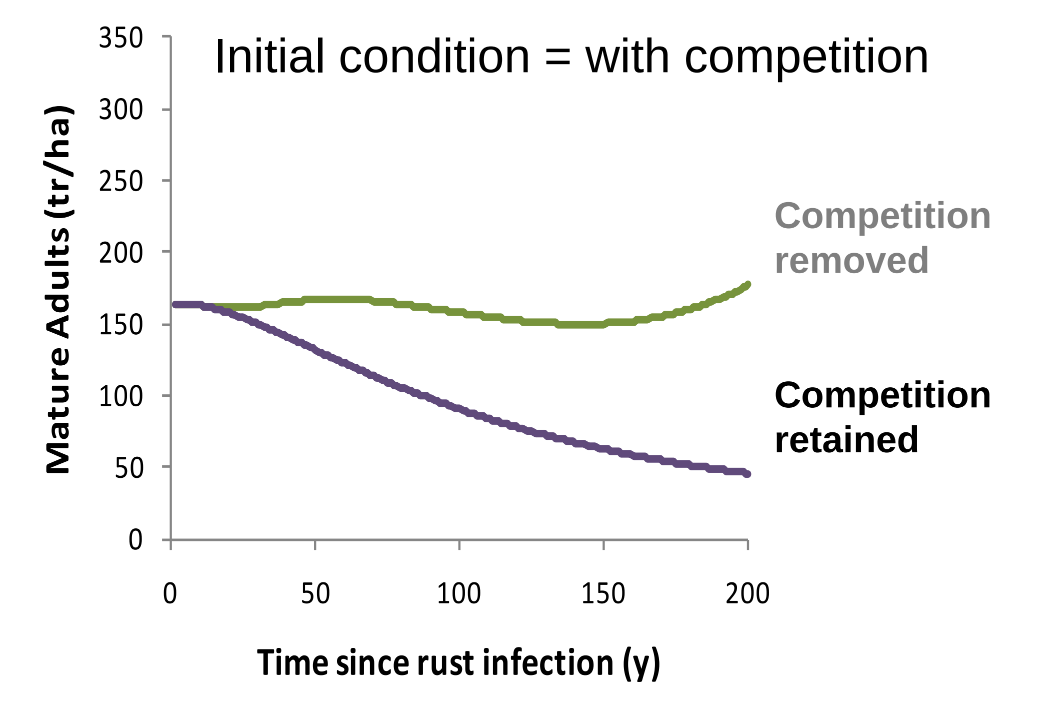
Managing demographics and resistance to sustain pine populations in the presence of WPBR



Stimulate regeneration via site preparation to sustain a reproductive population

Remove competing vegetation → increase regeneration

Treatments such as cutting or prescribed fire are effective if implemented at or before rust introduction.



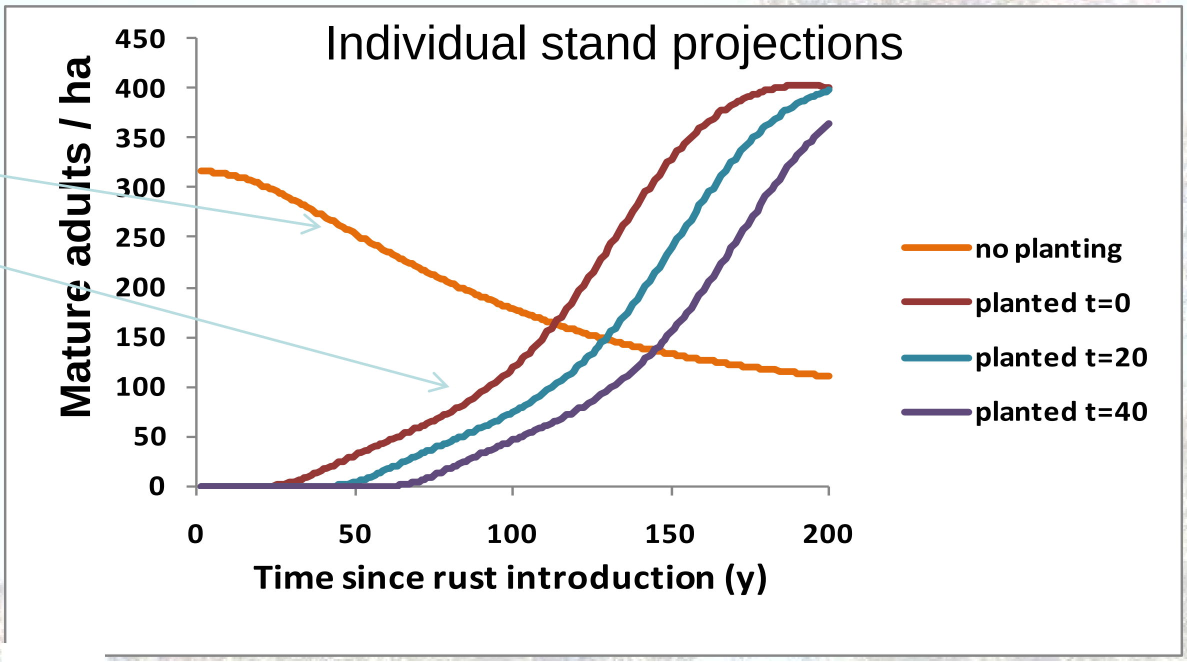
Stimulating regeneration by removing competition can sustain adult populations

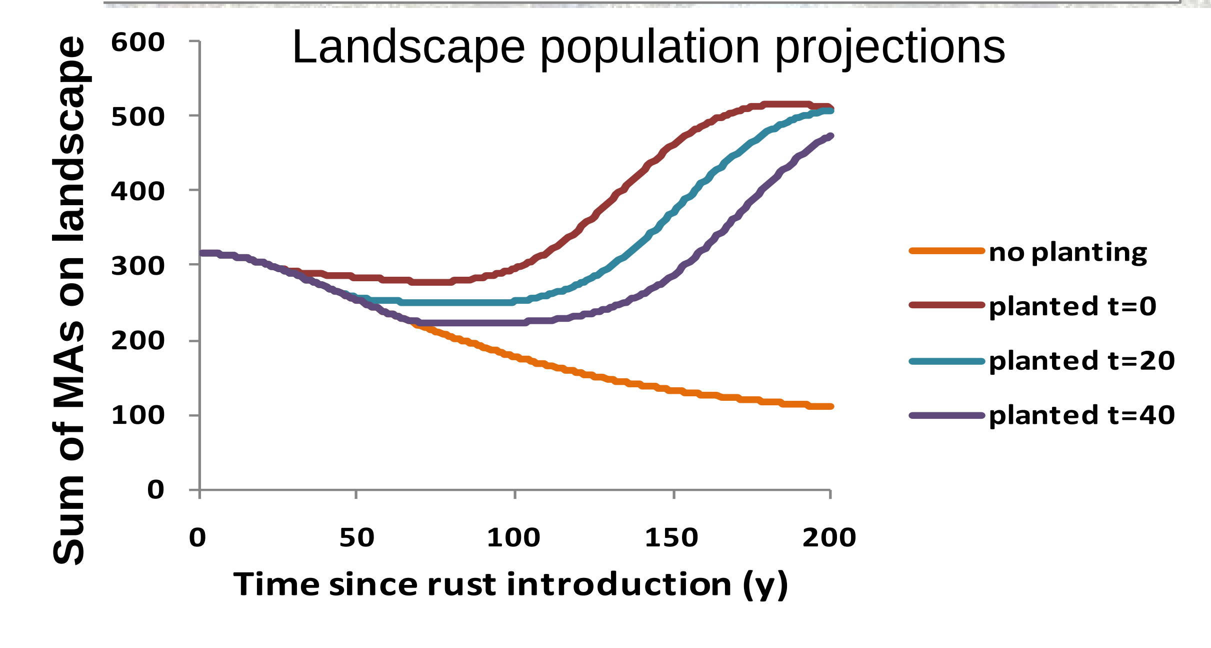
Increase resistance via seedling outplanting

Intact forest in one area
Plant a nearby area

Plant 1000 seedling that have a Freq R=0.20

Plant at time = 0, 20 or 40 years post-rust introduction





Time of planting affects its effectiveness to sustain a reproductive population

Conclusions – Population Modeling

- Stands with more regeneration capacity and less competition do better when rust is introduced.

- Initial frequency of rust resistance in the stand affects how the population responds to rust introduction.
  - Without management, even forests with high frequencies of resistance in the base population will undergo a significant reduction in reproductive trees 100+ years after rust introduction
  - Unclear if the ecosystem, in reality, will have enough resiliency to recover from the dip.
  - Management is needed to mitigate the reduction in population

- Removing competition (thinning) and outplanting seedlings with genetic resistance can stop and/or grow populations of reproductive adult trees, but timing matters

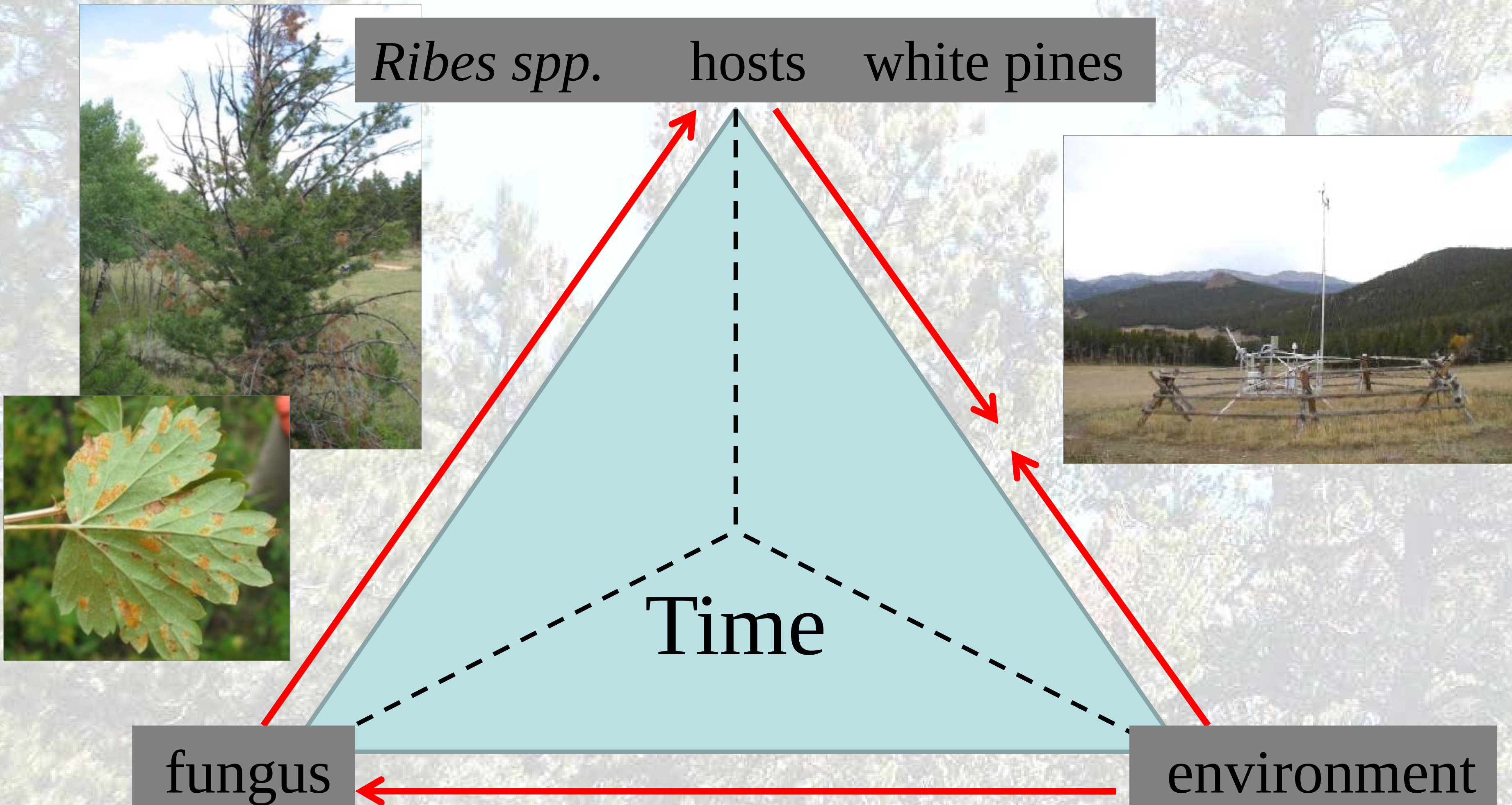
Epidemiology Modeling

W. Jacobi

Colorado State University

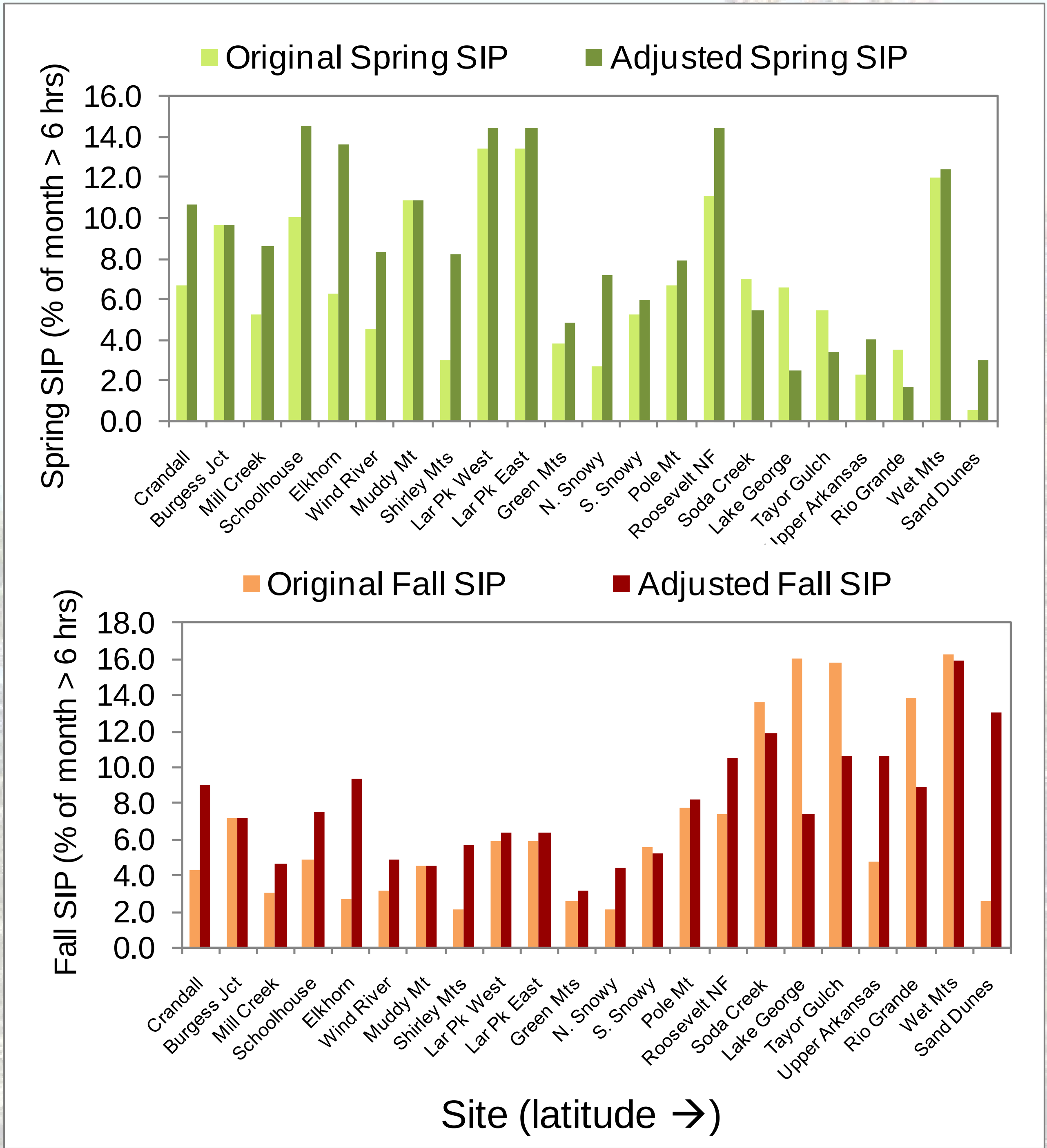
Can micro-scale meteorological conditions help predict impacts and movement of white pine blister rust?

Disease epidemiology is complex!



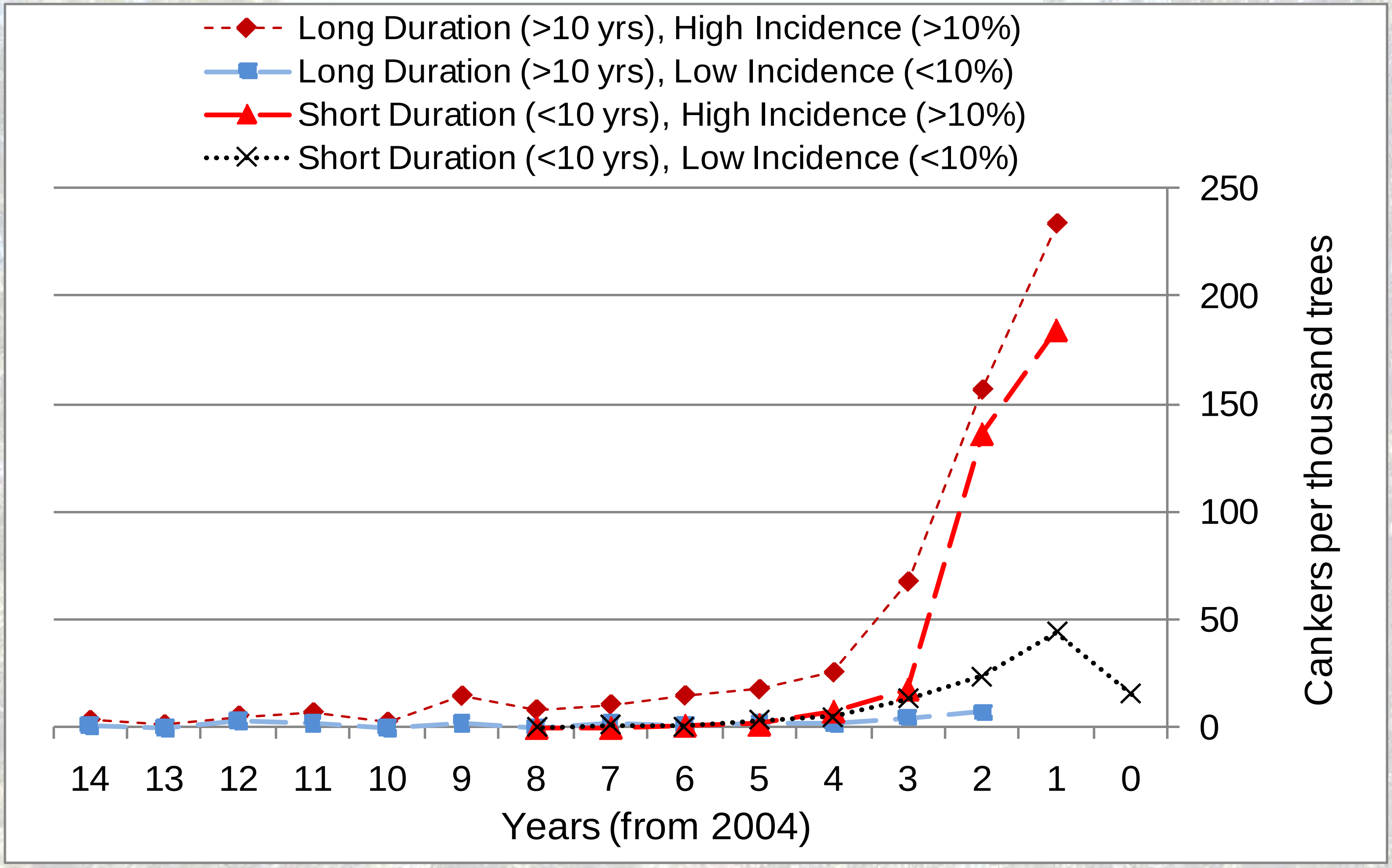
Suitable infection periods (SIP) for various disease stages vary widely across white pine environments and seasons: where is the environment <u>most suitable in both seasons</u>?

SIP = >6 hrs between 32-75º F and >90% RH



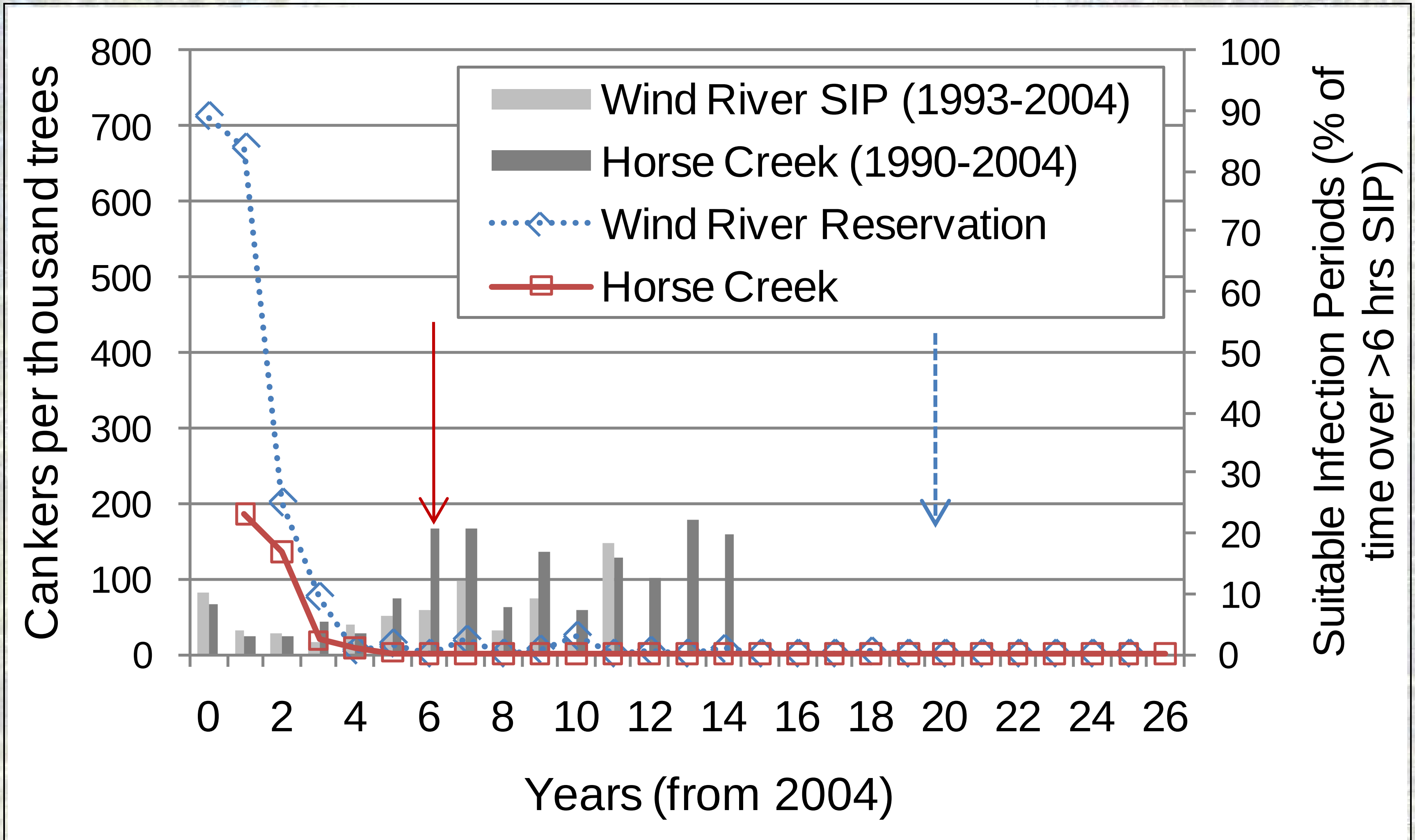
WPBR ‘intensification’ (success) varies across white pine environments:

Some areas have had low levels of disease for long periods of time and some areas have high levels of disease over short periods



Combining disease information and yearly weather data at sites across CO and WY:

Yearly suitable infection period data can help elucidate WPBR epidemics and 'wave years'



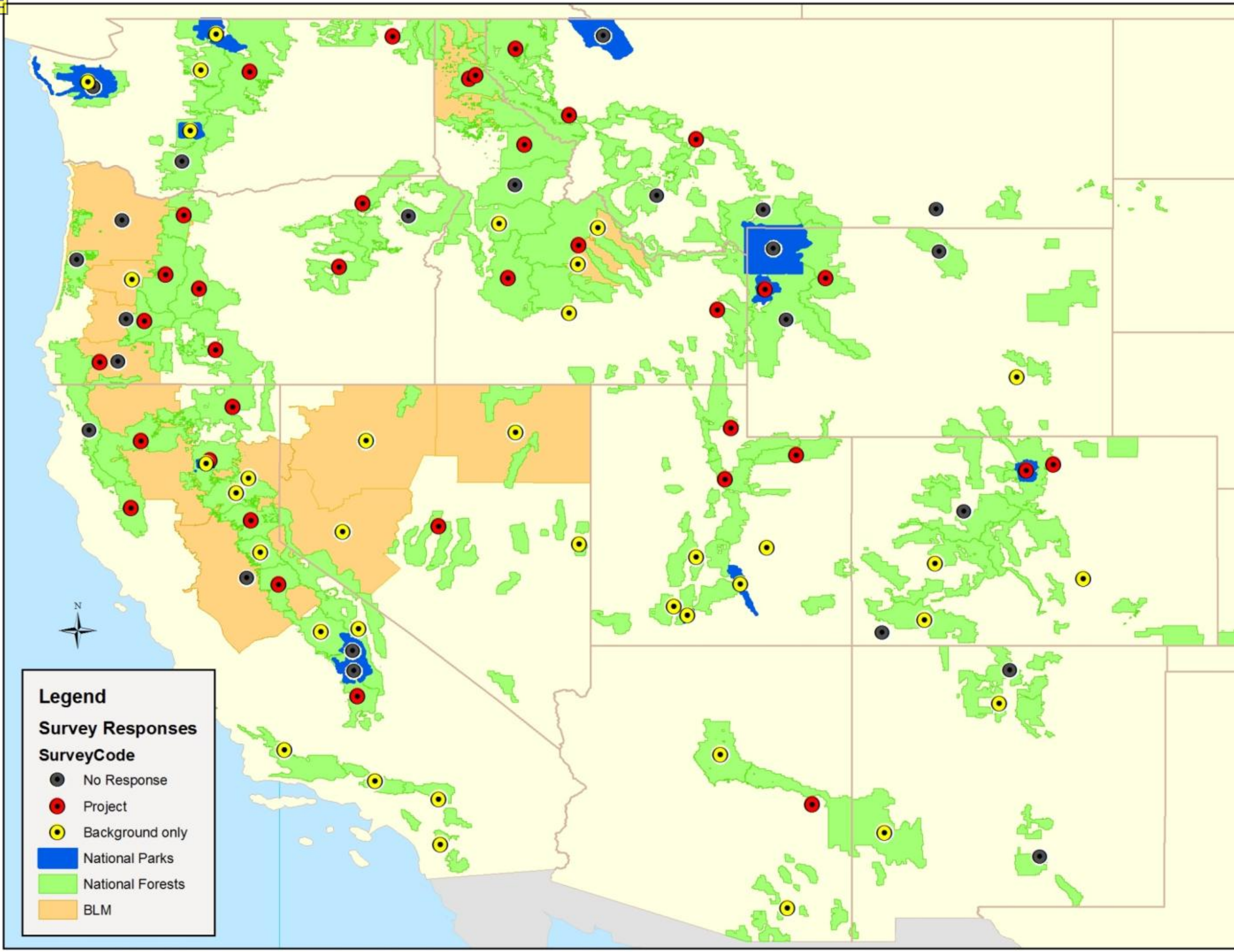
Conclusions - Epidemiology

- Local disease intensification is related to:
  - meteorological conditions and weather patterns in mtn. ranges
  - alternate host densities
  - topography and elevation
  - age of infestation
- Local disease intensification is difficult to predict since variables are unique to each location
- Revisiting permanent plots / monitoring plots will help us refine impact predictions with more sites and more combinations of different host densities and weather conditions
- Epidemiology models can assist econ models in predicting how much mortality/damage will occur based on site specific hazard ratings (hosts + weather conditions)

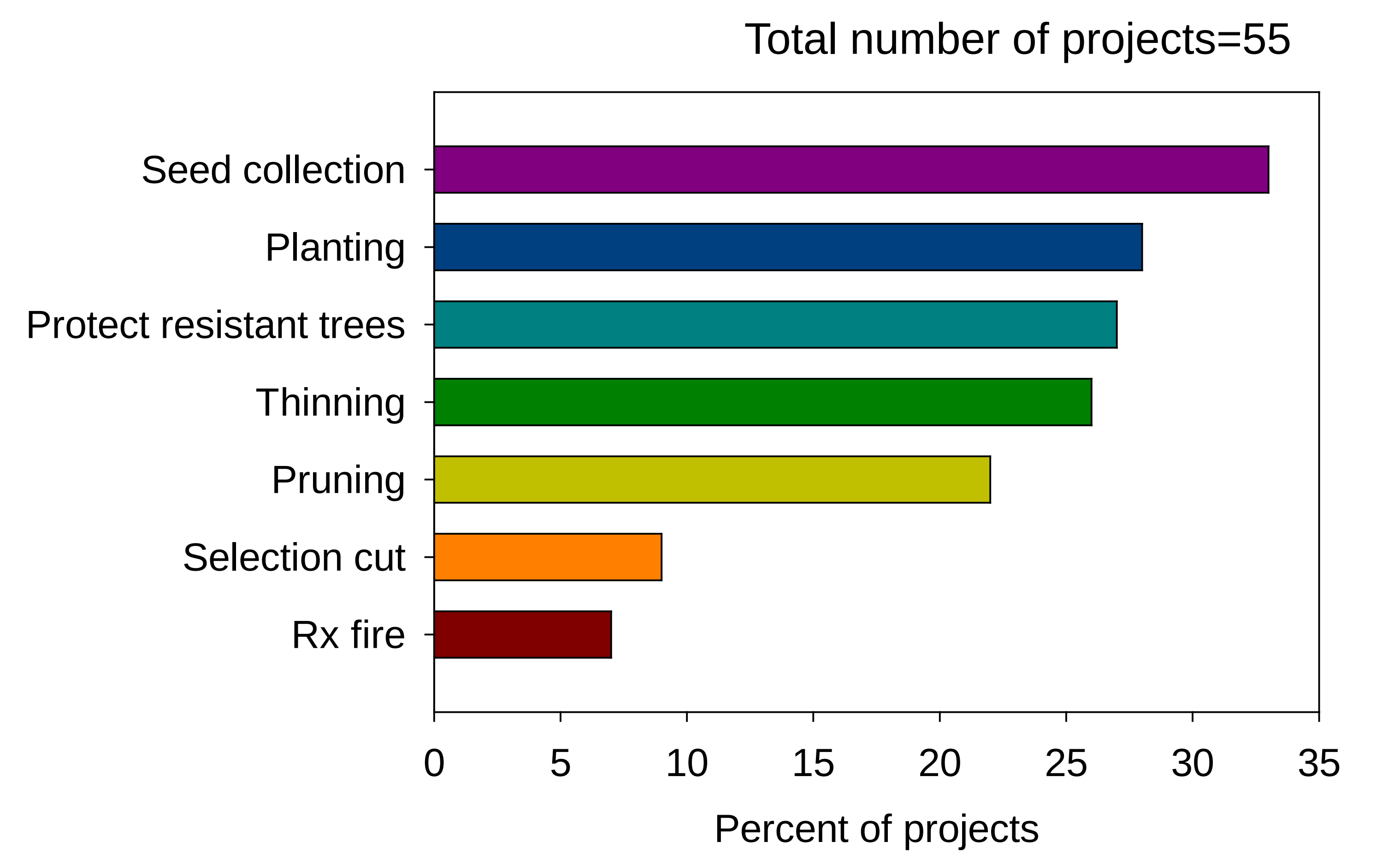
Cost of Treatment Data

C. Nelson

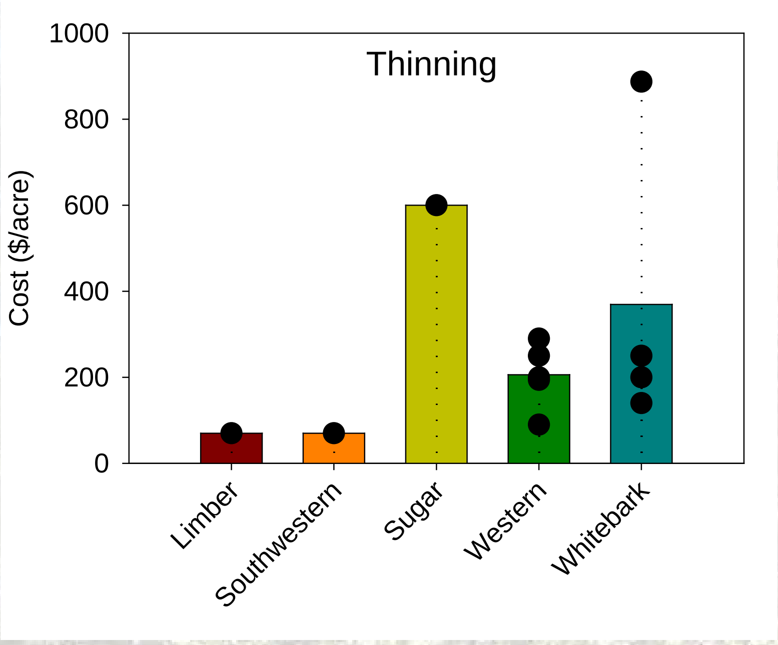
The University of Montana

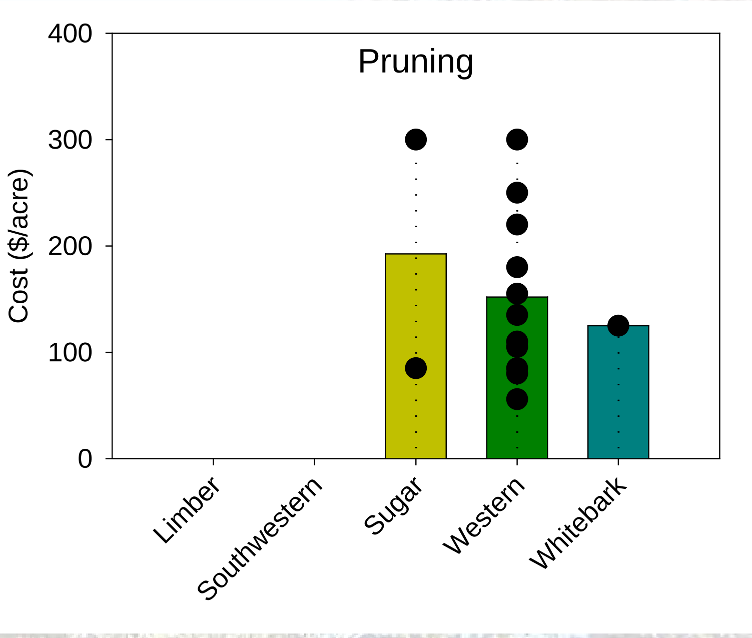

N
Legend
Survey Responses
SurveyCode
No Response
Project
Background only
National Parks
National Forests
BLM

Types of treatments



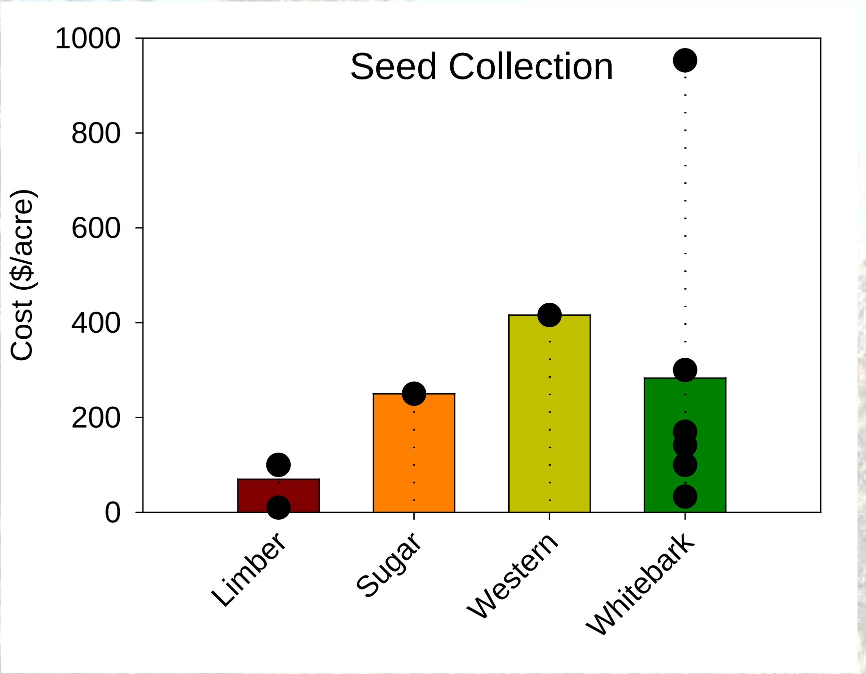
Treatment Costs

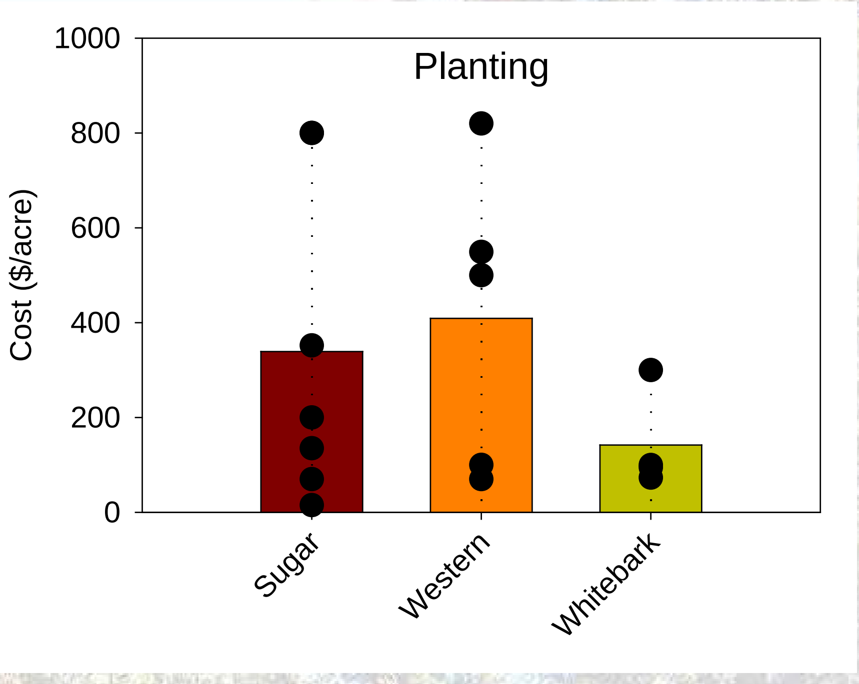




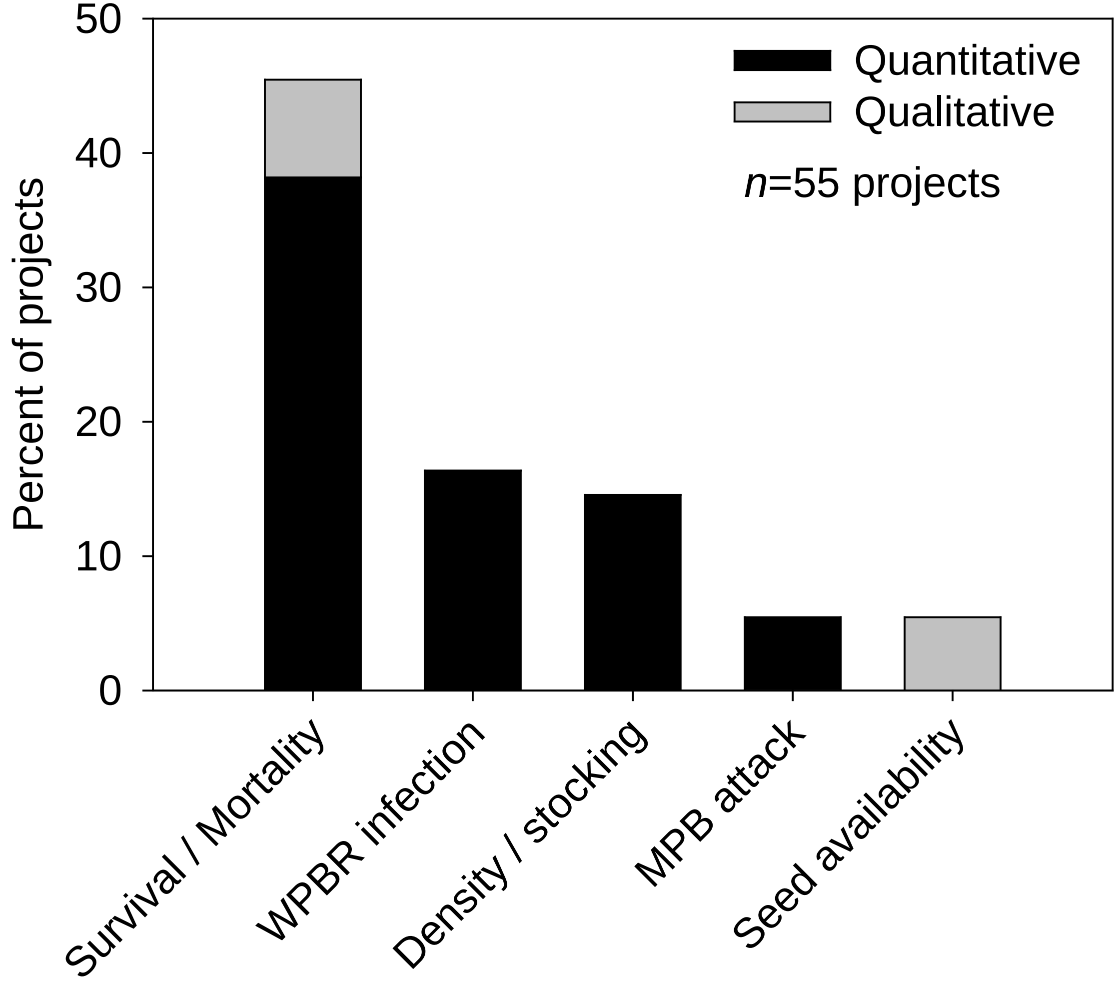
Prescribed fire = $297/acre, n=3 (1 sugar, 1 whitebark, 1 western)

Treatment Costs

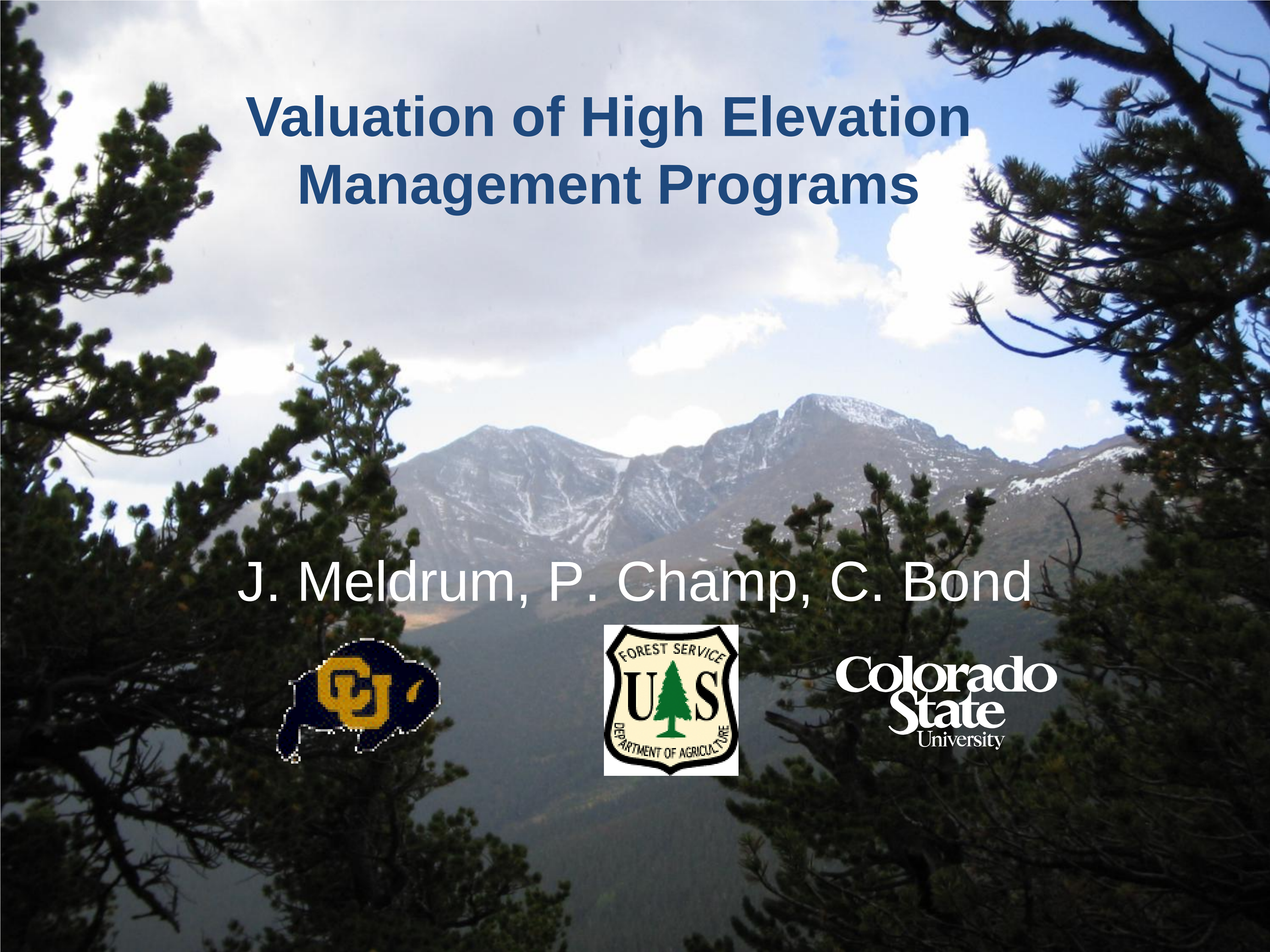




Variables Monitored



Valuation of High Elevation Management Programs



J. Meldrum, P. Champ, C. Bond

Survey details

- Complex, multidimensional management problem
- Information collected included general and specific attitudes, contingent valuation questions, and choice experiment

Foxtail Pine

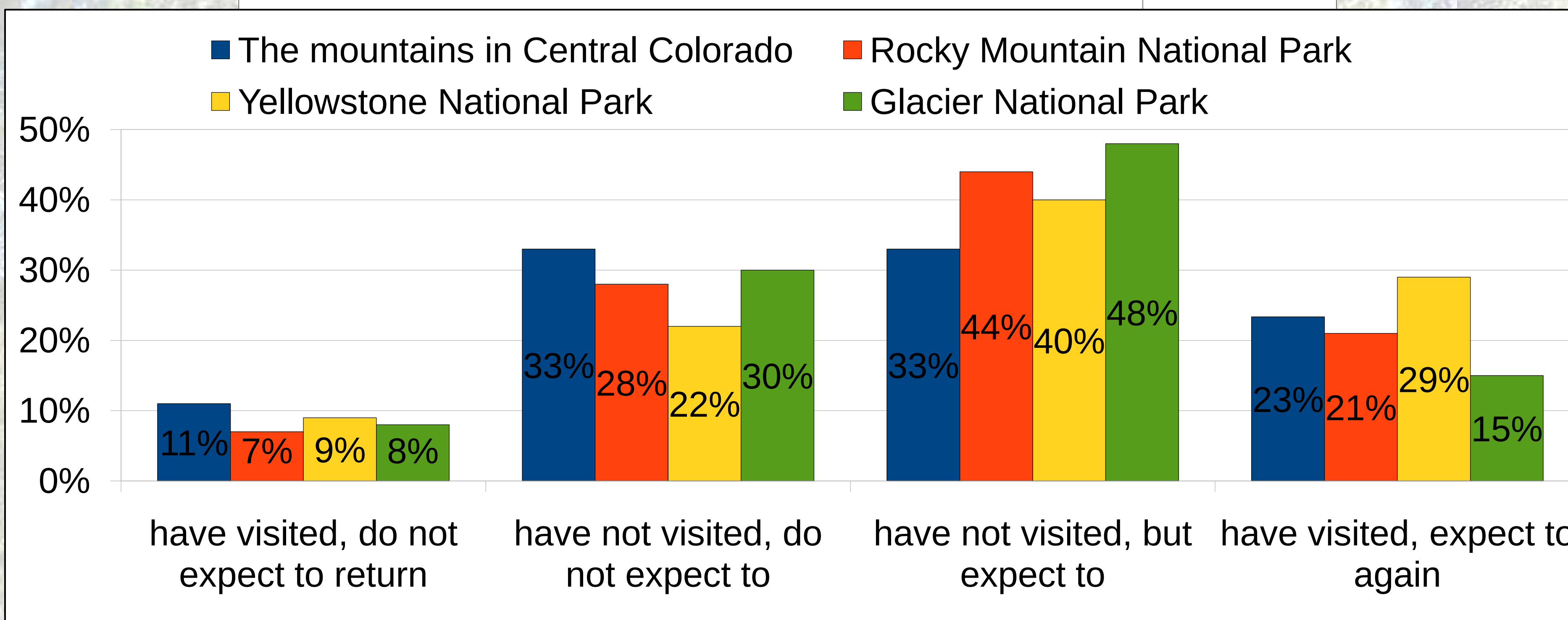
- Administered by Knowledge Networks, Inc.
- 20 minute online survey
- Probability-based sample
- General population in western United States
- N=542

Description of sample

Sample	Raw	Weighted	Truncated, Weighed	Population
Mountain region (MT, ID, WY, CO, NM, AZ, UT, NV) (vs Pacific)	71%	32%	31%	34%
Female	53%	51%	53%	50%
Age 18-29	16%	23%	23%	24%
Age 30-44	22%	28%	30%	28%
Age 45-59	30%	26%	24%	27%
Age 60+	31%	22%	24%	22%
Less than High School Education	10%	15%	14%	16%
High School	23%	25%	23%	27%
Some College	35%	31%	32%	31%
Bachelor Degree and beyond	32%	29%	30%	26%
In a Metropolitan Statistical Area	86%	91%	92%	91%
Household Internet Access	76%	68%	69%	76%
Number	542	542	484	27,115,377

Visitation and familiarity

Heard of any of the five-needled pine trees	35%
Heard of a high-elevation forest	50%
Heard of white pine blister rust	12%
Been to a high-elevation forest in the Western US	51%



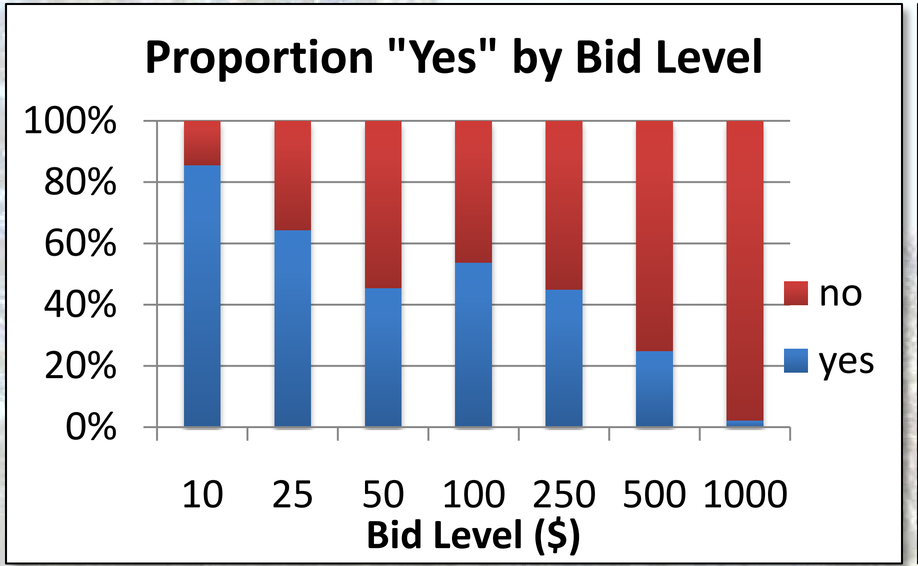
Likert Scale Attitudes

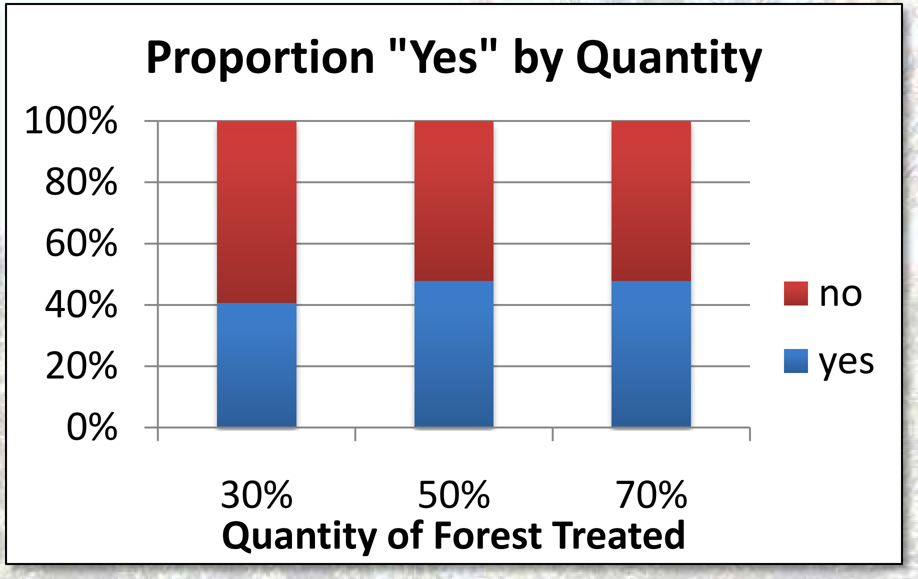
Attitudes (* - specific to high-elevation forests)	Mean	Agree
Existence for future generations*	4.2	76%
Protect from threat of extinction*	4.0	68%
Responsibility to protect from introduced pests	4.0	66%
Recreation activities*	3.4	47%
Treating forests to which I am personally attached*	3.4	41%
Related tourism *	3.1	29%
Oppose all new taxes	3.0	23%
People should not intervene*	2.7	22%

Contingent Valuation Question

"Suppose managers treat **[quantity]%** of the high-elevation forests in the Western United States. As a result, these acres will be healthy in 100 years from now. The remainder of the acreage would not be treated. Would your household be willing to pay a one-time cost of **$[bid]** to fund this program?“

Aggregate Preferences





- Average WTP =
  - **$166 per household**
  - 95% confidence interval: $77 to $254

Logit Model	
Bid	-0.380*** *(.059)*
Constant	0.629*** *(.211)*

Groups of People by Attitude

- 40% values both protection and recreation
- 25% values protection but not recreation
- 35% of population does not care, not willing to pay anything

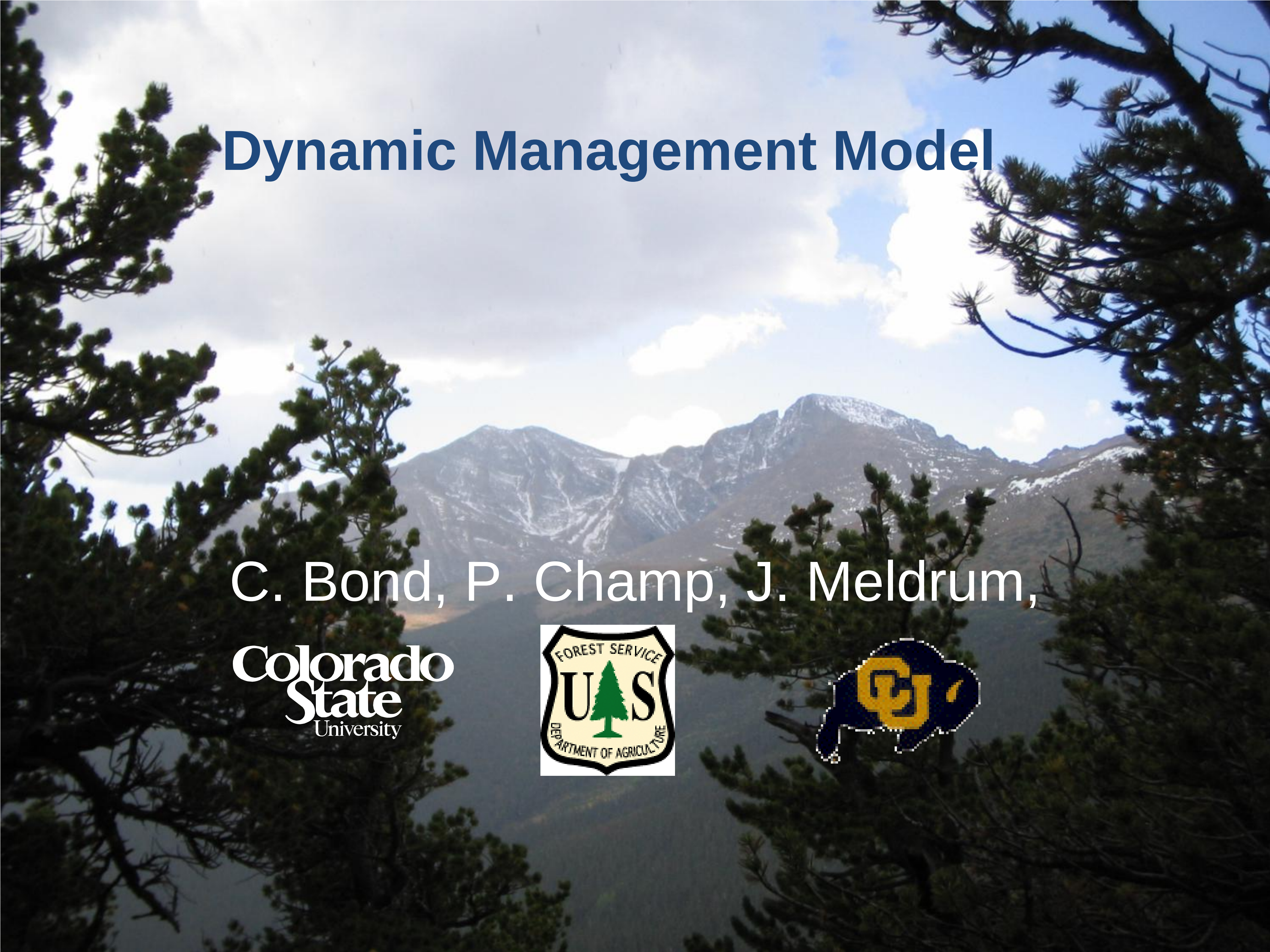
Size of class	35%	40%	25%
WTP	$-824 *($6180)*	$336 *($70)*	$390 *($46)*
Demographics	Average	Average	Average
Attitudes	Strongly opposed to protection, against recreation	Strongly approve of protection, for recreation	Approve of protection, slightly against recreation

Conclusions – CV Heterogeneity

- Average WTP for management of WPBR in high-elevation forests is $166/household (+/-$89)
  – 2/3 of population values management highly
  – Remaining 1/3 does not at all

- On average, long-run sustainability seems more important than shorter-term recreation benefits
  – “Protect” attitudes influence choice, “Play” do not
  – 40% of population values both, 25% only protection
  – 42% finds all features important, 28% with highest values finds only “functional” features important

Dynamic Management Model



C. Bond, P. Champ, J. Meldrum,

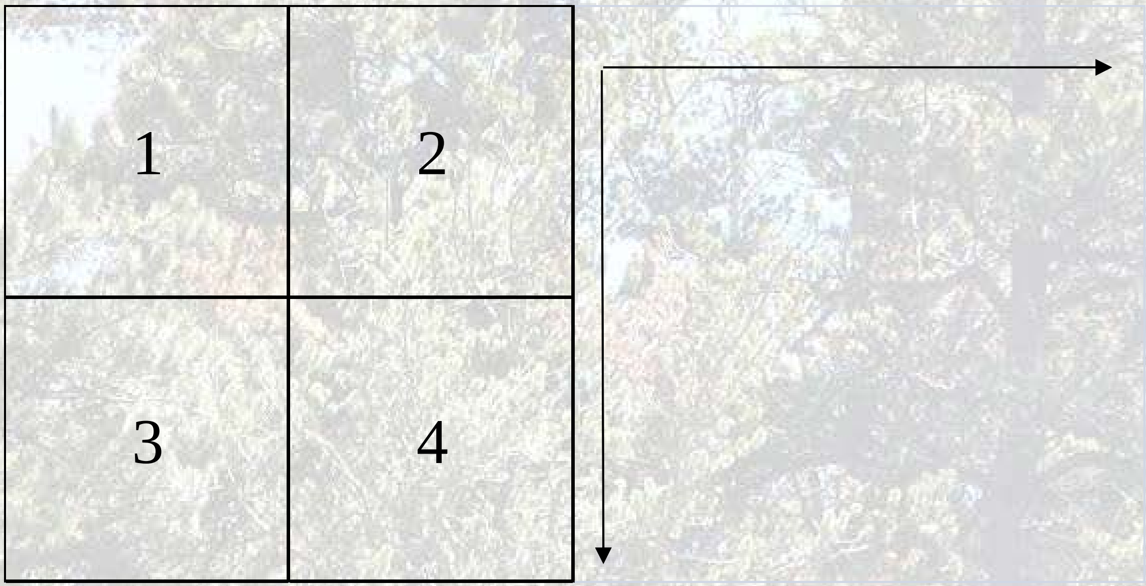
Dynamic Programming Model

- Cellular, spatial representation of forest stands
- Discrete time, discrete space (simple!)
- Directional, stochastic spread of a pest that cannot be contained or eradicated
- Once a stand is infected, the transitions are deterministic for that stand
- Varying levels of treatment efficacy

$$
\begin{aligned}
V(x_t,\theta_t) &= \max_{c_t}\left\{u(c_t,x_t)+\beta E\left[V(x_{t+1},\theta_{t+1})\right]\right\} \\
&= \max_{c}\left\{u(c_t,x_t)\right. \\
&\quad \left.+\beta E\left[V\left(f(c_t,x_t;\gamma,\alpha)+\varepsilon_{t+1},G(c_t,\varepsilon_{t+1},x_t,\theta_t)\right)\right]\right\}
\end{aligned}
$$

The Forest

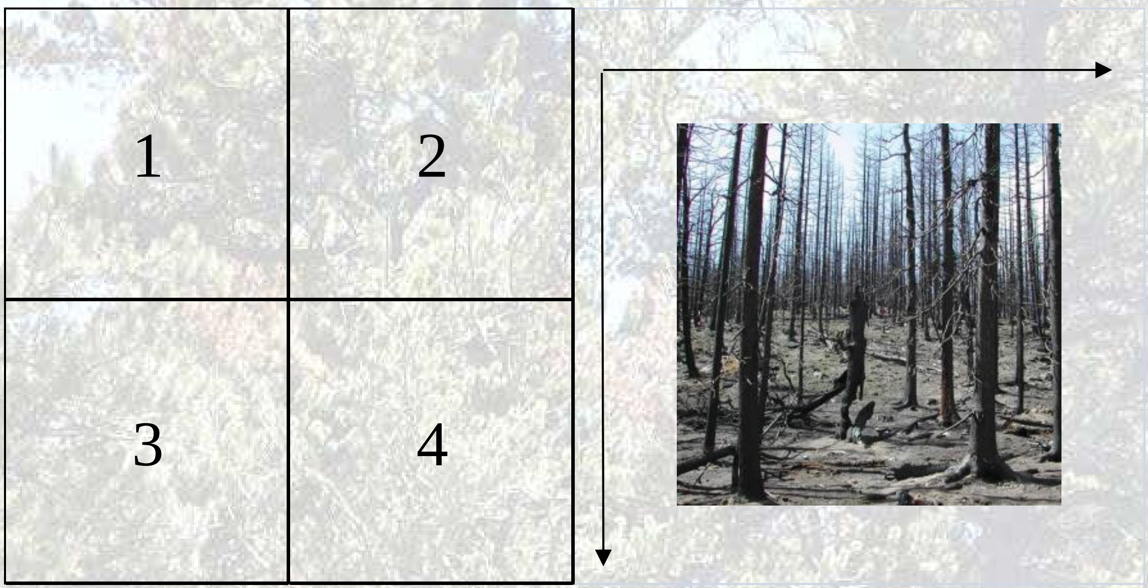
- A spatially explicit representation of individual homogeneous stands (*N*=4)
- WPBR spread is directional in nature, as represented by Markov transition matrix



The Forest

- WPBR spread is directional in nature, as represented by Markov transition matrix
- **z** is the neighbor matrix, where z_{ij}=1 indicates *j* is an infected neighbor of *i*

$$\mathbf{z} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix}$$



Probabilities of Establishment

- Probabilities of infection in each stand (ϕ_i) are a function of # of infected neighboring stands $\bar{n}_i$, and the state of the forest $\mathbf{x}$

# of infected neighboring stands ($\bar{n}_i$)	$\Pr\left(\phi_i \mid \bar{n}_i(\mathbf{x},\mathbf{z})\right)$	
	Deterministic	**Stochastic**
0	0.0	0.1
1	1.0	0.6
2	1.0	0.8
3	1.0	0.9

State Transitions for Each Stand, Perfect Efficacy

- Once infected, a stand transitions from healthy to not healthy (1 → 2 → 3), with a corresponding decline in ecosystem service benefits

- Once treated, a stand transitions from healthy to not healthy (6 → 5 → 4), with a corresponding increase in ecosystem service benefits (with a probability of one)

- Treatment stops the decline with a lag of one period
  - -- For example, treating a stand at state 2 (moderately healthy) in time period *t* will result in the stand transitioning to state 6 (not healthy) in *t*+1, state 5 in *t*+2, and state 4 in *t*+3 and thereafter

Assumed Benefits and Costs per Period (Baseline)

State of stand x_i	Description	Per-stand benefits $f(x_i)$	Per-stand treatment costs $c(u_i, x_i)$
	Uninfected and not established		
0	Uninfected, healthy	10	7
	Infected and established		
1	Infected and healthy	10	7
2	Infected and moderately healthy	5	5
3	Infected and not healthy	0	2
4	Treated and healthy	10	7
5	Treated and moderately healthy	5	5
6	Treated and not healthy	0	2

Results – Deterministic Spread

				Optimal Treated Stands and Proactive Indicator			
Starting States				max 1 treated		max 2 treated	
Stand 1	Stand 2	Stand 3	Stand 4	Treated Stand	Proactive?	Treated Stands	Proactive?
0	0	0	0	none	no	none	no
1	0	0	0	1	no	1,2	yes
1	1	0	0	1	no	1,2	no
1	4	0	0	1	no	1,3	yes
2	0	0	0	2	yes	1,2	yes
2	4	4	1	3	n/a	3,4	n/a
5	4	4	1	4	n/a	4	n/a
6	4	4	5	none	n/a	none	n/a
4	4	4	4	none	n/a	none	n/a

- Max 1 Stand: 13% (145 of 1,105) of optimal strategies are proactive
  - -- occur mostly when stand to NW is infected and others are in states 4-6 [opportunity costs of treating infected stand are small]
- Max 2 Stands: 41% of optimal strategies are proactive
  - -- occur mostly when two or more stands are infected, and at least one has been treated
  - -- degrading cells to the NW are generally treated first

Results – Increased Relative Cost of Treating Uninfected Stands

- Double the cost treating uninfected stand, halve the cost of treating a non-healthy stand
  - Proactive strategies (treating the uninfected stands) are optimal for 57% of possible cases, up from 41% under the baseline scenario. WHY?

OPPORTUNITY COSTS!!!!!!

Intuition of Results

- Marginal benefits of proactive management:
  - Immediate protection of uninfected stands
  - (Discounted) cost savings of treating degraded stands
- Marginal costs of proactive management:
  - Loss of ecosystem services from infected stands

Results: The Discount Rate

- If the discount rate is sufficiently low (less than about 43%) under the baseline cost scenario, then proactive management is part of the optimal plan

Results: Uncertainty

- Very little difference in optimal policies from deterministic to stochastic spread
  - Exception: 2 infected stands, one treated, other 2 are uninfected and include stand 4
  - Policy: Treat stand 4…it is most threatened

- Conclusion: The probability transition matrix helps create a preference for *which* stands to proactively manage, not the total number

Conclusions: Dynamic Model

- Proactive management strategies tend to be optimal when, *ceteris paribus*:
  - More resources are available for treatment
  - Costs of treatment are rapidly rising in forest health
  - Discount rate is low

- Uncertainty, at least at these levels, does not affect the overall incentive, but informs which stand(s) to treat

Future Explorations

- Improved parameterizations and further exploration of sensitivity, incorporating all the data we collected
- Improved state-space representation of the forest, including state levels and number of stands

Questions, Comments, Etc?

More information forthcoming in High Five Conference Proceedings, USDA Forest Service Proceedings RMRS-P-63, 2011, and various manuscripts in the literature