Choosing Efficient Treatment Options for Invasive Plants by Assessing Costs and Benefits in a Spatial Risk-Based Optimization Framework

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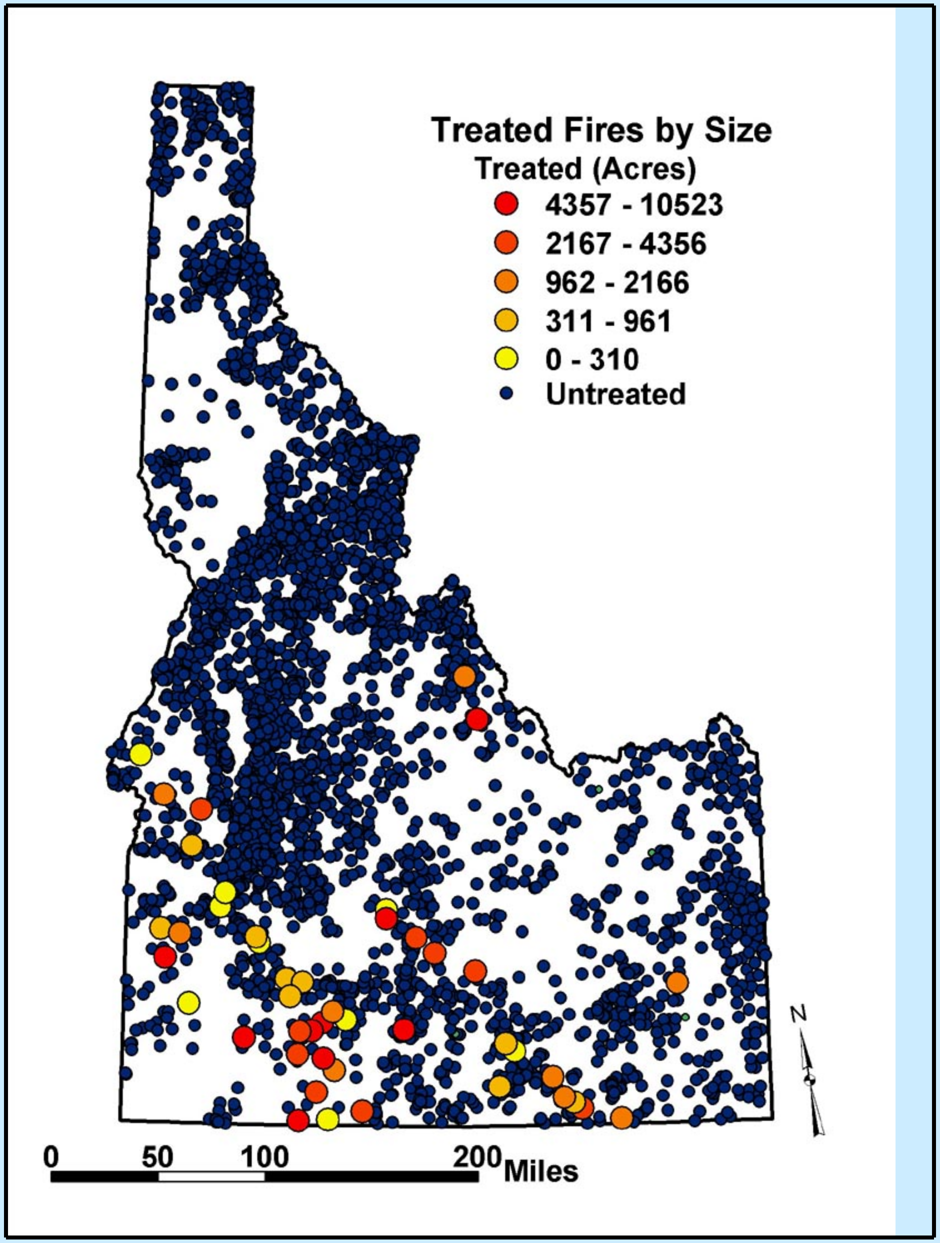
2001-03 Idaho Fires Treated under Emergency Stabilization & Rehabilitation and Burned Area Rehabilitation Programs



Source Data: USFS, BLM

Native-Dominated Site

Cheatgrass- & Medusahead-Dominated Site

Project Goals

- A decision-support tool to help allocate restoration effort to maximize social benefits
- Address the question: Where should restoration efforts be concentrated?

Research Approach

1. Characterize management problems and response options
2. Identify ecosystem services affected and frame benefits analysis
3. Evaluate data available to inform assessment of benefits, costs & risks
4. Develop risk-adjusted cost-effectiveness framework for decision support
5. Test integrated simulation optimization for comparing options and assessing uncertainty

Framing Benefit Assessment

- Which areas can / do provide benefits in terms of ecosystem services?
- What damages / costs are avoided by restoring now at various locations?
- How confident are we that restoring will generate future streams of benefits?
- How urgent is treatment at this site?

Benefits: Costs Avoided with Cheatgrass Management

Ecosystem Service	Costs
b_1 = Recreational Antelope Hunting	Increased costs, reduced bag rates, reduced quality of experience.
b_2 = Production of animal forage for commercial ranching	With fire - lost profits – if no substitute land, reduces productivity and/or increases costs. BLM policy to shift ranchers off burned areas for 2-3 yrs. Without fire - Increased variability of returns (?)
b_3 = Property protection	Increased risk of property damage due to fire with cheatgrass
b_4 = Existence values	Sage / sage grouse are characteristic species at risk. Loss of sage appears irreversible without human intervention.

Treatment options to prevent cheatgrass domination

Intensity ↓

- No treatment
- Aerial seeding only (mix of native/non-native)
- Aerial seeding + chaining
- Aerial seeding + chaining + herbicide
- Aerial seeding + chaining + drill-seeding

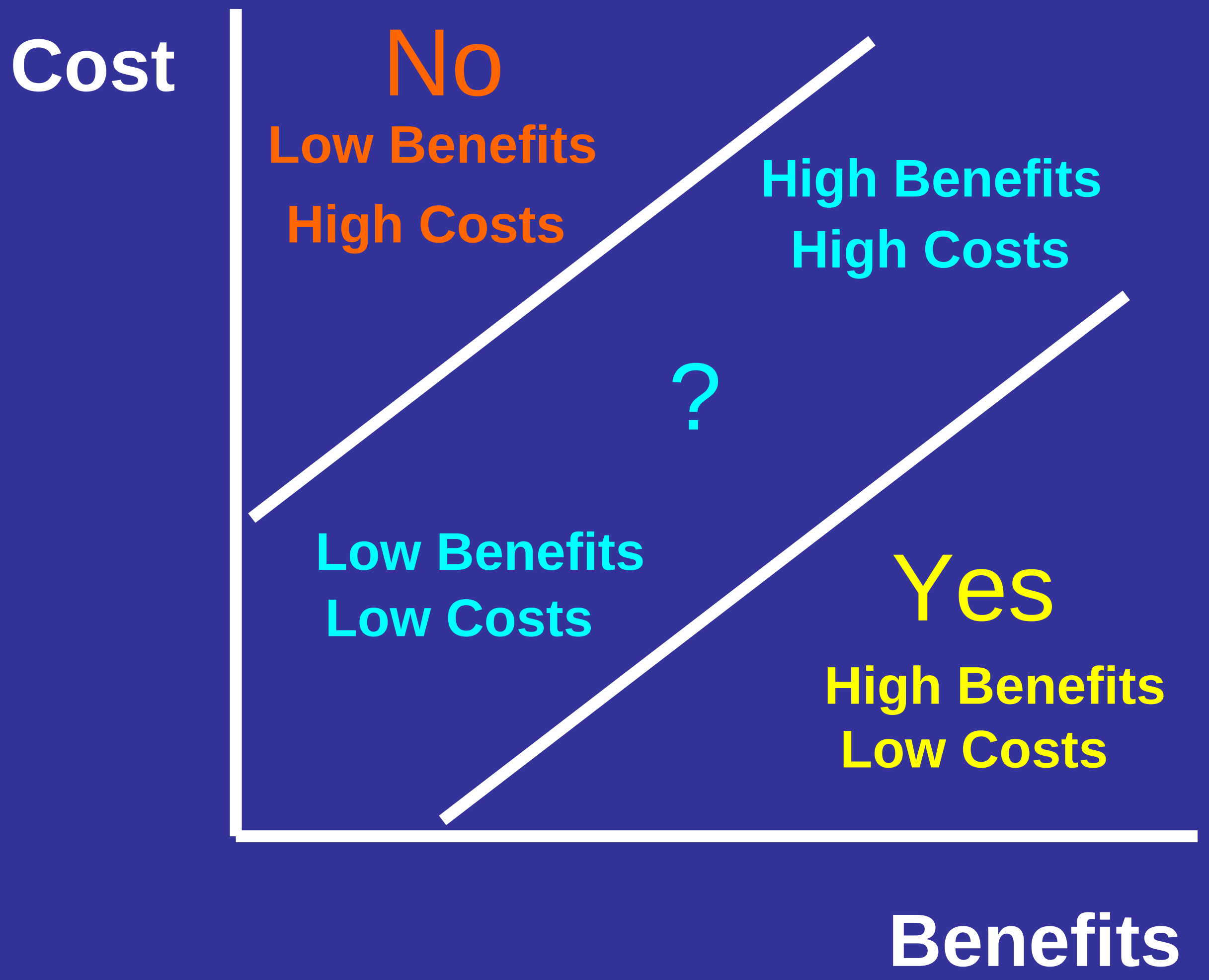
- Intensive sheep grazing

Evaluate Risk-Adjusted Cost-Effectiveness

1. Benefits of Successful Restoration
2. Probability of Successful Restoration
3. Costs of Treatment

$$\text{Cost-Effectiveness} = \frac{\Delta\text{Benefits} * \text{Probability of Success}}{\text{Costs of Treatment}}$$

Comparing Restoration Options



Burned Area Restoration Optimization Model

Objective

Maximize benefits of multiple ecosystem services subject to a given budget constraint

$$B_t = \Sigma_i \Sigma_j w_j (b_{ij}^{with} - b_{ij}^{without})$$

i = Location *i, (sum over subset of fires)*

j = Benefit *j (brec, bforage bprop, bexist)*

t = 2-3 years following restoration

Control Variables

k = treatment, the level of preventative/restorative treatment provided to burned area *i*

w = weights assigned to benefits ***j***

Budget Constraint

$$TC_{\mathbf{i}} = \Sigma_k FC + JC_k{*}JT_i + TCA_{ik}{*}A$$

FC = Fixed Costs

JC_k = Journey (Travel) Cost, personnel and equipment

JT_i = Journey Time (hours)

TCA_{ik} = Treatment Cost per Acre

A_i = area treated (acres)

k = treatment(s)

Estimating Change in Benefits with Treatment

$$b_{ij} = f\,(b_{max_{ij}}, S_i, C_i)$$

$b_{max_{ij}}$ = maximum possible site benefits

S_i = probability of success (desirable plants dominant in year 2-3)

C_i = contiguity / connectedness of native vegetation proxy for fire risk to neighboring lands

Assessing Site Restorability

Restorability:

$S_i = \mathrm{P}(r_i, \tau_k)$

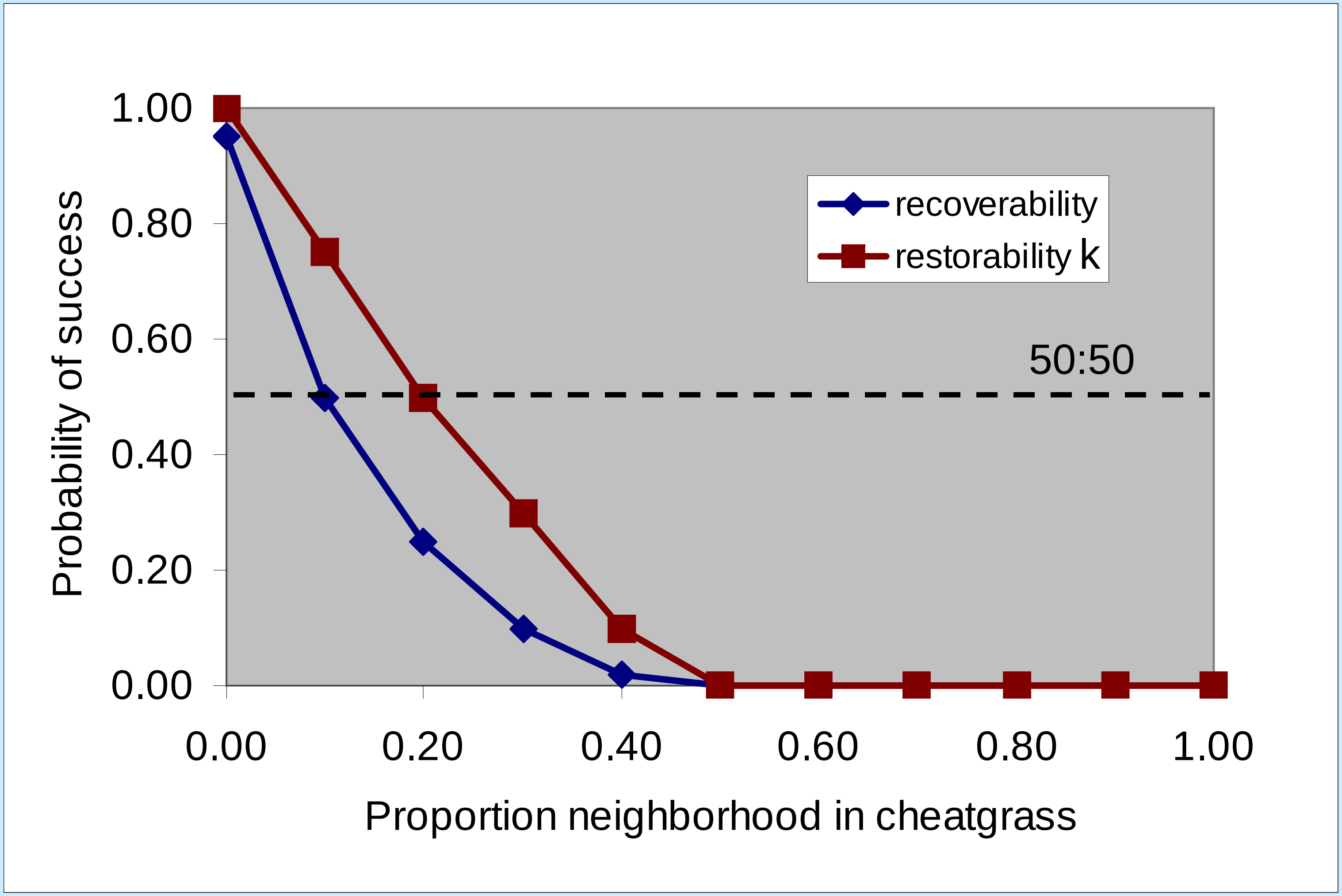
r_i = site recoverability

τ_k = treatment effectiveness

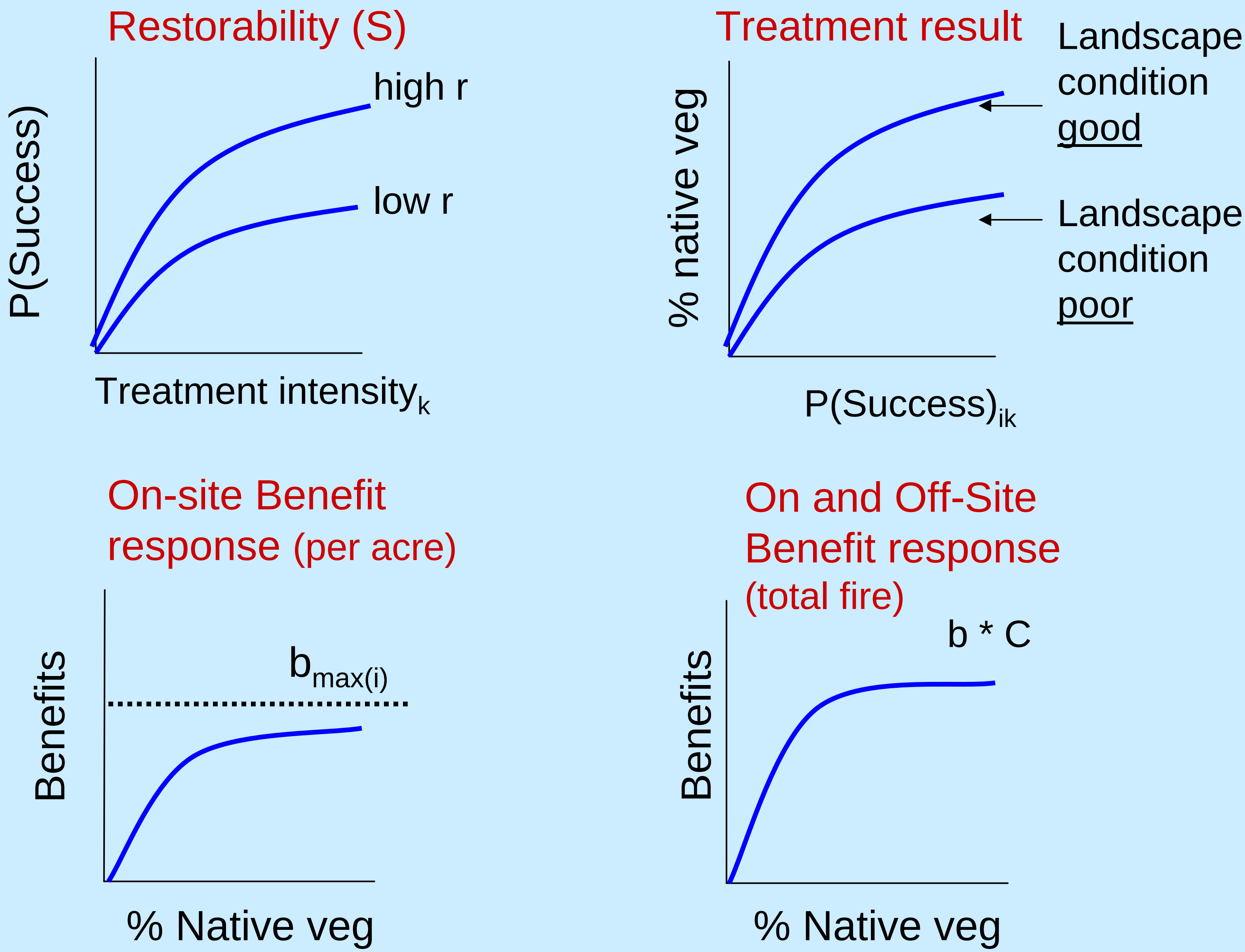
k = treatment

Recoverability and restorability based on % neighborhood in cheatgrass

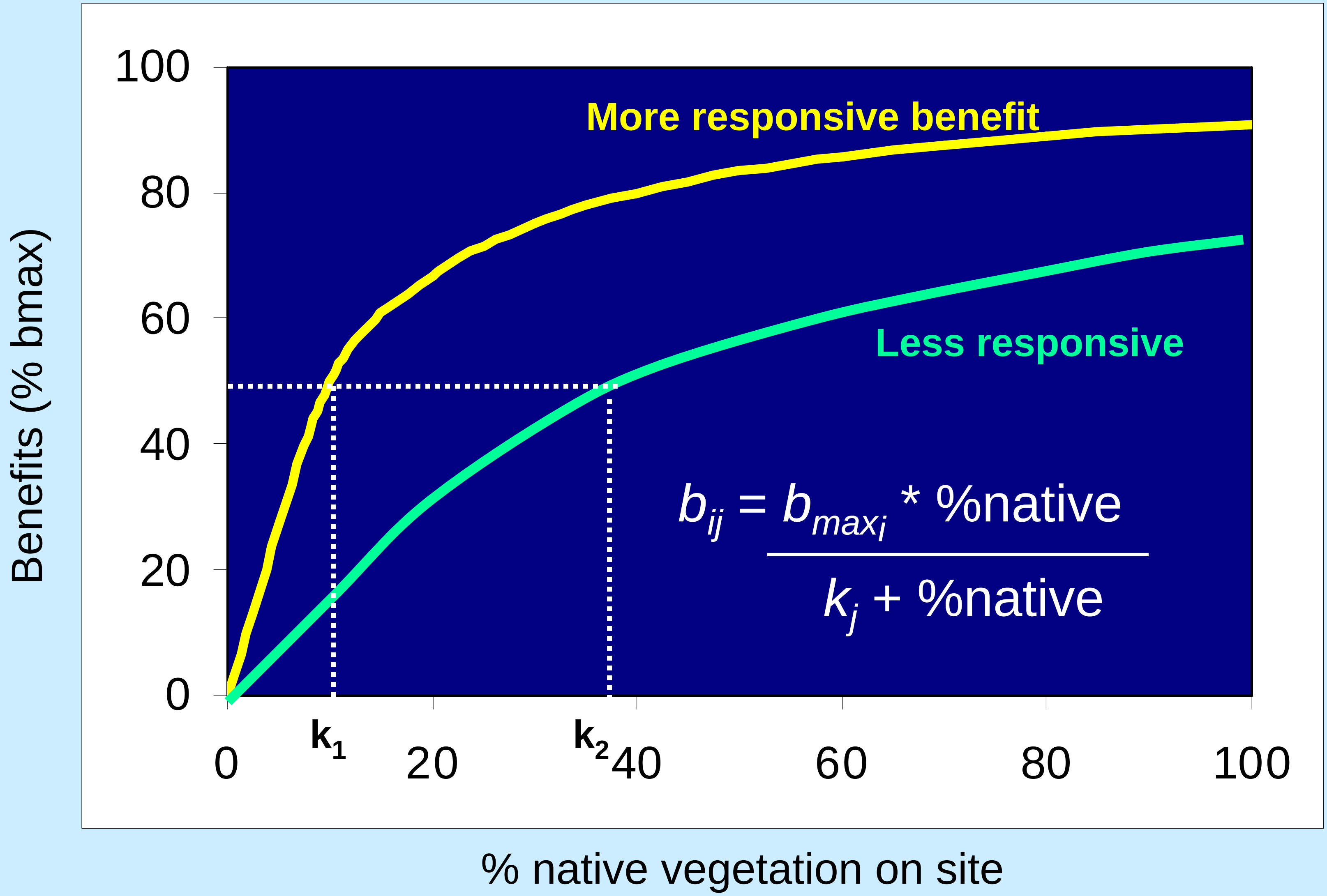
(holding all else constant)



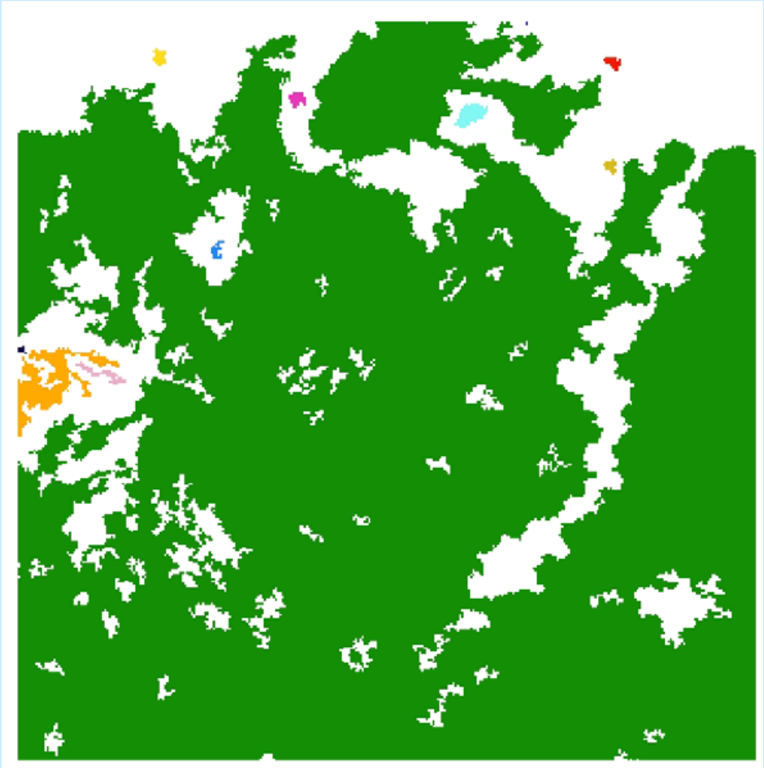
Calculating Risk-Adjusted Site Benefits

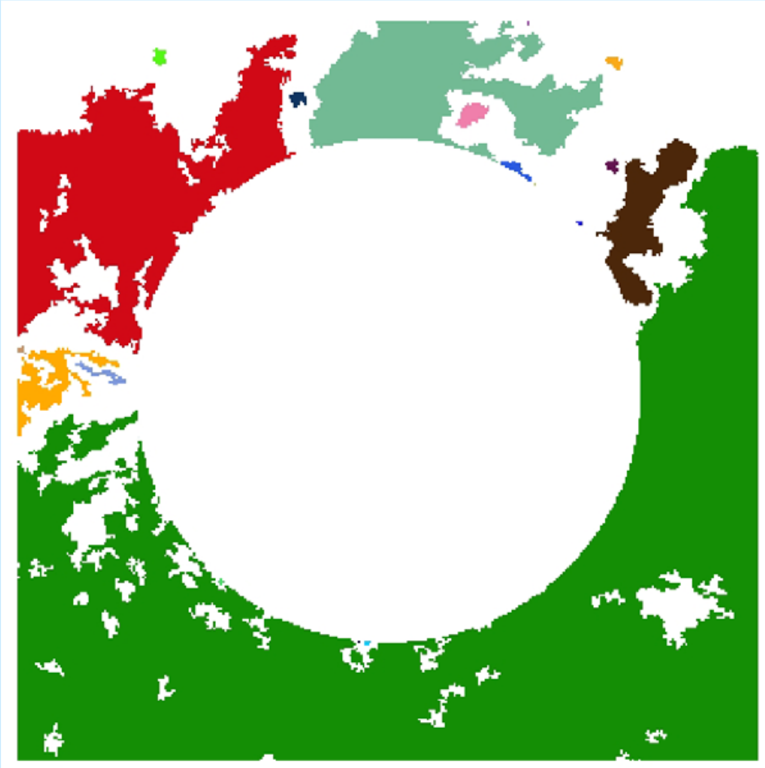


Benefits vs. % native vegetation



Effect of Fire on Landscape Connectivity





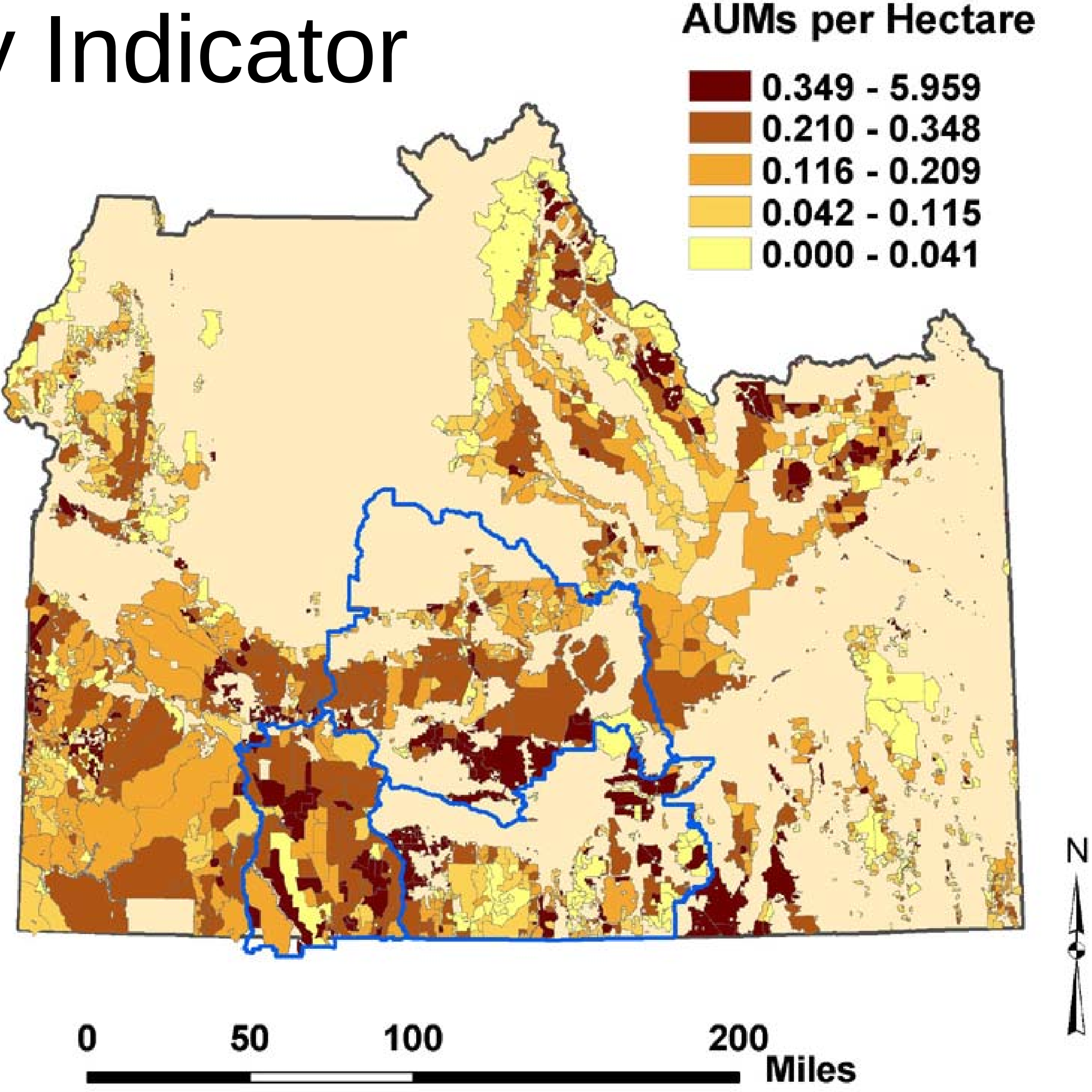
Mean Contiguity = 0.666
Largest Patch Index = 75.2

Mean Contiguity = 0.576
Largest Patch Index = 31.7

Measuring b_{max}

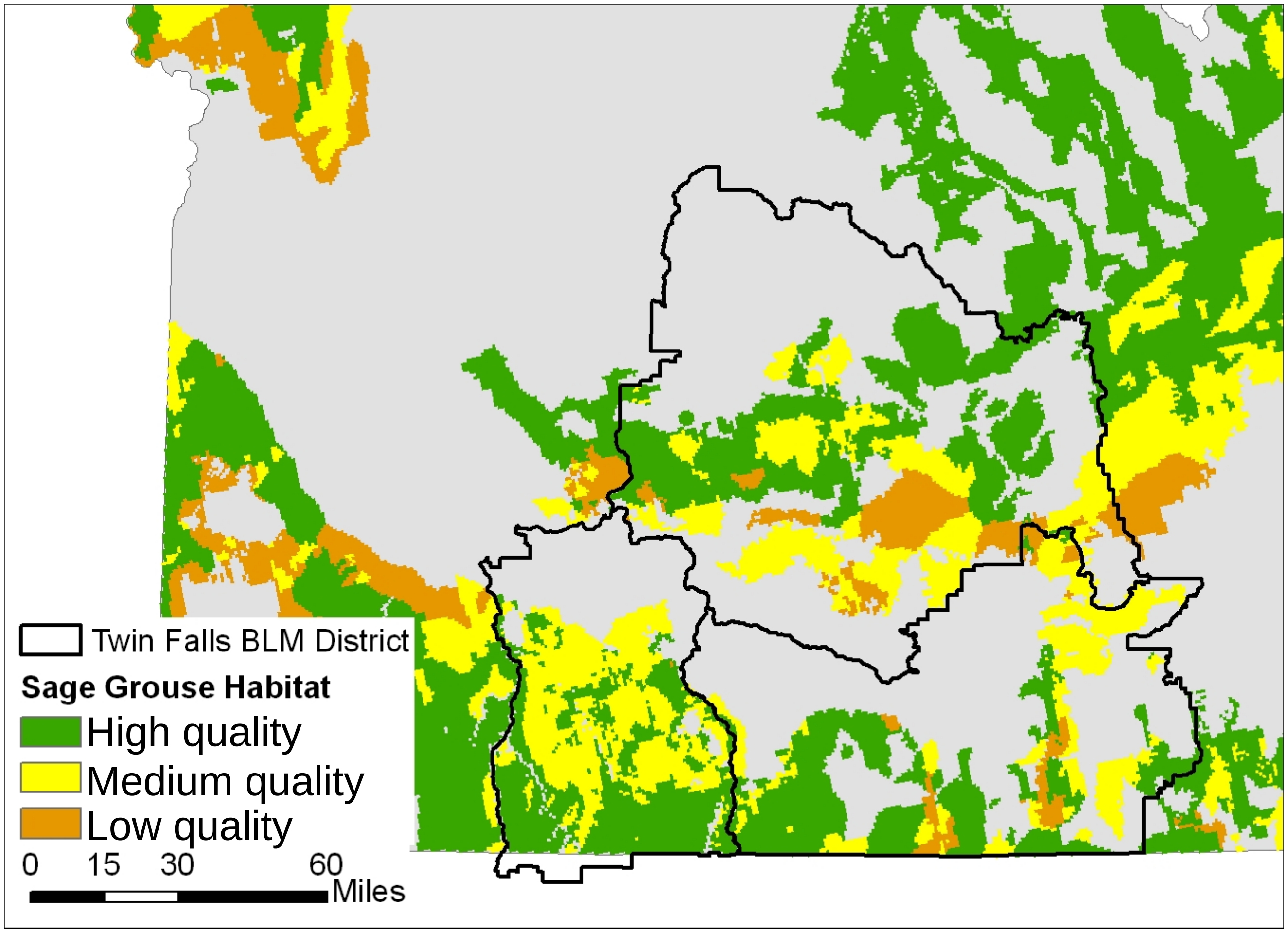
- Site quality
- Landscape quality
- Scarcity / replaceability / substitutability
- Risk of service disruption

Site Quality: Grazing Quality Indicator

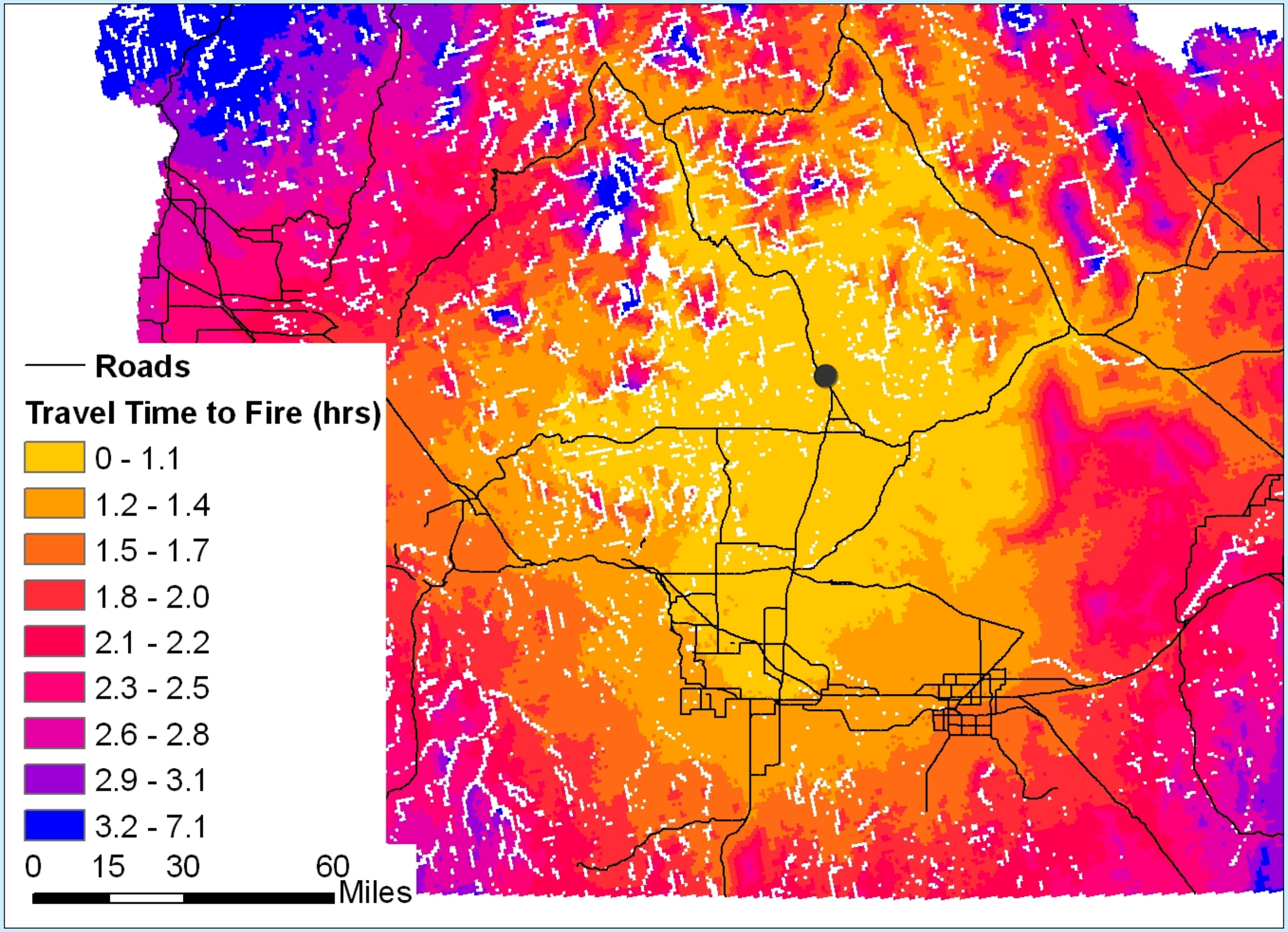


Source data: BLM

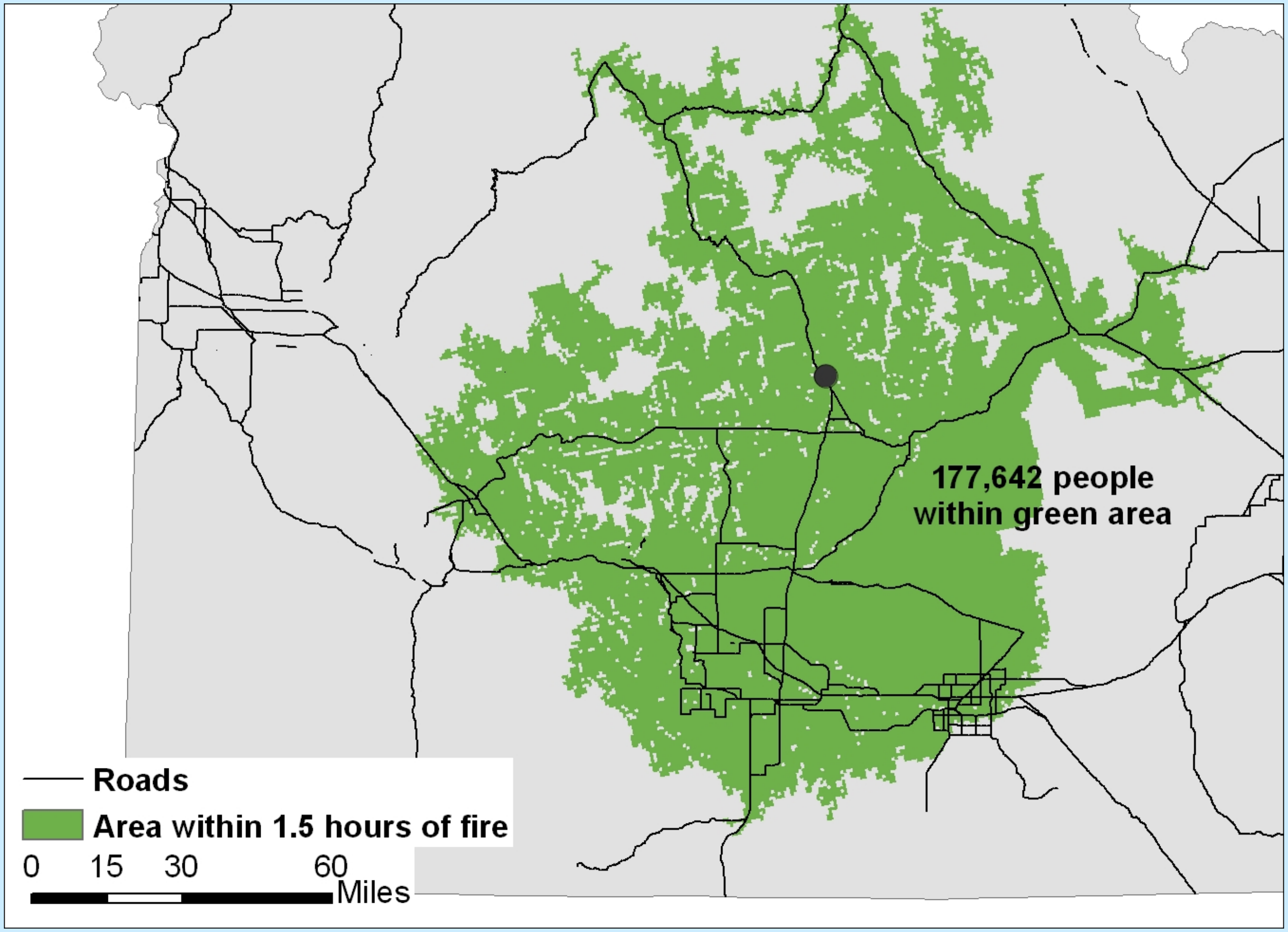
Site Quality: Sage Grouse Habitat



Accessibility: Travel Time to Site



Accessibility: Population within 1.5 Hours of Site



Results

Restorability Regression Analysis Results (ordinal logit)

Reduced Success (negative coefficients)	Enhanced Success (positive coefficients)
• % Infested	• Elevation*
• Herbicide use	• Herbicide x %Infested*
• Drill seeding	• Drill seeding x %Infested
	• Native seeds*
	• Fencing
	• Spending per acre
	• Fire size

* Coefficients significant at > 95%

Seed Choice and Project Success

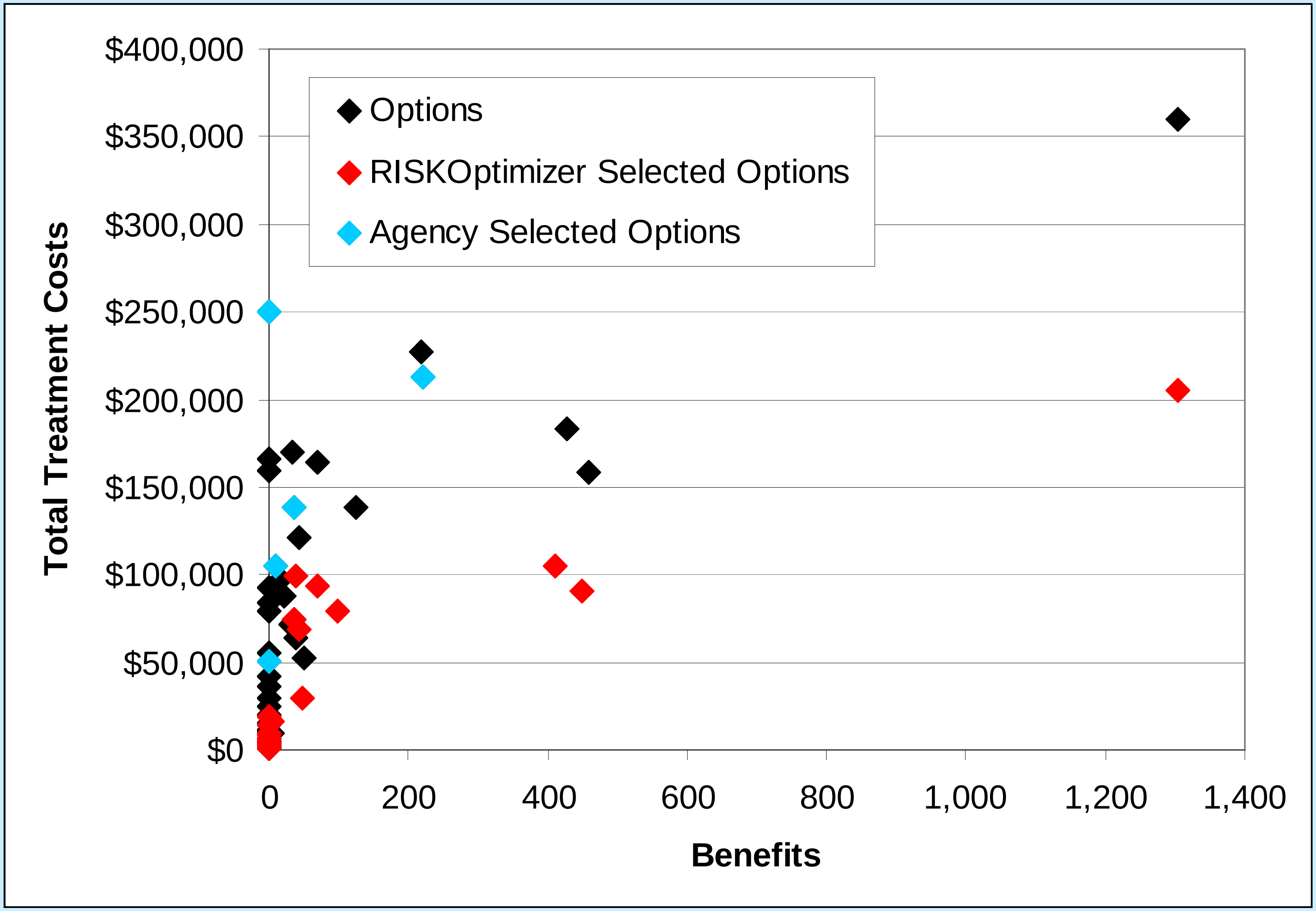
(2001-2003)

Treatment Cost Empirical Modeling

Dependent variable = Treatment cost per acre

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	6.763	.524		12.898	.000
ln (fire size)*	-.304	.071	-.441	-4.275	.000
drill seed dummy	.646	.200	.344	3.238	.003
herbicide dummy	.386	.216	.218	1.792	.082
state dummy (ID)*	-1.368	.322	-.756	-4.246	.000
native dummy*	.675	.248	.359	2.725	.010
WUI dummy	-.192	.446	-.045	-.431	.669
slope class	-.042	.327	-.013	-.128	.899
protected area	-.305	.273	-.117	-1.117	.272
fencing dummy	-.292	.245	-.141	-1.189	.243
Ln (airport travel time)	-.297	.205	-.186	-1.448	.157

Costs vs. Risk-Adjusted Benefits



Optimization Output vs. Management Decisions

equal weights to benefits

	Total Acres Treated	**Total Change in Benefit Units**	**Total Cost**
RISKOptimizer Treated Sites	48,140	626,439	$999,500
Agency Treated Sites	25,850	67,149	$1,254,000

Lessons Learned

- **Assessing Restorability**
  - Need data on *untreated* sites to distinguish recovery rate from restoration rate

- **Assessing Benefits**
  - Managers want to incorporate all benefits not just monetized benefits
  - Benefit indicator calculations are time-consuming but can be automated
  - Further research needed to ensure benefit measures adjust to changing scarcity
  - Static analysis can incorporate concepts of benefit persistence

  - Data not available to quantitatively assess reduction in fire risk
  - Dynamic model required to directly assess value of increasing fire-free interval

Why we decided to try *RISKOptimizer* Software

- Deals explicitly with uncertainty regarding inputs/processes/outcomes
- Combines simulation & optimization
- Moderate-cost ($500) software tool that can be implemented as an Excel add-in

RISKOptimizer Software Overview

- Combines Monte Carlo simulation with genetic algorithm-based optimization in models that contain uncertain factors

- Can find optimal solutions to problems that are “unsolvable” using standard linear and non-linear optimizers

Impact of Uncertainty on Simulation/Optimization

Example 1: Certain Input Variables

B = change in EBI with Treatment   B = 500

C = cost of treatment   C = $100

Results

B/C = 5

Example 2: Uncertain Input Variables – only 2 possible values per input

B= 300 or 500   C = $50 or $150

Results

B/C = 6	300/$50	B/C = 10	500/$50
B/C = 2	300/$150	B/C = 3	500/$150

Example 3: Uncertain Input Variables – site-specific probability of values

E.g., B = (500, 200-600)   C = $(100, (10))

Results

B/C = f(B,C) which will differ for each site

RISKOptimizer Software Overview

Allows the user to describe the range and probability distributions for each uncertain factor, and then

1. Runs full simulations for each possible trial by selecting factor values based on probabilities
2. Stops simulating and selecting factor values after a selected time period or number of iterations
3. Picks the solution that best fits the distribution of the target cell being maximized or minimized

General Approach

Step 1 **Enter all factors** (inputs, outputs, weights, constraints, etc.),

Step 2 **Define all processes** (relationships among factors)

Step 3 **Identify which factors are uncertain** and their expected range and probability distributions.

Step 4 **Identify the target cell** to be maximized

- Weighted sum of our four benefit indicators.

Step 5 **Identify adjustable cells** (control variables):

- Weights on each benefit indicator (defined by the user)
- Treatment intensity at each area (solved by the program)

Step 6 **Identify constraints**

- "Hard" – budget
- "Soft" – policy choices that limit the optimization

Step 7 **Assign a weight to each benefit** (user preferences)

Step 8 **Run the program and assess results**

Step 9 **Perform sensitivity tests** on assumptions, weights, etc.

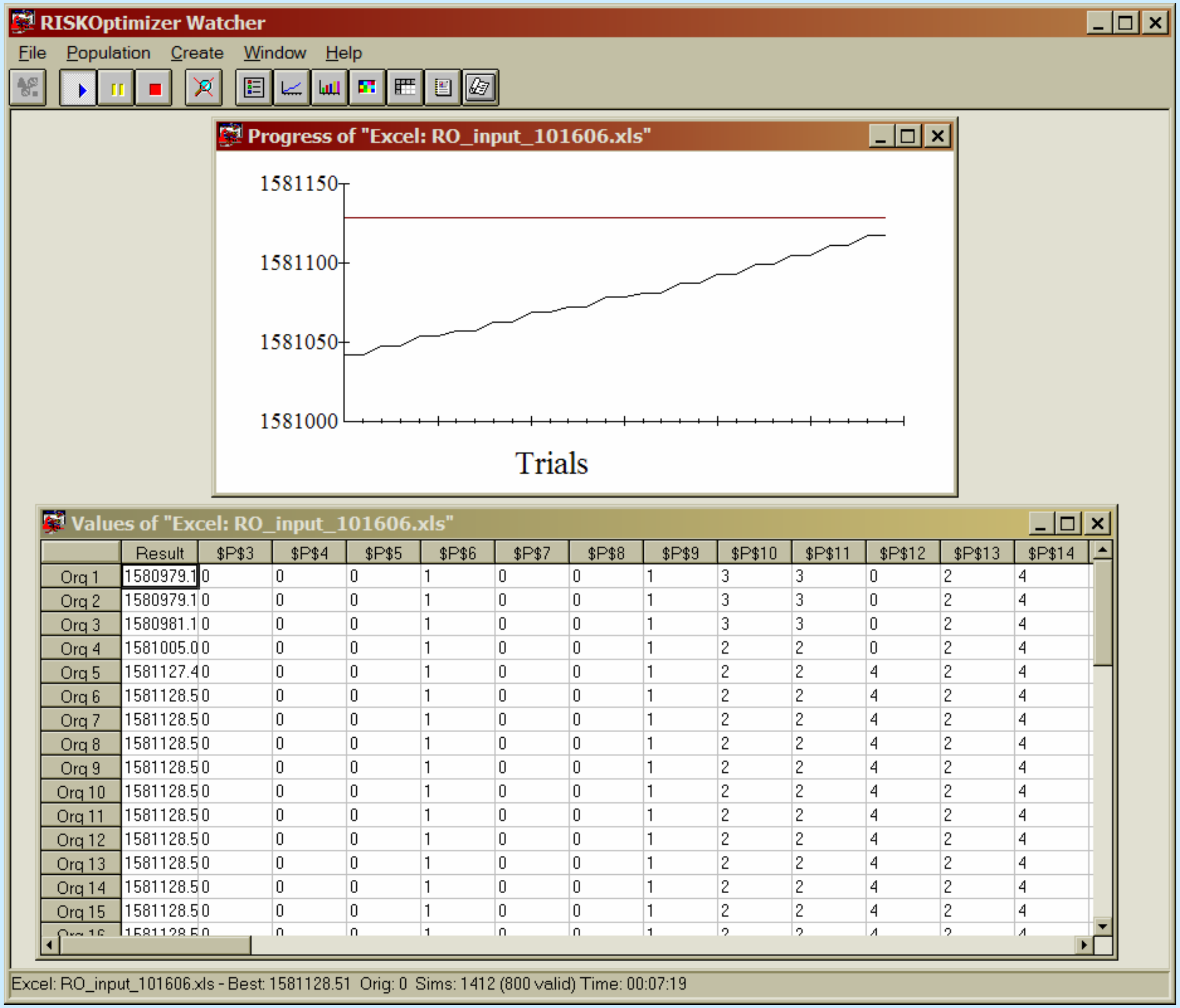
Step 10 **Interpret results** and develop recommendations

Cheatgrass Optimization Model

CHEATGRASS TREATMENT SIMULATION / OPTIMIZATION MODEL

OBJECTIVE	Maximize sum of weighted benefit indicators from all sites
CONSTRAINTS	Hard -- Total cost for all treatment cannot exceed $1,000,000
	Soft -- Varies based on policy decisions (e.g., restrictions on treatment or spending allocations)
CONTROL VARIABLE	Treatment intensity at each site:
	0 = no treatment
	1 = seeding (native/non-native)
	2 = seeding and herbicide
	3 = seeding, herbicide, and drill seeding/harrowing
	4 = seeding, herbicide, drill seeding/harrowing, and follow-up treatment
MODEL PROCESSES	Effects of post-fire treatment on cheatgrass cover
	Effects of landscape factors on site benefits
	Effects of landscape factors on treatment success
	Effects of site/landscape characteristics on site treatment costs
	Effects of cheatgrass cover on site benefits
	Effects of cheatgrass cover on landscape benefits
SENSITIVITY ANALYSIS	Adjust relative weights of benefit categories
	Assess and compare constraint penalties (shadow prices)

RISKOptimizer Progress Watcher



	Result	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Org 1	1580979.1	0	0	0	1	0	0	1	3	3	0	2	4
Org 2	1580979.1	0	0	0	1	0	0	1	3	3	0	2	4
Org 3	1580981.1	0	0	0	1	0	0	1	3	3	0	2	4
Org 4	1581005.0	0	0	0	1	0	0	1	2	2	0	2	4
Org 5	1581127.4	0	0	0	1	0	0	1	2	2	4	2	4
Org 6	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 7	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 8	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 9	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 10	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 11	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 12	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 13	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 14	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4
Org 15	1581128.5	0	0	0	1	0	0	1	2	2	4	2	4

Sample *RISKOptimizer* Output

Microsoft Excel - RO_input_101606.xls

PROGRAM INPUT

BENEFIT WEIGHTS	
Benefit Category	**Weight**
Recreational/Hunting	0.25
Grazing	0.25
Property Protection	0.25
Habitat/Existence Value	0.25

PROGRAM OUTPUT -- Optimal Solution

OPTIMAL BENEFIT SOLUTION	
Benefit Category	**Change in Benefit Units**
Change in Recreational/Hunting Benefits	108,608
Change in Grazing Benefits	168,172
Change in Property Protection Benefits	2,670
Change in Habitat/Existence Value Benefits	346,989
Total change in benefits	626,439

TOTAL COST	$999,544

PROGRAM SOLUTION	
Treatment Type	**# Fires**
No Treatment	26
Aerial seeding only	17
Aerial seeding + chaining	11
Aerial seeding + chaining + herbicide	5
Aerial seeding + chaining + drill-seeding	9

Average fire size per treatment type	Acres
No Treatment	2,601.6
Aerial seeding only	2,628.3
Aerial seeding + chaining	184.9
Aerial seeding + chaining + herbicide	262.2
Aerial seeding + chaining + drill-seeding	12.7

RISKOptimizer Summary / Intro / Ouput / Model / Bt Intensity Lookup / RecovLookup / Costs / Sheet10

Conclusions

1. Details are important to managers, so site-specific analysis for comparing benefits, costs, risks are most useful
2. Benefit response functions are not well understood; but screening-level economic analysis based on first principles of ecology and economics can work
3. Data are sufficient to perform screening level analysis, but results are sensitive to the functional form of benefits
4. Weights on benefits are only critical when benefits compete; when they do, weights can significantly change the optimal allocation of treatment effort and treatment intensities
5. A simple decision framework that is based on costs and various types of benefits, incorporates uncertainty, and provides a means for testing hypotheses regarding competing and complementary benefits is most useful.
6. Decision-support tools that follow sound economic principles and reveal underlying assumptions and value judgments provide a better basis for both expert and stakeholder involvement in decision-making and promote cost- and risk-conscious solutions