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

State Variables Year t
Ecological State: $S_{t,m}^R$, R=T,NT
Years in State $S_{t,m}^R$: $s_{t,m}^R$, R=T,NT

No Treatment

- Fire ($P_{t,m}^{NT} = 1$)
  - Wildfire Suppression Cost, no Treatment: $P_{t,m}^{NT} \times WC_{t,m}^{NT}$

- No Fire ($P_{t,m}^{NT} = 0$)

Treatment

- Fire ($P_{t,m}^T = 1$)
  - Treatment Cost: $T_{t,m}^T \times TC_{t,m}^T$

- No Fire ($P_{t,m}^T = 0$)

  No Treatment ($T_{t,m} = 0$)

  Treatment ($T_{t,m} = 1$)

    Treatment Fail ($Q_{t,m}^T = 0$)

    Treatment Success ($Q_{t,m}^T = 1$)

Net Benefits Year t:

$$\left( P_{t,m}^{NT} \times WC_{t,m}^{NT} \right) - \left( P_{t,m}^T \times WC_{t,m}^T + T_{t,m}^T \times TC_{t,m}^T \right)$$
Develop and parameterize for applicable ecological models

Wyoming Sagebrush System - WSS

Mountain Big Sagebrush System - MBS
Wyoming Sagebrush System

<table>
<thead>
<tr>
<th>Wyoming sagebrush steppe results ($ per acre; 2010 dollars).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial ecological state</td>
</tr>
<tr>
<td>WSS-1 Shrubs and perennial grasses</td>
</tr>
<tr>
<td>WSS-2 Decadent sagebrush with annual grasses</td>
</tr>
<tr>
<td>WSS-3 Invasive annual grass dominated</td>
</tr>
<tr>
<td>Mean number of wildfires — no treatment</td>
</tr>
<tr>
<td>Mean number of wildfires — with treatment</td>
</tr>
<tr>
<td>Mean total suppression costs (NPV) — no treatment</td>
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<td>Mean total suppression costs (NPV) — with treatment</td>
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<tr>
<td>Mean wildfire suppression costs savings (NPV)</td>
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<tr>
<td>Mean number of treatments</td>
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<tr>
<td>Mean number of successful treatments</td>
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<tr>
<td>Mean treatment costs (NPV)</td>
</tr>
<tr>
<td>Mean wildfire suppression costs savings net of treatment costs (NPV)</td>
</tr>
<tr>
<td>Mean benefit–cost ratio (NPV)</td>
</tr>
<tr>
<td>a 5th and 95th percentiles.</td>
</tr>
<tr>
<td>‘Final State’ is the final state of the system (WSS-1, WSS-2, or WSS-3) after 200 years.</td>
</tr>
</tbody>
</table>
Mountain Big Sagebrush

<table>
<thead>
<tr>
<th>Initial ecological state</th>
<th>MBS-1a</th>
<th>MBS-1b</th>
<th>MBS-2</th>
<th>MBS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shrubs and perennial grasses</td>
<td>Pinyon-juniper, shrubs and perennial grasses</td>
<td>Closed-canopy pinyon-juniper with annual grass</td>
<td>Invasive annual grass dominated</td>
</tr>
<tr>
<td>Mean number of wildfires — no treatment</td>
<td>6.6 (1, 18)</td>
<td>14.7 (0, 26)</td>
<td>15.0 (0, 26)</td>
<td>22.0 (15, 29)</td>
</tr>
<tr>
<td>Mean number of wildfires — with treatment</td>
<td>3.4 (1, 7)</td>
<td>34 (1, 7)</td>
<td>12.8 (1, 28)</td>
<td>7.5 (2, 17)</td>
</tr>
<tr>
<td>Mean total suppression costs (NPV) — no treatment</td>
<td>$273.4 ($1, 11, $770.2)</td>
<td>$560.7 ($0, $1,903.3)</td>
<td>$576.2 ($0, $1,937.4)</td>
<td>$1,447.7 ($352.5, $2,883.6)</td>
</tr>
<tr>
<td>Mean total suppression costs (NPV) — with treatment</td>
<td>$1,643 ($1, 13, $539.0)</td>
<td>$1,582 ($13, $498.2)</td>
<td>$793.0 ($5.9, $2,443.6)</td>
<td>$894.1 ($28.5, $2,381.1)</td>
</tr>
<tr>
<td>Mean wildfire suppression costs savings (NPV)</td>
<td>$109.1 ($252.6, $521.2)</td>
<td>$402.5 ($80.9, $1,575.9)</td>
<td>$216.8 ($188.5, $1,83.1)</td>
<td>$553.6 ($7.5, $1719.4)</td>
</tr>
<tr>
<td>Mean number of treatments</td>
<td>1.2 (1, 2)</td>
<td>1.1 (1, 2)</td>
<td>1.02 (1, 1)</td>
<td>0.97 (3, 119)</td>
</tr>
<tr>
<td>Mean number of successful treatments</td>
<td>1.2 (1, 2)</td>
<td>1.1 (1, 2)</td>
<td>1.0 (1, 1)</td>
<td>1.0 (1, 1)</td>
</tr>
<tr>
<td>Mean treatment costs (NPV)</td>
<td>$193 ($19.5, $19.9)</td>
<td>$447 ($4.55, $4.57)</td>
<td>$202.5 ($205.4, $205.4)</td>
<td>$2,886.1 ($465.8, $4958.7)</td>
</tr>
<tr>
<td>Final state — no treatmenta (MSS-1a, -1b, -2, -3)</td>
<td>5328, 394, 719, 3559</td>
<td>171, 6, 759, 9064</td>
<td>0, 0, 769, 9,231</td>
<td>9182, 599, 14, 205</td>
</tr>
<tr>
<td>Final state — with treatment (MSS-1a, -1b, -2, -3)</td>
<td>10,000, 0, 0, 0</td>
<td>9462, 538, 0, 0</td>
<td>4455.2, 5,258</td>
<td>9182, 599, 14, 205</td>
</tr>
<tr>
<td>Mean wildfire suppression costs savings net of treatment costs (NPV)</td>
<td>$89.8 (-$272.1, $502.7)</td>
<td>$579 (-$12,64, $1,530.4)</td>
<td>$419.3 ($2,090.7, $977.7)</td>
<td>$2,332.5 ($-492.78, $937.0)</td>
</tr>
<tr>
<td>Mean benefit-cost ratio (NPV)</td>
<td>5.7</td>
<td>9.0</td>
<td>1.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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
Sensitivity Analysis for Uncertainty of Ecological Parameters

<table>
<thead>
<tr>
<th>Initial state — WSS-1</th>
<th>Fire return interval in WSS-2 (years)</th>
<th>75</th>
<th>50</th>
<th>25</th>
<th>15</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total suppression costs (NPV) — no treatment</td>
<td>$349.80</td>
<td>$463.90</td>
<td>$662.00</td>
<td>$798.20</td>
<td>$1013.00</td>
<td></td>
</tr>
<tr>
<td>Mean total suppression costs (NPV) — with treatment</td>
<td>$56.00</td>
<td>$59.10</td>
<td>$57.30</td>
<td>$57.70</td>
<td>$59.20</td>
<td></td>
</tr>
<tr>
<td>Mean treatment costs (NPV)</td>
<td>$22.10</td>
<td>$22.09</td>
<td>$22.08</td>
<td>$22.08</td>
<td>$22.08</td>
<td></td>
</tr>
<tr>
<td>Mean wildfire suppression costs savings net of treatment costs (NPV)</td>
<td>$271.70</td>
<td>$382.70</td>
<td>$582.50</td>
<td>$718.50</td>
<td>$931.70</td>
<td></td>
</tr>
<tr>
<td>Mean benefit–cost ratio (NPV)</td>
<td>13.3</td>
<td>18.3</td>
<td>27.4</td>
<td>33.5</td>
<td>43.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial state — WSS-2</th>
<th>Fire return interval in WSS-2 (years)</th>
<th>75</th>
<th>50</th>
<th>25</th>
<th>15</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean total suppression costs (NPV) — no treatment</td>
<td>$364.20</td>
<td>$480.50</td>
<td>$686.50</td>
<td>$832.30</td>
<td>$1051.40</td>
<td></td>
</tr>
<tr>
<td>Mean total suppression costs (NPV) — with treatment</td>
<td>$231.40</td>
<td>$232.90</td>
<td>$258.80</td>
<td>$278.00</td>
<td>$415.00</td>
<td></td>
</tr>
<tr>
<td>Mean treatment costs (NPV)</td>
<td>$204.40</td>
<td>$202.92</td>
<td>$198.16</td>
<td>$193.36</td>
<td>$164.69</td>
<td></td>
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<tr>
<td>Mean wildfire suppression costs savings net of treatment costs (NPV)</td>
<td>$71.60</td>
<td>$44.60</td>
<td>$229.50</td>
<td>$360.90</td>
<td>$471.70</td>
<td></td>
</tr>
<tr>
<td>Mean benefit–cost ratio (NPV)</td>
<td>0.7</td>
<td>1.2</td>
<td>2.2</td>
<td>2.9</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

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 state 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

WTP for Range Land Treatment $35

To Prevent Further Loss $42

Male $41

New Resident $29

30<age<60 $31

30>age>60 $12

Long-time Resident $44

30<age<60 $53

30>age>60 $24

Female $45

New Resident $31

30<age<60 $43

30>age>60 $11

Long-time Resident $55

30<age<60 $64

30>age>60 $40

To Rehabilitate $26
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:


• 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)
Fuel and Restoration Treatments: Present Valued Net Benefits

\[ NPV_m = \sum_{t=1}^{200} \frac{1}{(1+r)^t} \left( P_{t,m}^{NT} W_{t,m}^{NT} - \sum_{t=1}^{200} \frac{1}{(1+r)^t} \left( P_{t,m}^{T} W_{t,m}^{T} + T_{t,m}^{T} T_{t,m}^{T} \right) \right) \]

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

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