INCORPORATING ECOLOGICAL DYNAMICS INTO RANGELAND TREATMENT AND RESTORATION DECISIONS

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Objectives

Economic analysis in decision contexts that involve altering ecological processes requires identifying and quantifying relationships between biophysical and social systems – key for management and informing policy related to complex systems (James et al. 2013; Eiswerth et al. 2015; Weltz et al. 2014).

Examples:

- Expected Present Valued Net Benefits of a proposed fuels treatment project on public land, in terms of fire suppression expenditures averted (Taylor et al. 2013).
- Expected Present Valued Net Benefits of fuel treatments/ restoration in terms of ranch returns and public goods benefits (Kobayashi et al. 2014).

Economic problem and definition of relevant units of change

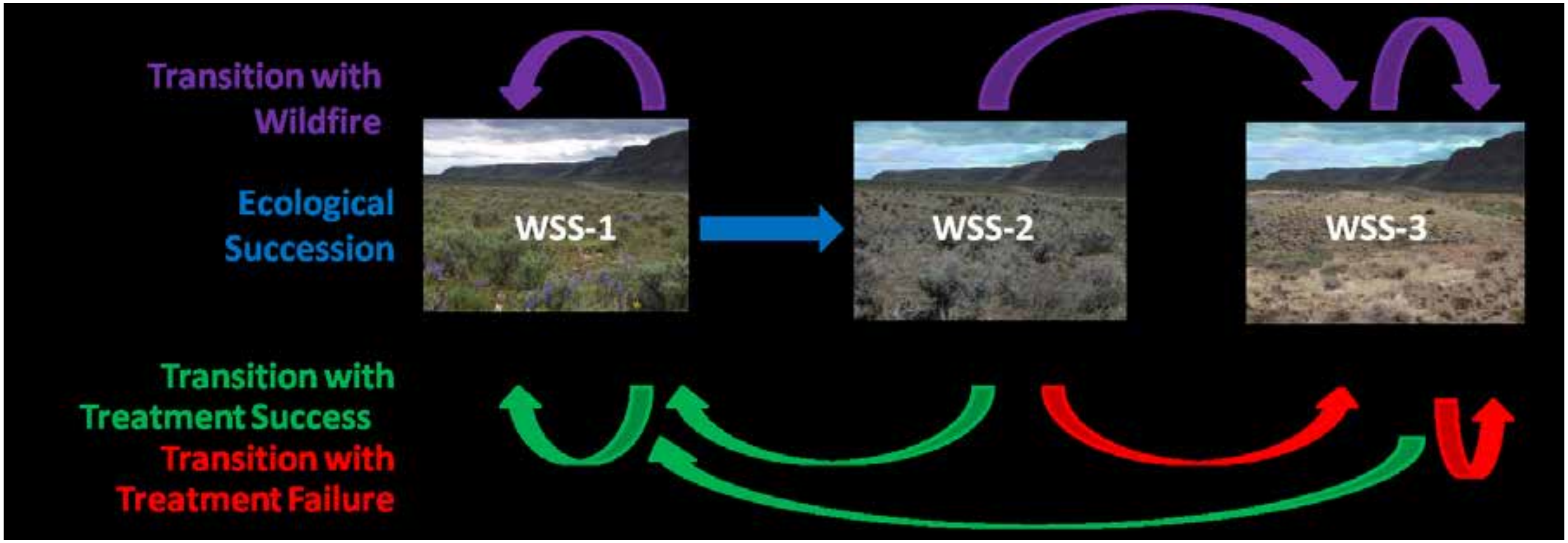
- Optimize net returns from fixed set of resources (assets) to achieve stated goals (cost effectiveness)
- Analytical Framework
  - Measure differences between constructed/simulated “with” and “without” scenarios
  - Quantify dollar-values associated with changes
- Biophysical changes and relationships include
  - Time frames and dynamics: with and without scenarios
  - Probabilistic events: stochastic effects (ignition, precip, drought)
    - Management changes odds of outcomes
  - Irreversibility: species loss, ecological thresholds
- Expected Present Value of Net Benefits

Measuring Costs and Benefits

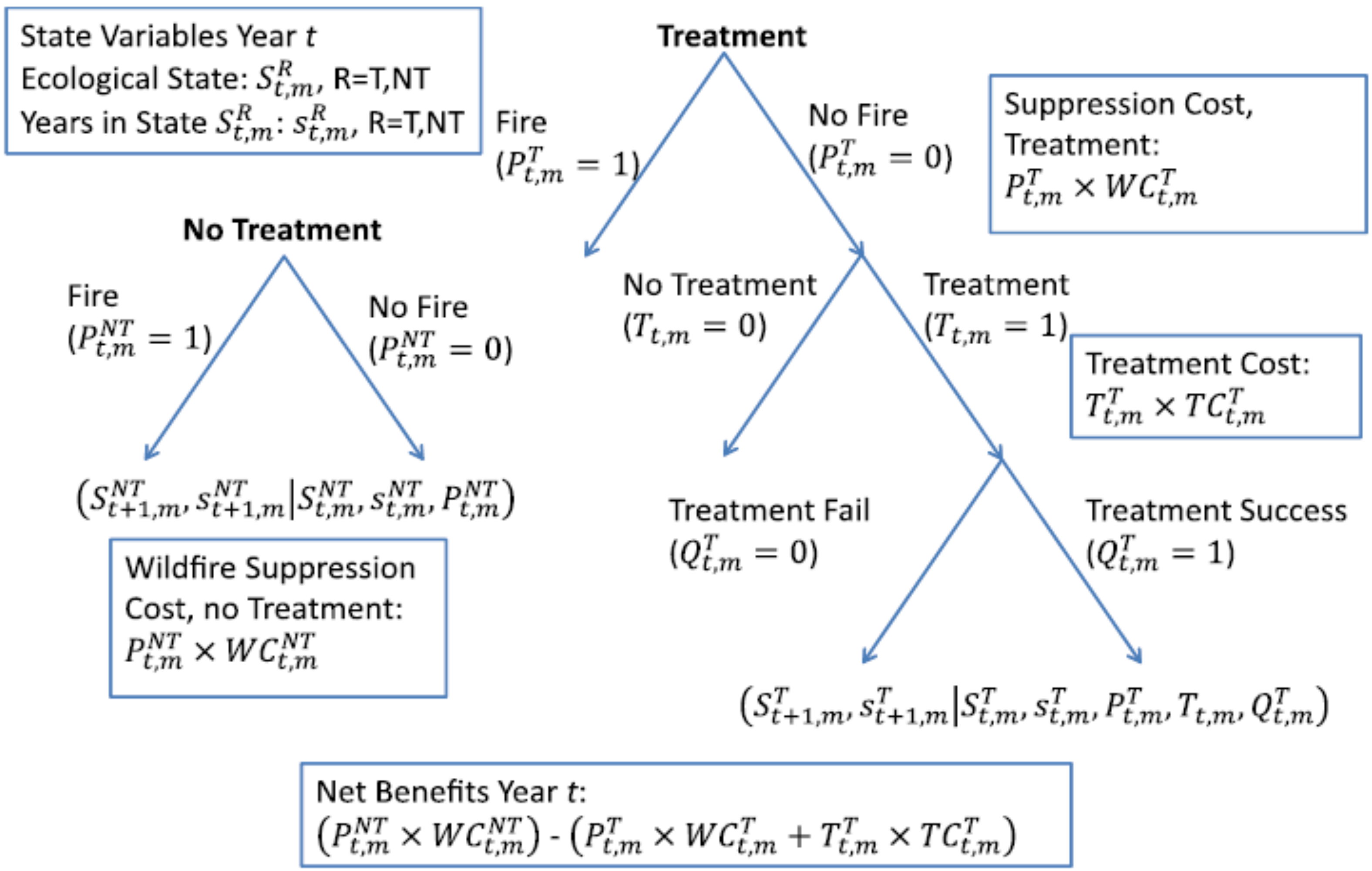
- Quantitative units for environmental changes initially in terms of biophysical changes (supply side)
  - Units of biophysical change associated with decision contexts, actions and practical increments of change (ppm contam)
- Units quantifiable in terms of benefits to society (demand side), or can be translated (x ppm = y decrease in fish population; z increase in respiratory-related hospital visits)
- Decision contexts often include
  - Uncertainty / incomplete information
  - Time frame and choice of when actions (inactions) taken
- Parameterize models with ecological and cost data

Ecological Dynamics

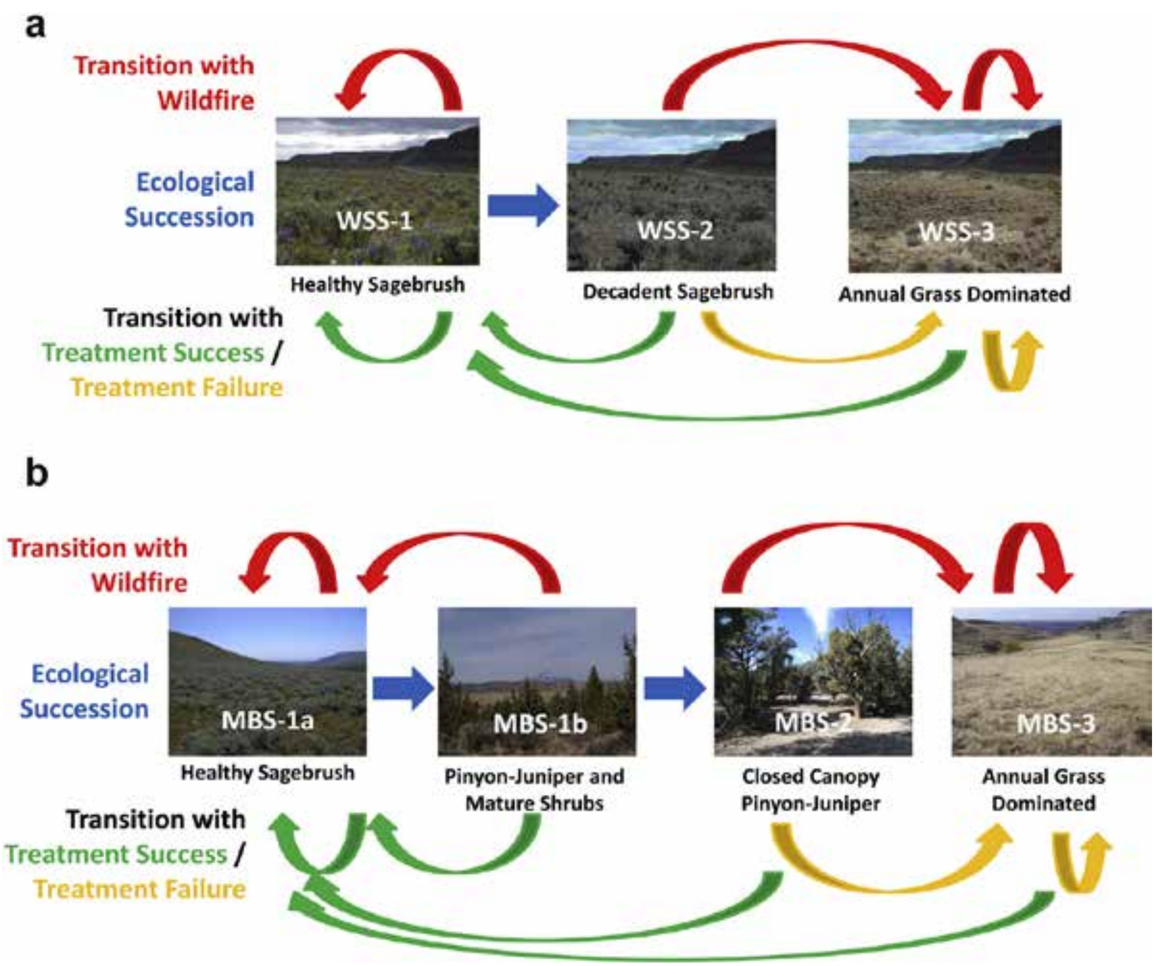
Stylized State and Transition Ecological Model for Western Rangelands



Decisions: timing and outcomes



Develop and parameterize for applicable ecological models



Wyoming Sagebrush System - WSS

Mountain Big Sagebrush System - MBS

Wyoming Sagebrush System

Wyoming sagebrush steppe results ($ per acre; 2010 dollars).

	Initial ecological state		
	WSS-1	WSS-2	WSS-3
	Shrubs and perennial grasses	Decadent sagebrush with annual grasses	Invasive annual grass dominated
Mean number of wildfires – no treatment	15.1 (0, 26)[a]	15.2 (0, 27)	22.2 (15, 30)
Mean number of wildfires – with treatment	1.8 (0, 4)	12.1 (0, 28)	6.4 (1, 17)
Mean total suppression costs (NPV) – no treatment	$349.8 ($0, $1141.1)	$364.2 ($0, $1218.6)	$389.8 ($149.6, $703.0)
Mean total suppression costs (NPV) – with treatment	$56.0 ($0, $250.5)	$231.4 ($0, $658.9)	$250.7 ($2.8, $607.6)
Mean wildfire suppression costs savings (NPV)	$293.8 ($0.0, $1043.8)	$132.8 (–$430.7 $934.1)	$139.1 ($0.6, $418.5)
Mean number of treatments	3.1 (2, 4)	2.0 (1, 4)	41.8 (5, 121)
Mean number of successful treatments	3.1 (2, 4)	1.5 (0, 4)	2.5 (1, 4)
Mean treatment costs (NPV)	$22.1 ($19.7, $23.5)	$204.4 ($205.4, $209.3)	$2526.9 ($469.5, $4974.9)
Final state – no treatment[b] (WSS-1, WSS-2, WSS-3)	0, 734, 9266	0, 731, 9269	0, 0, 10,000
Final state – with treatment (WSS-1, WSS-2, WSS-3)	10,000, 0, 0	4949, 0, 5051	9885, 0, 115
Mean wildfire suppression costs savings net of treatment costs (NPV)	$271.7 (–$23.5, $1021.6)	–$71.6 (–$636.1, $727.8)	–$2782.5 (–$4965.1, –$107.5)
Mean benefit–cost ratio (NPV)	13.3	0.7	0.06

[a] 5th and 95th percentiles.

[b] 'Final State' is the final state of the system (WSS-1, WSS-2, or WSS-3) after 200 years.

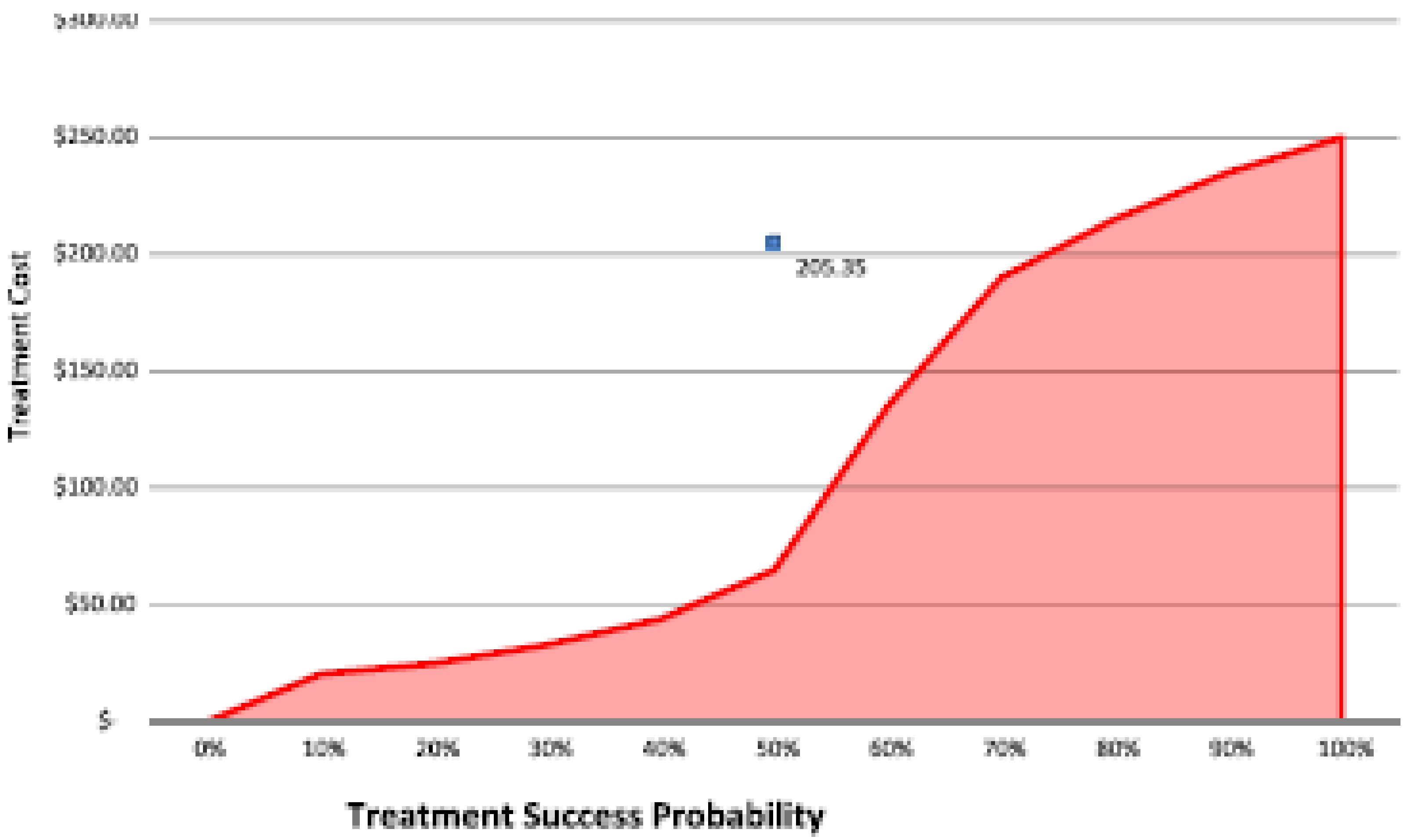
Mountain Big Sagebrush

Mountain Big Sagebrush results ($ per acre; 2010 dollars).

	Initial ecological state			
	MBS-1a	MBS-1b	MBS-2	MBS-3
	Shrubs and perennial grasses	Pinyon–juniper, shrubs and perennial grasses	Closed-canopy pinyon–juniper with annual grass	Invasive annual grass dominated
Mean number of wildfires – no treatment	6.6 (1, 18)[a]	14.7 (0, 26)	15.0 (0, 26)	22.0 (15, 29)
Mean number of wildfires – with treatment	3.4 (1, 7)	3.4 (1, 7)	12.8 (1, 28)	7.5 (2, 17)
Mean total suppression costs (NPV) – no treatment	$273.4 ($1.1, $770.2)	$560.7 ($0, $1903.3)	$576.2 ($0, $1937.4)	$1447.7 ($352.5, $2883.6)
Mean total suppression costs (NPV)– with treatment	$164.3 ($1.3, $539.0)	$158.2 ($1.3, $498.2)	$793.0 ($5.9, $2443.6)	$894.1 ($28.5, $2381.1)
Mean wildfire suppression costs savings (NPV)	$109.1 ($-252.6, $521.2)	$402.5 (–$80.9, $1575.9)	–$216.8 (–$1885.3, $1183.1)	$553.6 ($7.5, $1719.4)
Mean number of treatments	1.2 (1, 2)	1.1 (1, 2)	1.02 (1, 1)	39.7 (3, 119)
Mean number of successful treatments	1.2 (1, 2)	1.1 (1, 2)	0.5 (0, 1)	1.0 (1, 1)
Mean treatment costs (NPV)	$19.3 ($19.5, $19.9)	$44.7 ($45.5, $45.7)	$202.5 ($205.4, $205.4)	$2886.1 ($465.8, $4958.7)
Final state – no treatment[b] (MSS-1a, -1b, -2, -3)	5328, 394, 719, 3559	171, 6, 759, 9064	0, 0, 769, 9231	0, 0, 0, 10,000
Final state – with treatment (MSS-1a, -1b, -2, -3)	10,000, 0, 0, 0	9462, 538, 0, 0	4455, 2, 5258	9182, 599, 14, 205
Mean wildfire suppression costs savings net of treatment costs (NPV)	$89.8 (–$272.1, $502.7)	$357.9 (–$126.4, $1530.4)	–$419.3 ($2090.7, $977.7)	–$2,332.5 (–$4927.8, $937.0)
Mean benefit–cost ratio (NPV)	5.7	9.0	1.1	0.2

[a] 5th and 95th percentiles.
[b] 'Final State' is the final state of the system (MBS-1a, MBS-1b, MBS-2, or MBS-3) after 200 years.

Sensitivity Analysis for Probability of Treatment Success



Sensitivity Analysis for Uncertainty About Thresholds

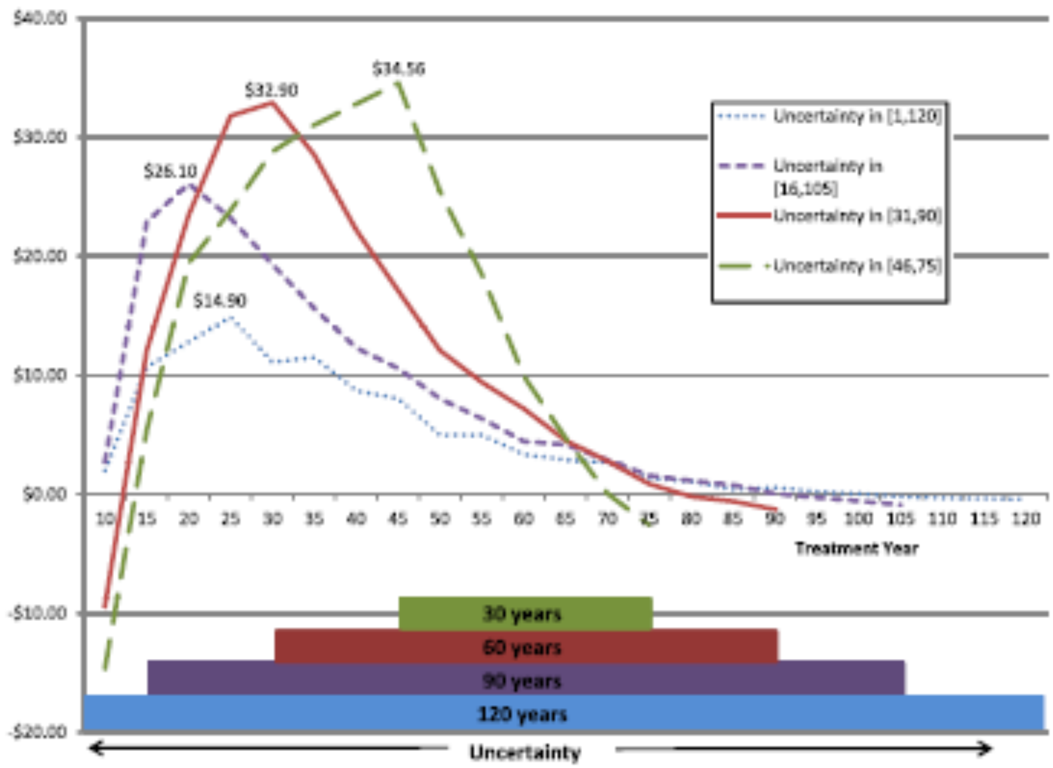


Fig. 5. Expected net benefits from treatment under an uncertain threshold between WSS-1 and WSS-2.

Sensitivity Analysis for Uncertainty of Ecological Parameters

Table 6
Impacts of shorter fire return intervals in WSS-2 on benefits and costs. Bold numbers signify that these numbers refer to the fire return intervals in WSS-2 listed in the top row.

	Fire return interval in WSS-2 (years)				
Initial state – WSS-1	**75**	**50**	**25**	**15**	**5**
Mean total suppression costs (NPV) – no treatment	$349.80	$463.90	$662.00	$798.20	$1013.00
Mean total suppression costs (NPV) – with treatment	$56.00	$59.10	$57.30	$57.70	$59.20
Mean treatment costs (NPV)	$22.10	$22.09	$22.09	$22.08	$22.08
Mean wildfire suppression costs savings net of treatment costs (NPV)	$271.70	$382.70	$582.50	$718.50	$931.70
Mean benefit–cost ratio (NPV)	13.3	18.3	27.4	33.5	43.2
Initial State – WSS-2	**75**	**50**	**25**	**15**	**5**
Mean total suppression costs (NPV) – no treatment	$364.20	$480.50	$686.50	$832.30	$1051.40
Mean total suppression costs (NPV) – with treatment	$231.40	$232.90	$258.80	$278.00	$415.00
Mean treatment costs (NPV)	$204.40	$202.92	$198.16	$193.36	$164.69
Mean wildfire suppression costs savings net of treatment costs (NPV)	–$71.60	$44.60	$229.50	$360.90	$471.70
Mean benefit–cost ratio (NPV)	0.7	1.2	2.2	2.9	3.9

Simulations with alternative fire-return intervals
Treatments on initial states 1 and 2 for WSS

Ranch Model

- Three STM states from previous example
- Representative ranch with initial condition in states 1 or 2
- Quantify private incentives to invest in rehabilitation treatment, contrast private net benefits with public net benefits, which include wildfire costs averted, habitat
- Difference – inform policy
- Stochastic dynamic programming: max ranch profits subject to STM ecological dynamics, ranch ops, etc.
- Decision variables each period: stock size (cattle sales and purchases), treatment acreage.
- Stochastic each period: fire ignition, success rate of treatment (if treatment)

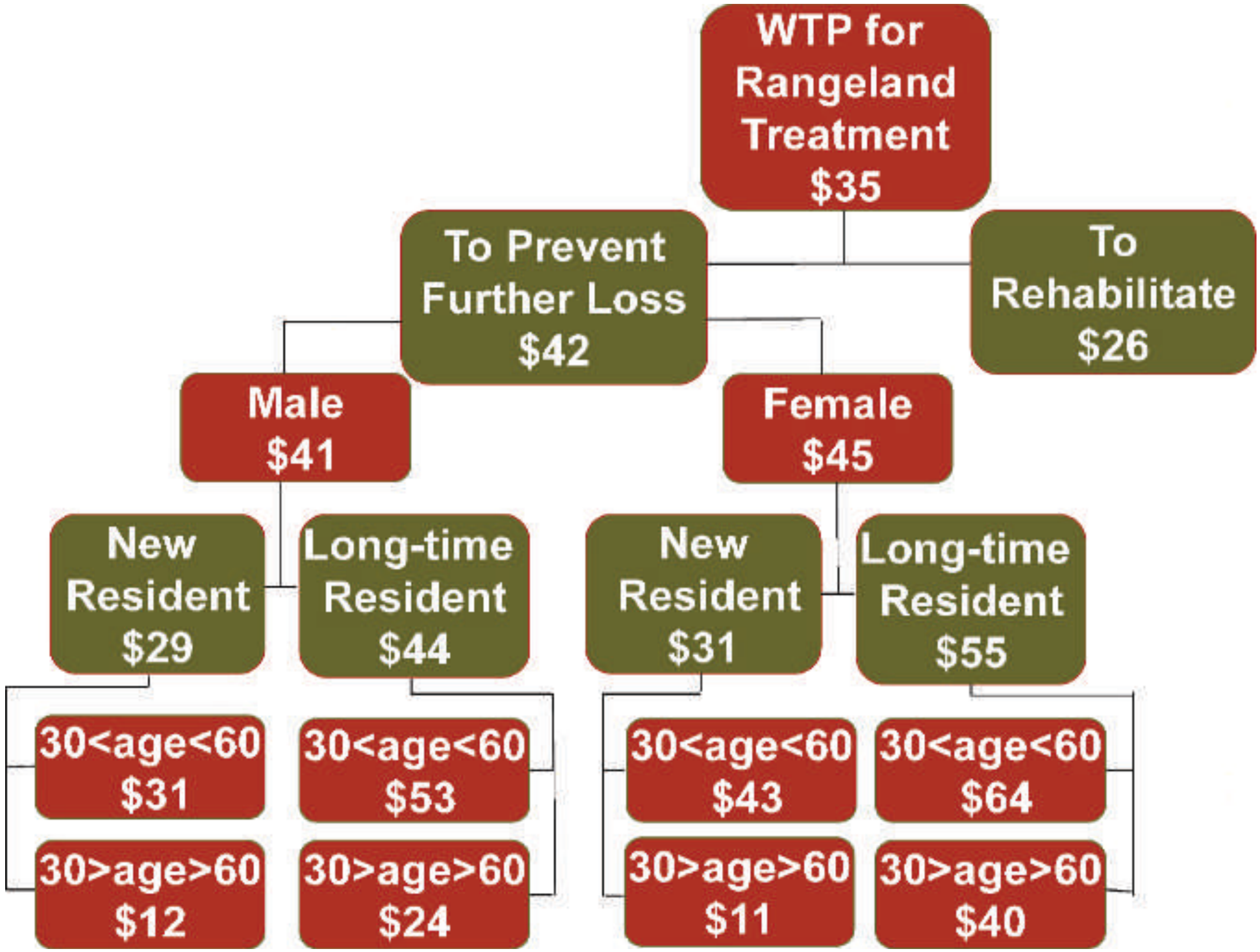
Ranch model

- Treatment costs from low to high:
  - state 1 < state 2 < state 3
- Probability of treatment success:
  - State 1> state 2 > state 3
- Vary assumptions:
  - Rancher understands STM framework (uses all information used to parameterize the model
  - Rancher does not become aware of STM until after first fire

Ranch model results

- If fully aware of STM information:
  - If initial conditions are State 1: rancher profits highest if perform treatments (costs are lower and prob of success higher)
  - If initial conditions are State 2: rancher profits highest when treatments are limited, rangeland crosses to State 3
  - Suggest that subsidies to lower treatment costs most effective directed towards ranchers with state 2 land (not state 2 or 1).
- If not aware of STM information: behaves as if will stay in initial sate and not cross thresholds (to states 2 or 3)
  - Relative to having full knowledge, probability of crossing to state 3 increases with initial conditions in states 1 or 2.
  - Overall lower profits: higher at first, then decline over time.
  - Differences are a measure of value of extension / tech transfer

Valuation of Public WTP



Summary and Discussion

- Connections between biophysical and economic changes require complex systems modeling
- Sensitivity analyses in ecological/economic modeling is a practical tool for environmental management and decision-making
- Scope for a set of ecological/economic models adapted and parameterized for the different ecological types and conditions on a large heterogenous landscape to be used together to create ‘topographical’ maps with “isobars” of net benefits of treatment and timing for pretreatment planning.

Recent and Future Work

- Ecological-economic models with uncertainty and time dynamics developed to estimate expected returns from investment in fuel treatments, measured as reduced future wildfire suppression and post-fire rehabilitation costs
  - Intermountain west where invasive annual grasses (bromus species) and other disturbances have altered the fire cycle and ecological dynamics
  - Ponderosa Pine systems where a history of over suppression of forest fire has resulted in accumulation of fuels and altered ecological dynamics
- Recently awarded a grant to develop models for four more ecosystems to broadly characterize the range of ecological conditions in areas of the Southern Colorado Plateau that experience significant and costly wildfire activity.
- Goal: incorporate other major ecological systems – to use for standardized economic analysis for (1) evaluation of programs and policies (2) for pre-treatment determination of where and when to treat to maximize expected returns of treatment resources

Citations

Related Publications:

•Eisworth, M., R. Epanchin-Niell, K. Rollins, and M.H. Taylor. 2015. “Economic Modeling and the Management of Brome Grasses: Accounting for Ecosystem Dynamics, Ecological Thresholds, and Spatial Interdependencies,” Chapter in “Exotic Brome Grasses in Semi-Arid Ecosystems of the Western US: Assessing Current and Future Invasions, Impacts, and Management Alternatives,” Edited by Matt Germino, Cini Brown, and Jeanne Chambers. Springer, New York.

•Taylor, M.H., A.J. Sanchez-Meador, Y. Kim, K. Rollins and H. Will. 2015. The Economics of Ecological Restoration and Hazardous Fuel Reduction Treatments in the Ponderosa Pine Forest Ecosystem. In review, *Forest Science*.

•Kobayashi, M., K. Rollins, and M.H. Taylor. 2014. "Optimal Livestock Management on Sagebrush Rangeland with Ecological Thresholds, Wildfire, and Invasive Plants", *Land Economics* 90 (4).

•Weltz, M.A., K. Spaeth, M. Taylor, K. Rollins, F. Pierson, L. Jolley, M. Nearing, and S.K. Nouwakpo. 2014. Cheatgrass Invasion and Woody Species Encroachment in the Great Basin: Benefit of Conservation. *Journal of Soil and Water Conservation*. 69(2).

•Taylor, M., K. Rollins, M. Kobayashi, and R. Tausch. 2013. "The Economics of Fuel Management: Wildfire, Invasive Plants, and the Evolution of Sagebrush Rangelands in the Western United States", *Journal of Environmental Management* 126: 157-173.

•James, J.J., R. Sheley, T. Erickson, K. Rollins, M.H. Taylor, J. Aronson, and K.W. Dixon. 2013. "A Systems Approach to Restoring Degraded Drylands", Applied Ecology 50(3): 730-739. (Editor’s Choice Award)

•Kim, Y., W. Covington, P. Ervin, R. Fitch, E. Kalies, D. Rideout, K. Rollins, A. Sanchez-Meader, M. Taylor, W. Wu, J. Yoder. 2013. The Efficacy of hazardous fuel treatments: A rapid assessment of the economic and ecologic consequences of alternative hazardous fuel treatments. Ecological Restoration Institute, Northern Arizona University. 28 pp. http://library.eri.nau.edu/gsdl/collect/erilibra/index/assoc/D2013004.dir/doc.pdf

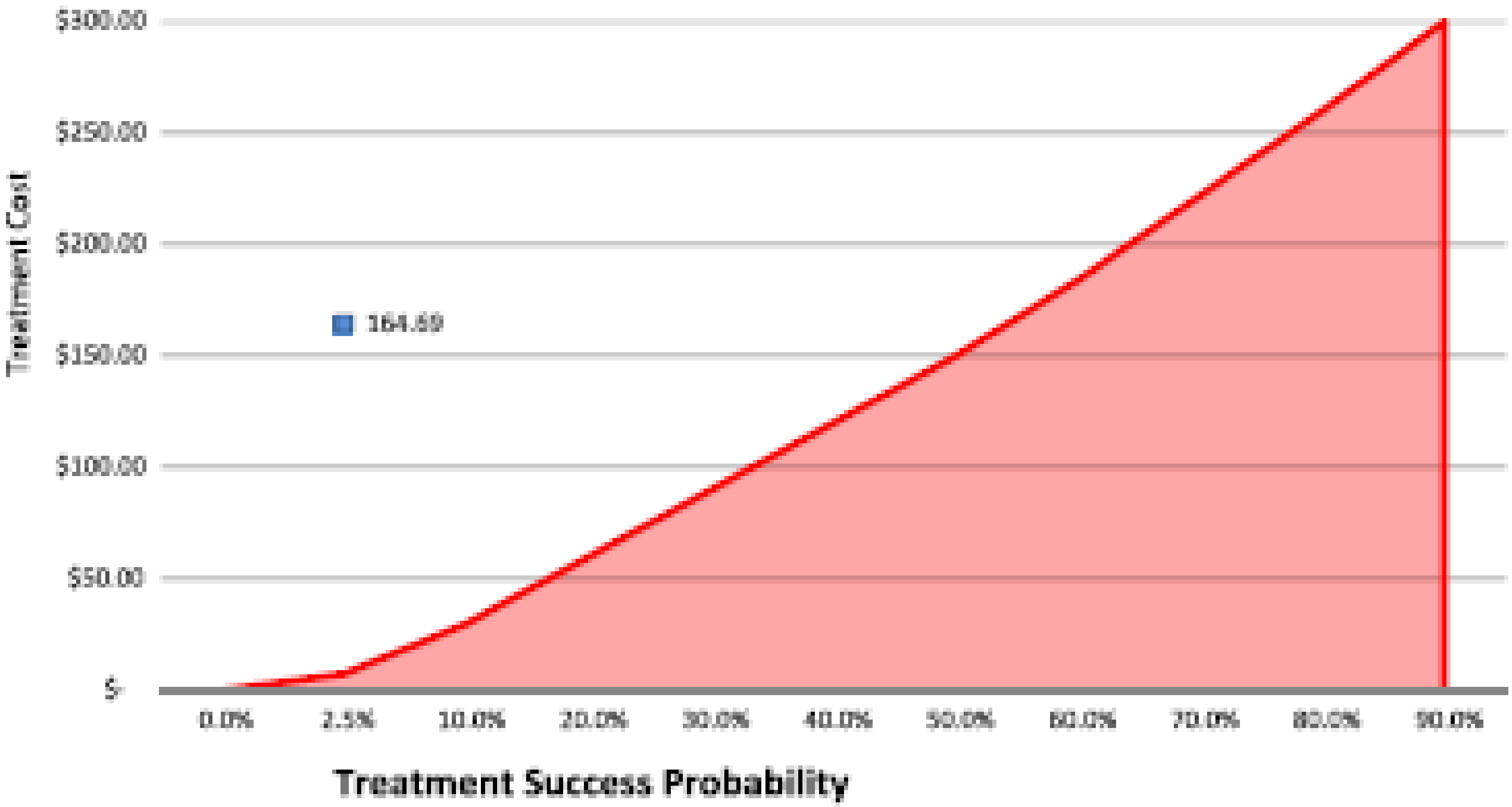
•Taylor, M. and K. Rollins. 2012. "Using Ecological Models to Coordinate Valuation of Ecological Change on Western Rangelands for ex post Application to Policy Analysis", *Western Economics Forum* 11(1):13-2.

•Taylor, M. and K. Rollins. 2012. "The Economics of Ecologically Based Invasive Plant Management on High Desert Rangelands", *Rangelands* 34(6): 48-52.

•Kobayashi, M., K. Rollins, and M.D.R. Evans. 2010. "Sensitivity of WTP Estimates to Definition of 'Yes': Reinterpreting Expressed Response Intensity”, *Agricultural and Resource Economics Review* 39(1):37-55.

Basis of a new JFSP/BLM/DOI Sponsored Research Project (2014-17):

•Evaluating the Economic Returns of Fuel Treatments at Multiple Spatial Scales: Accounting for Treatment, Timing and Ecological Conditions, Kimberly Rollins (UNR), Michael Taylor (UNR) and Andrew Joel Sanchez Meador (ERI at NAU)



$300.00
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Treatment Cost
164.69
0.0%
2.5%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
Treatment Success Probability

Fuel and Restoration Treatments: Present Valued Net Benefits

$$\mathrm{NPV}_m = \sum_{t=1}^{200} \frac{1}{(1+r)^t} \left(P_{t,m}^{\mathrm{NT}} \mathrm{WC}_{t,m}^{\mathrm{NT}} \right) - \sum_{t=1}^{200} \frac{1}{(1+r)^t} \left(P_{t,m}^{T} \mathrm{WC}_{t,m}^{T} + T_{t,m}^{T} \mathrm{TC}_{t,m}^{T} \right)$$

Expected values calculated from simulation with stochastic parameters run 10,000 times:

$$E[\mathrm{NPV}] = \sum_{m=1}^{10{,}000} \mathrm{NPV}_m.$$