

Integrating Ecological and Economic Models in the Analysis of Ecosystem Services and Biodiversity Conservation

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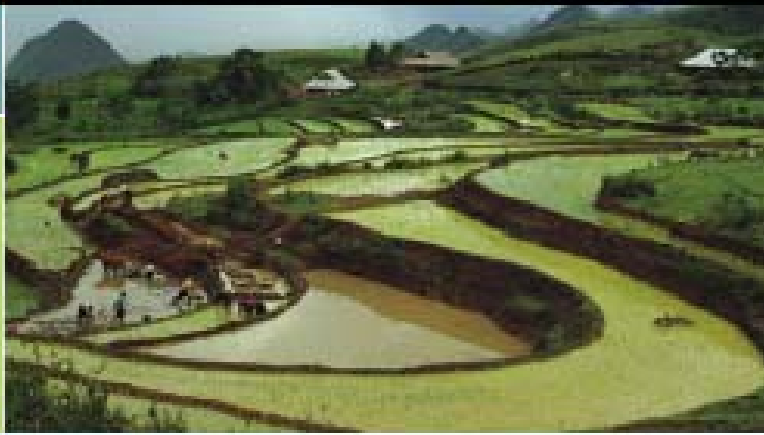
Beijer Institute of Ecological Economics

Motivation for an evaluation of ecosystem services and biodiversity

- Ecosystems and biodiversity provide a wide array of goods and services of value to people
- Provision of ecosystem services often is not factored into important decisions that affect ecosystems
- Distortions in decision-making damage the provision of ecosystem services making human society and the environment poorer

Motivation for an evaluation of ecosystem services and biodiversity

- Individuals and firms are not rewarded for protecting environmental quality necessary for sustained provision of ecosystem services and conserving biodiversity
- Unless society fixes this imbalance and begins to properly account for the value of nature we are unlikely to see fundamental change necessary to sustain ecosystem services and conserve biodiversity



ECOSYSTEMS AND HUMAN WELL-BEING

Synthesis



MILLENNIUM ECOSYSTEM ASSESSMENT

The MA:
ecosystems and
human well-being
are linked

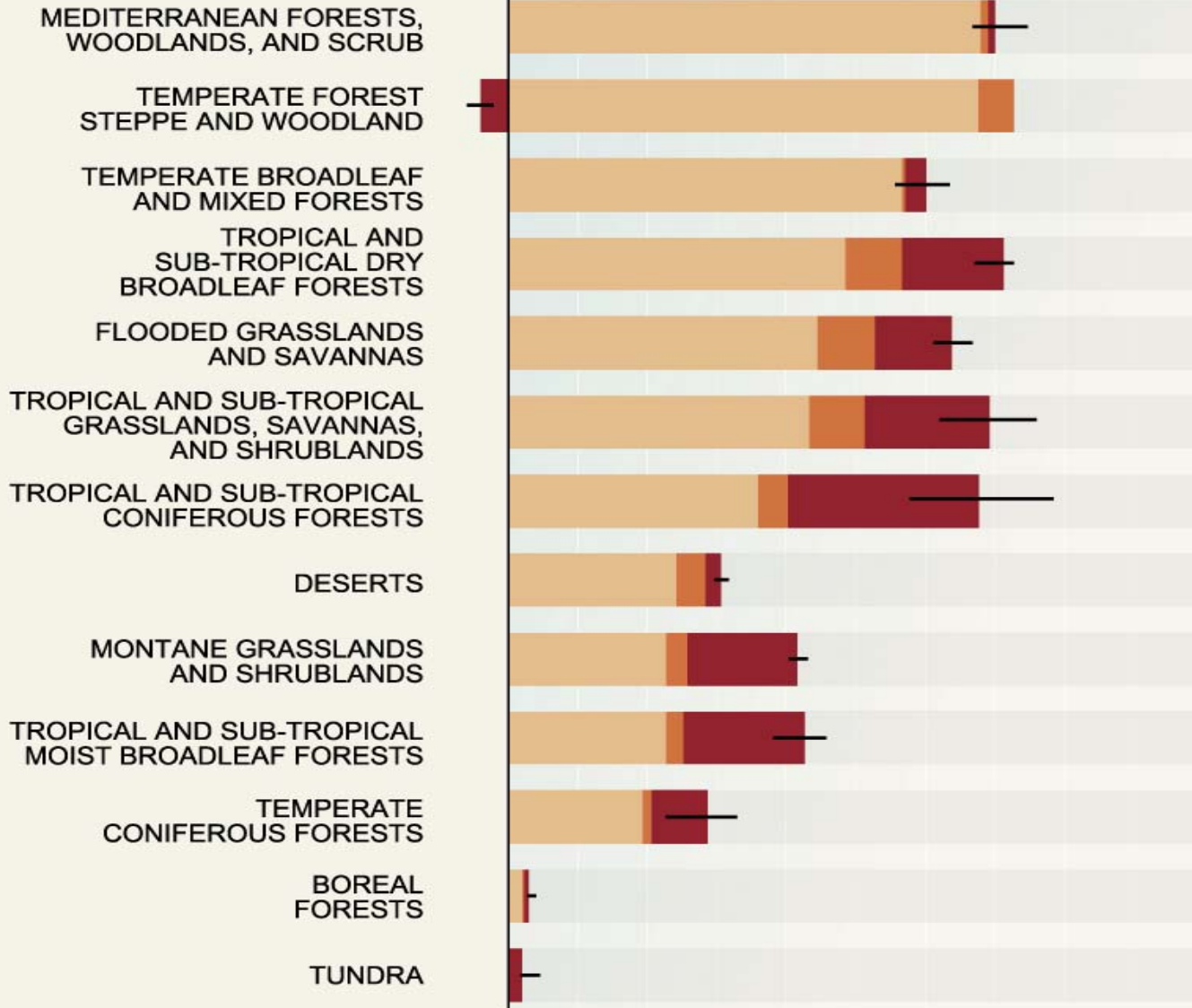
Ecosystem services:
ecosystems provide
vital goods and
services of value to
people

Linkage of ecosystems and human welfare

1. Human actions cause changes in ecosystems and biodiversity
 2. Changes in ecosystems and biodiversity lead to changes in human well-being
- The MA
 - Lots of information on (1)
 - Did not provide conclusive evidence on (2)

Fraction of potential area converted

- 10 0 10 20 30 40 50 60 70 80 90 100 %



Conversion of original biomes

Loss by 1950
 Loss between 1950 and 1990
 Projected loss by 2050^b

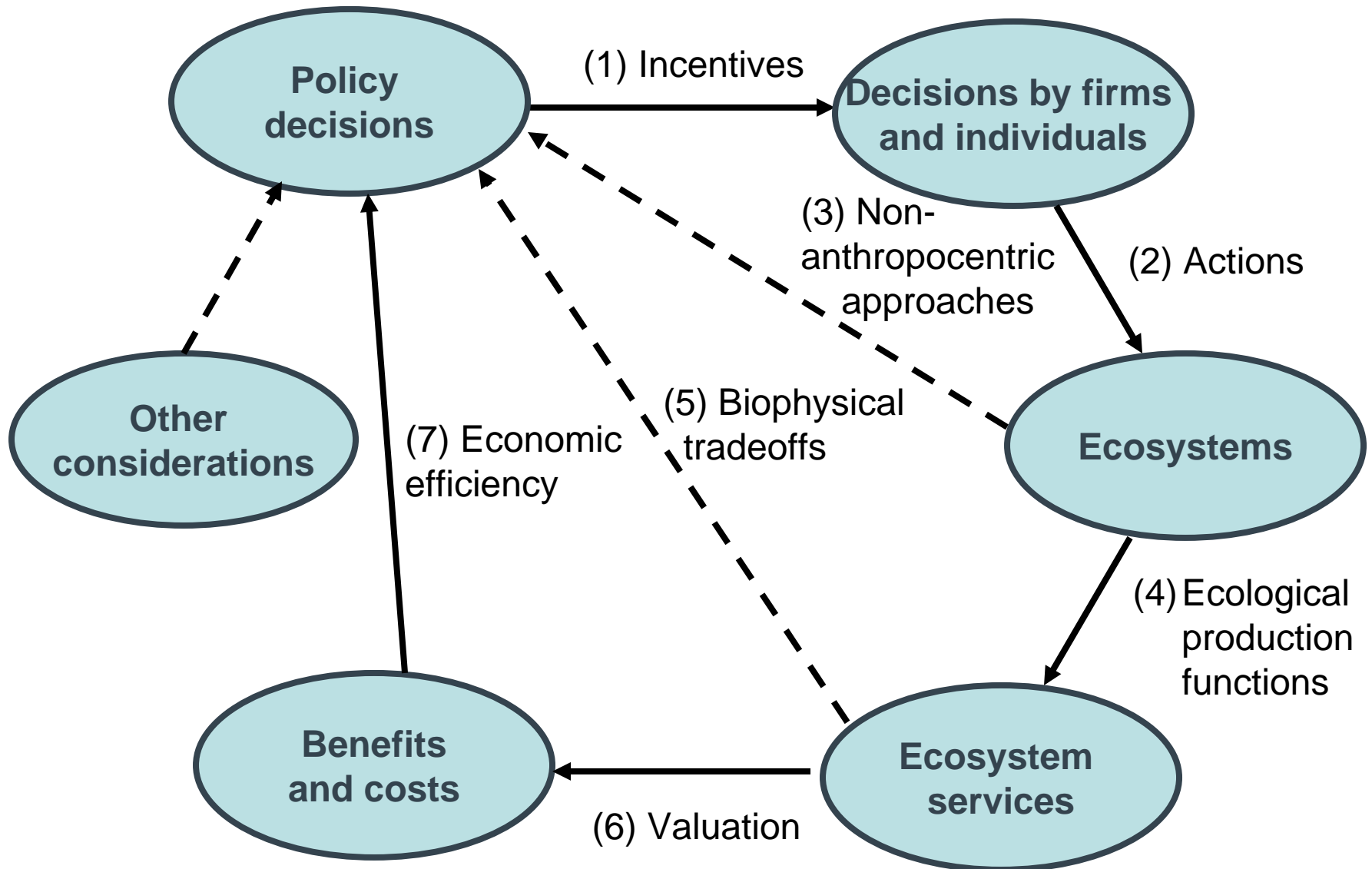
The MA gap

- Relative lack of credible quantitative evidence on the link from ecosystem structure and function to human well-being
- Research agenda:
- Demonstrate this link and show the value of nature
- Policy/institutions: incentives to conserve nature in order to maximize net benefits

Tasks to mainstream the value of nature in everyday decisions

1. Improve understanding of the likely consequences of human actions on ecosystems
2. Improve understanding of the impacts of ecosystem change on ecosystem services and biodiversity
3. Improve understanding of the value of these impacts on human welfare
4. Tie understanding of impacts and values to incentives
 - Everyday decisions of individuals and firms
 - Societal policy choices

**Figure 1: Integrating ecology and economics:
A research agenda for ecosystem services and biodiversity conservation**

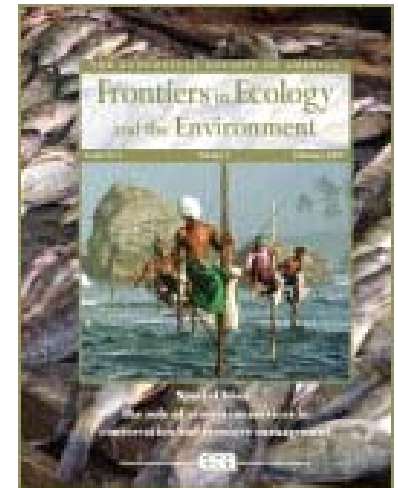


The Natural Capital Project: Mainstreaming ecosystem services



“InVEST”
Integrated Valuation of Ecosystem
Services and Tradeoffs

<http://www.naturalcapitalproject.org/InVEST.html>



Feb 2009 Issue

Outline of rest of talk

- Provide three examples of integrated ecological and economic models in the analysis of ecosystem services and biodiversity conservation
 1. Where to put things? Spatial land management with biological and economic objectives
 2. Modeling multiple ecosystem services and tradeoffs at landscape scales
 3. The efficiency of voluntary incentive policies for preventing biodiversity loss

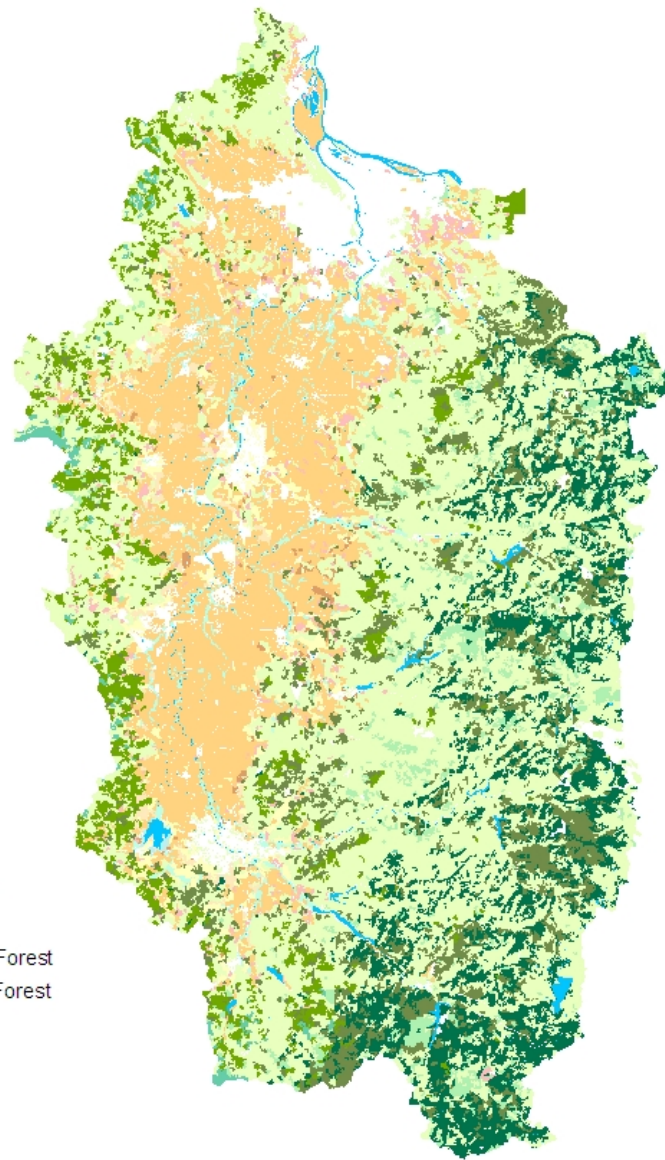
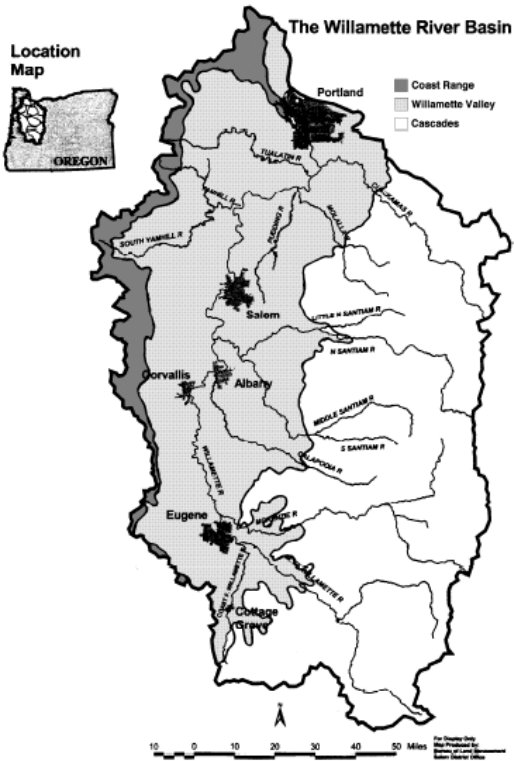
Where to put things? Spatial land management with biological and economic objectives



Polasky et al. 2008. *Biological Conservation* 141(6): 1505-1524.

Coauthors

- Erik Nelson (economist, spatial analyst), University of Minnesota
- Jeff Camm (operations research), University of Cincinnati
- Blair Csuti (conservation biology), Oregon Zoo
- Paul Fackler (economist), North Carolina State University
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- Jeff Arthur (operations research), Oregon State University
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- Jimmy Kagan (conservation biologist), Oregon State University and Oregon Natural Heritage Information Center
- Claire Montgomery (economist), Oregon State University
- Tony Starfield (systems modeler), University of Minnesota
- Claudine Tobalske (spatial data base analyst), Oregon State University and Oregon Natural Heritage Information Center



Willamette Basin

Current Land Cover

- Floating Vegetation
- Riparian Forest
- Low Structure Agriculture
- Meadow
- Deciduous, Mixed Close Forest
- Deciduous, Mixed Open Forest
- Oak Hardwood
- Scrub-Shrub
- Shrub-Riparian
- Conifer, 21-40 Years
- Conifer, 41-80 Years
- Conifer, 81-200 Years
- Conifer, 200 Plus Years
- Water

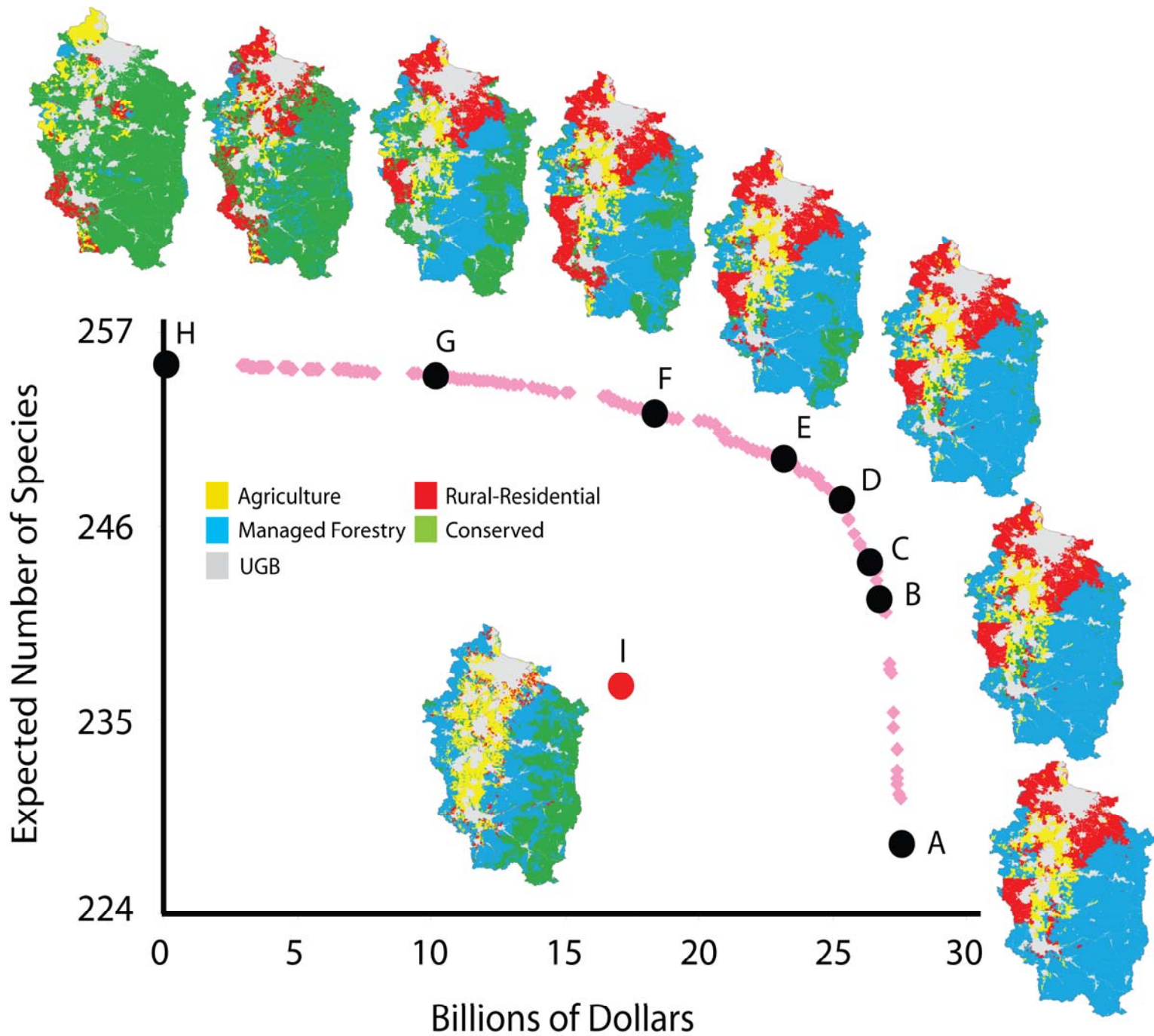
Polasky et al.
Biological Conservation
2008

Biological model: effect of land use/land cover of species persistence

- Predict a land use pattern's ability to support viable populations of a large set of species
- Each species' appraisal of a land use pattern depends on three species-specific traits:
 - habitat compatibility (which includes geographic range, habitat type and special features like whether there is water access)
 - the amount of habitat required for a breeding pair
 - dispersal ability between suitable patches of habitat

Economic model: effect of land use on value of commodities produced

- Predict the present value of rents for a parcel generated by a land use of the parcel and the characteristics of the parcel
- The economic return for a land use pattern is the sum of the present value of rents over all of the parcels patches of habitat



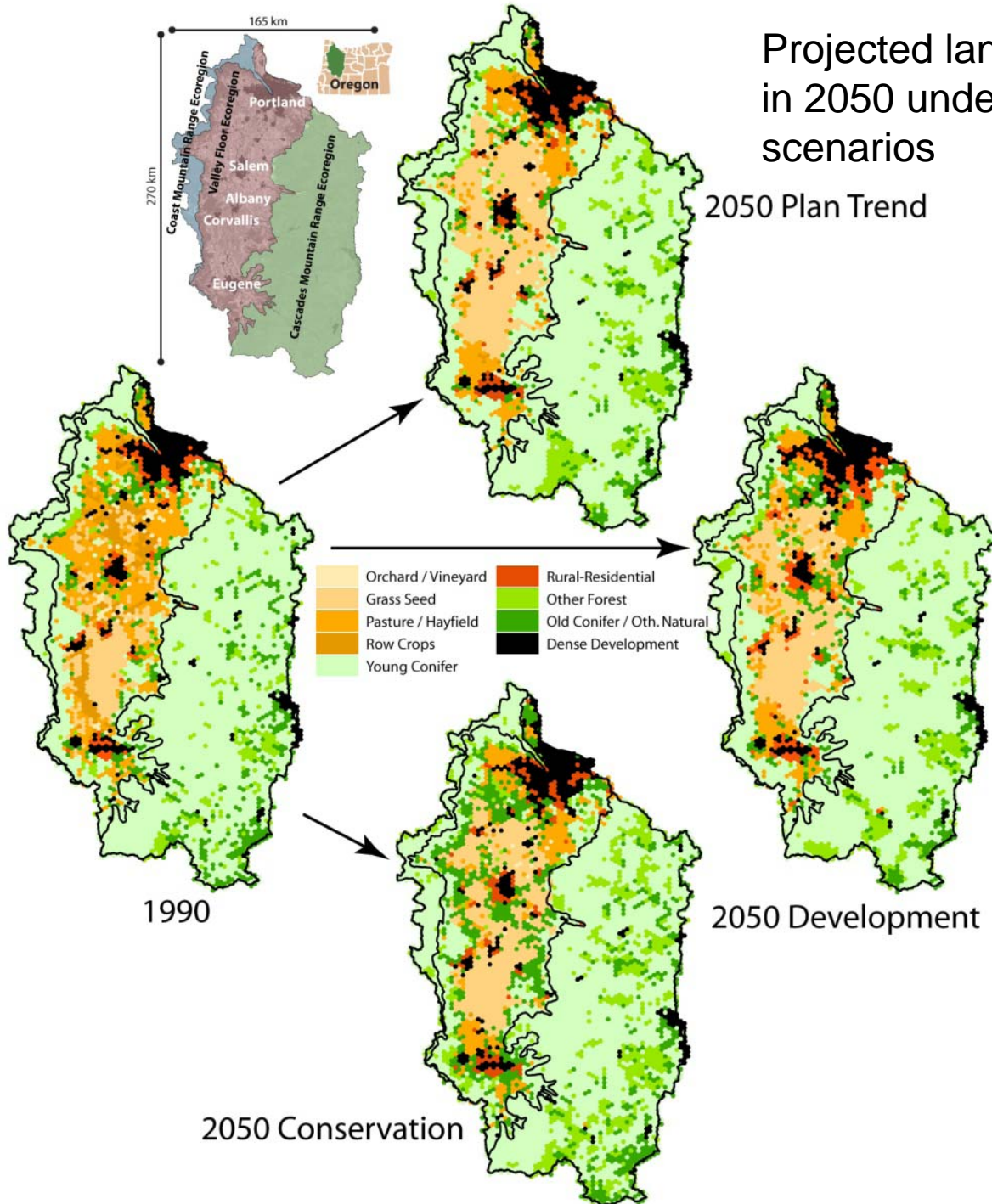
Modeling multiple ecosystem services and tradeoffs at landscape scales



Nelson, et al. 2009. *Frontiers in Ecology and the Environment* 7(1): 4–11

Coauthors

- Erik Nelson, Natural Capital Project, Stanford University
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- M. Rebecca Shaw, The Nature Conservancy – California



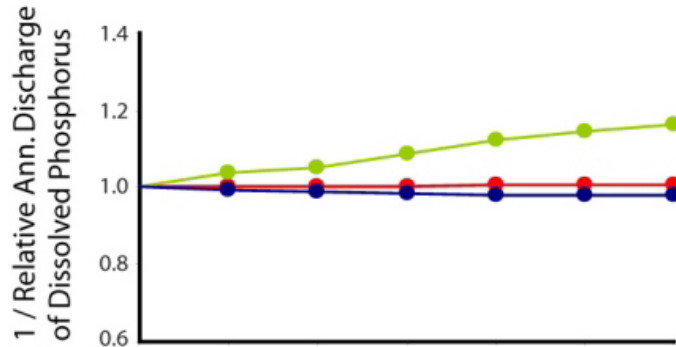
Projected land use change in 2050 under the three scenarios

Modeling multiple services under alternative scenarios

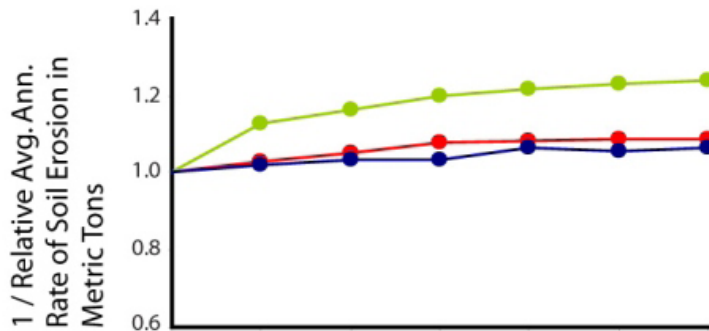
- Model outputs: service provision and biodiversity
 - Water quality (reduced phosphorus loadings)
 - Storm peak mitigation (flooding reduction)
 - Soil conservation (sediment retention)
 - Climate stabilization (carbon sequestration)
 - Biodiversity (species conservation)
 - Market returns to landowners (agricultural crop production, timber harvest and housing values)

Outputs through time

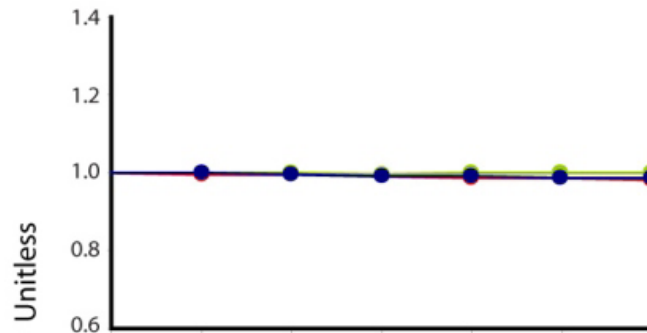
Water Quality



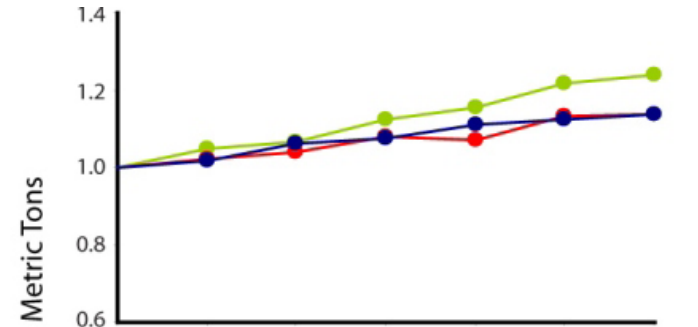
Potential Soil Conservation



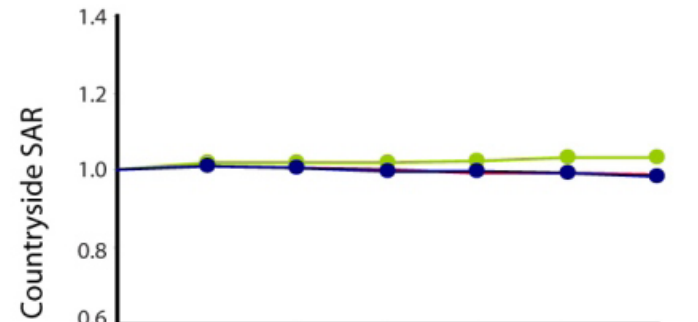
Storm Peak Management



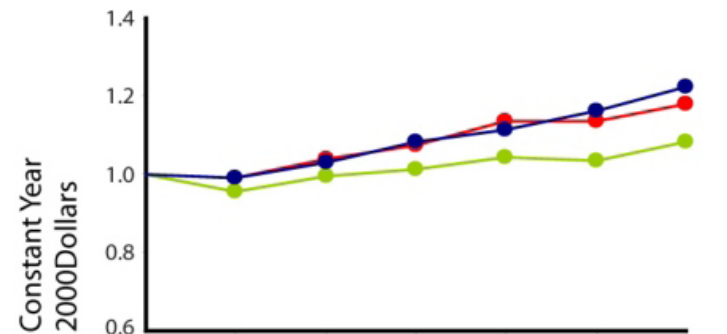
Carbon Sequestration

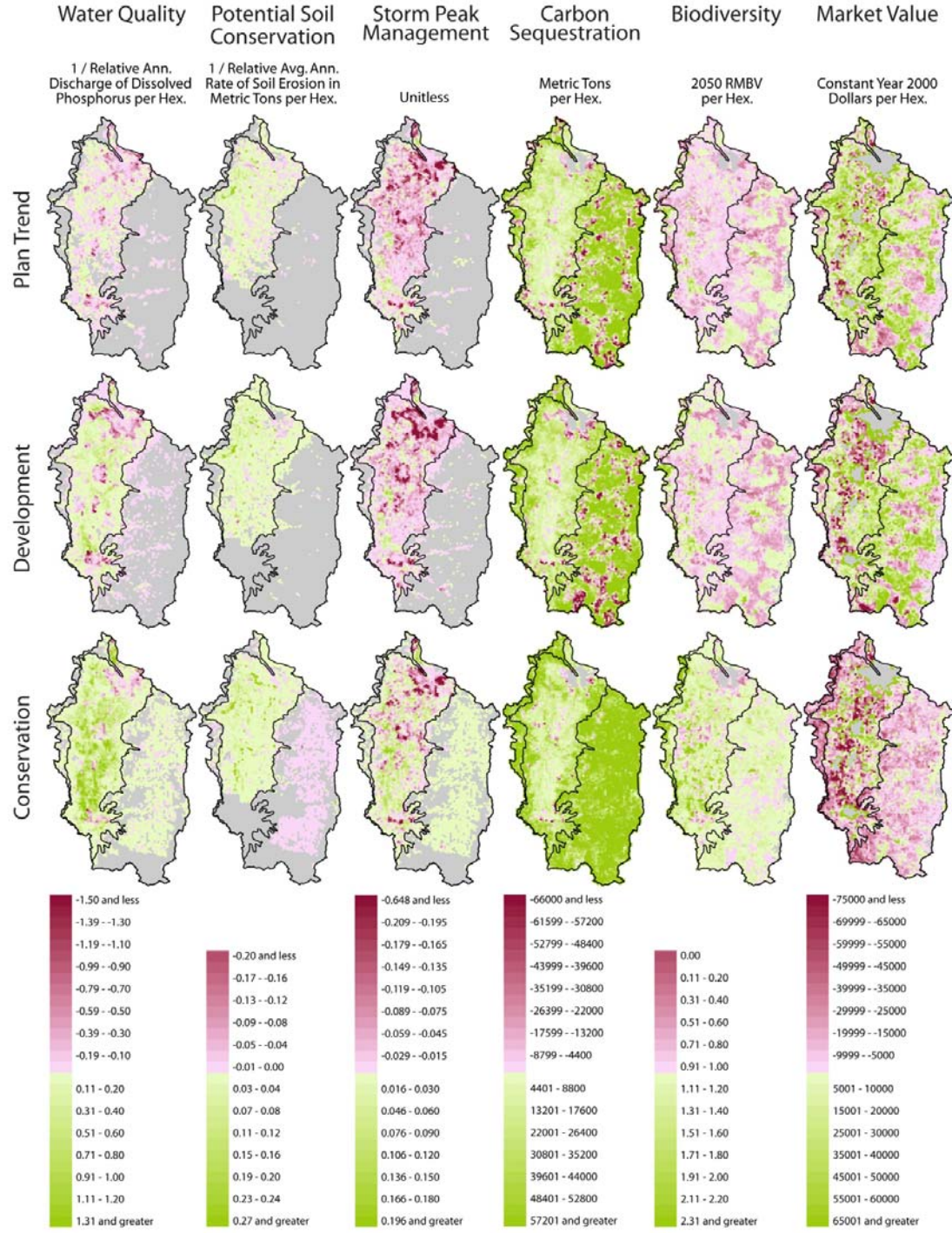


Biodiversity

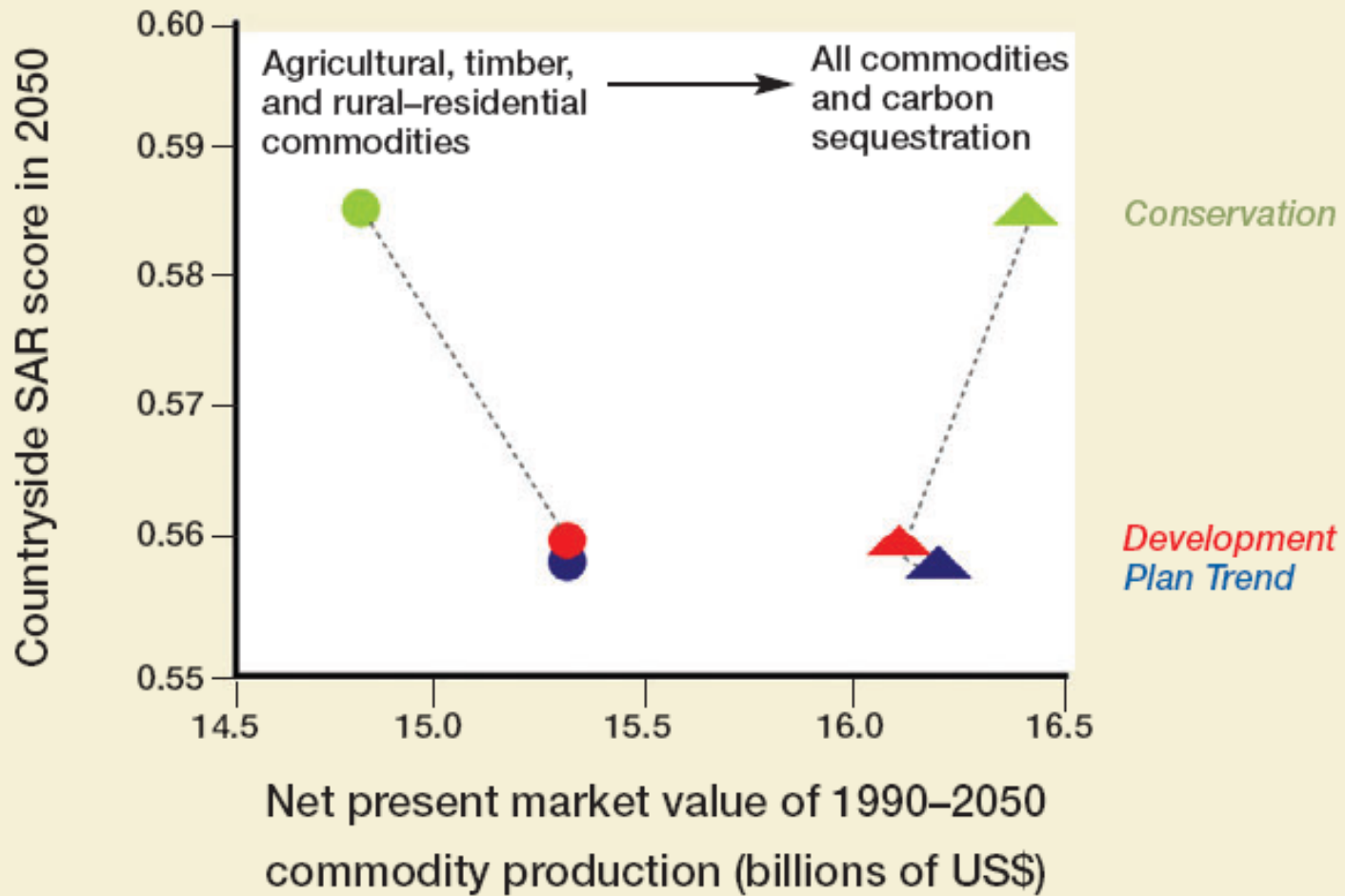


Market Value





Maps of change in service provision



The efficiency of voluntary incentive policies for preventing biodiversity loss



Lewis et al. 2008. In review.

Coauthors

- David Lewis (University of Wisconsin)
- Erik Nelson (Natural Capital Project, Stanford University)
- Andrew Plantinga (Oregon State University)

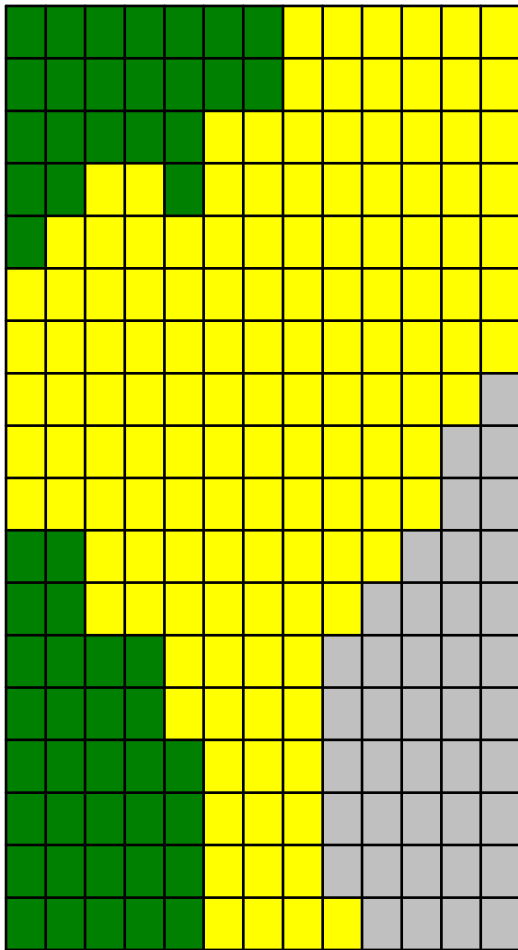
Conservation and private land

- Voluntary incentives for species conservation on private lands
 - Conservation Reserve Program
 - Wildlife Habitat Incentives Program (WHIP)
 - Conservation easements
 - Conservation banking under the Endangered Species Act
- Basic question: can voluntary incentives achieve efficient spatial allocations of private land use?

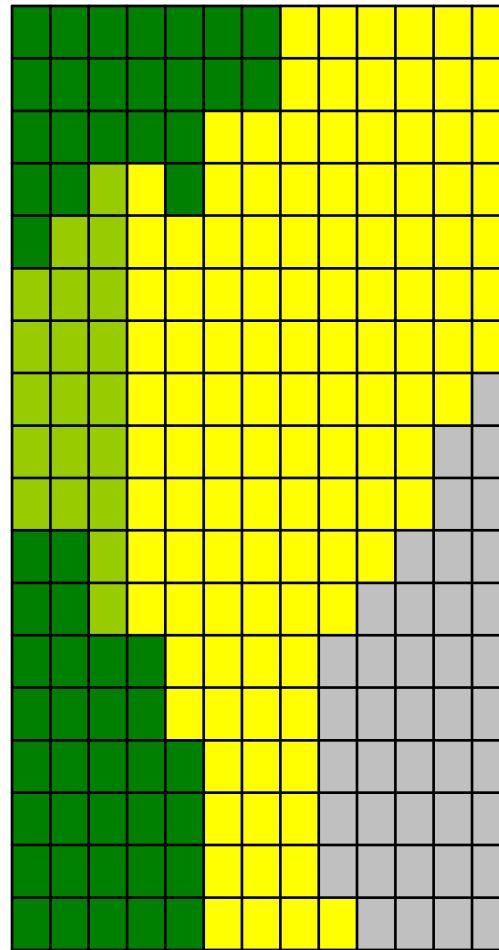
The spatial problem

Coordinated

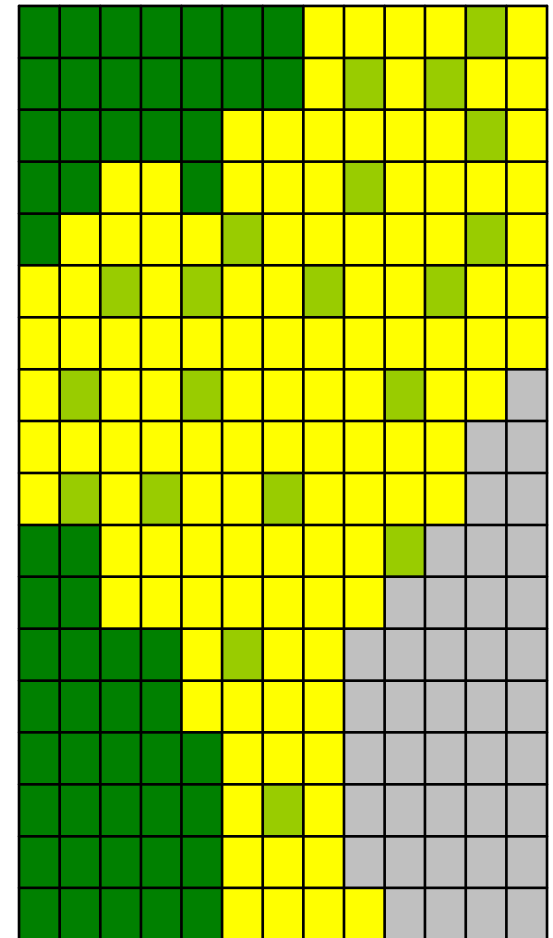
Uncoordinated



Initial landscape



Landscape with
conservation land



Landscape with
conservation land

This paper

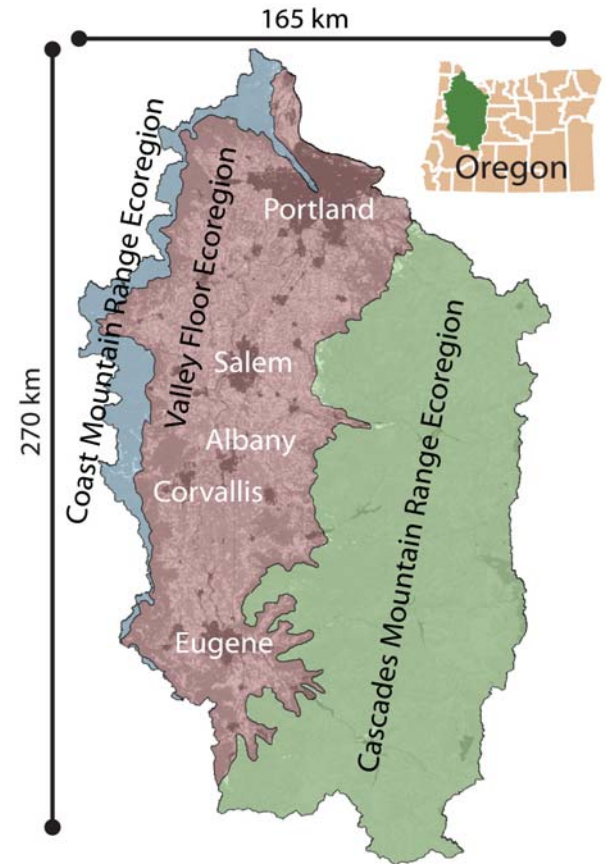
- Two outstanding questions
 - On actual landscapes, how efficient are voluntary incentive-based policies?
 - How important is biological and economic information for improving the efficiency of policies?

This paper

- Integrating earlier work
 - Econometric land-use models
 - Lubowski, Plantinga, and Stavins JEEM 2006
 - Spatially-explicit landscape simulations of incentive-based policies
 - Lewis and Plantinga Land Econ 2007
 - Spatial management
 - Polasky, Nelson et al. Ecol Applications 2005
 - Polasky, Nelson, et al. Biol Cons 2008
 - Preliminary examination of incentive-based policies
 - Nelson, Polasky, Lewis, Plantinga, Lonsdorf, White, Bael, and Lawler PNAS 2008

Steps in the analysis

- 1) Simulate responses to voluntary incentives
 - Econometric model of land-use change
 - Use the econometric results to estimate parcel-level willingness-to-accept
 - Simulating the spatial pattern of conservation lands
- 2) Score the landscape for species conservation
- 3) Derive the optimal spatial arrangement of conservation lands
- 4) Application to the Willamette Basin
 - Species of “conservation concern” are modeled
 - A range of alternative voluntary incentive policies are considered
 - Comparison to the optimal planner’s solution



Econometric model of land-use change

- Random parameters logit model is estimated with data for Oregon and Washington west of the Cascade Crest
- Repeated plot-level data from the National Resources Inventory (15,356 plots at four points in time; 1982, 1987, 1992, 1997)
- Four major land uses (crops, pasture, forest, urban) are modeled, representing most of the privately owned land in the region
- Data on county average net revenues for all uses from Lubowski (2002) and plot-level land quality measures from the NRI
- Observed land-use changes are modeled in terms of annualized net returns from alternative uses

Estimation

- Separate models estimated for parcels starting in crops (3,504 pooled observations) and pasture (4,637 pooled observations)
- Four ending uses are crops, pasture, forest, urban
- Models are not estimated for parcels starting in forest and urban because few or no parcels change out of these uses

Specification of net returns

- For parcel i beginning in use j , the net return to choosing use k by the end of time period t is:

$$\underbrace{R_{ikt} - rC_{ijkt}}_{\text{parcel net return to use } k} = \underbrace{\alpha_{jk}}_{\text{alternative-specific constant}} + \underbrace{\sigma_{1jk} \omega_{1c(i)jk}}_{\text{county error component}} + \underbrace{\sigma_{2jk} \omega_{2ijk}}_{\text{parcel error component}} + \underbrace{\beta_{0jk} R_{c(i)kt} + \beta_{1jk} LCC_i R_{c(i)kt}}_{\text{county average net revenue adjusted for parcel land quality}} + \underbrace{\varepsilon_{ijkt}}_{\text{error term}}$$

Transition probabilities

- The probability that parcel i changes from use j to k during time period t is given by:

$$P_{ijkt} = F(\mathbf{R}_{c(i)t}, LCC_i, \boldsymbol{\omega}_{1c(i)j}, \boldsymbol{\omega}_{2ij}; \boldsymbol{\alpha}_j, \boldsymbol{\beta}_j, \boldsymbol{\sigma}_j)$$

- As with the WTA values, sets of transition probabilities are differentiated by starting use, county, and LCC

Maximum net return to a parcel

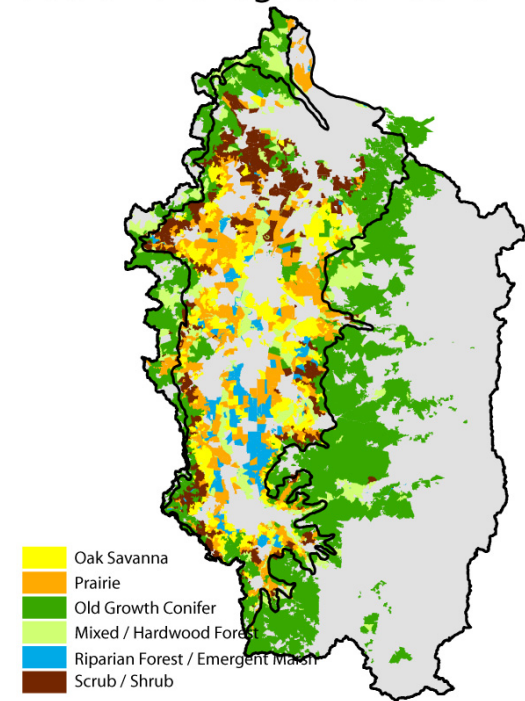
$$R_{ijt}^* = \frac{1}{\xi_j} \left(\ln \left[\sum_k \exp(\alpha_{jk} + \sigma_{1jk} \varpi_{1c(i)jk} + \sigma_{2jk} \varpi_{2ijk} + \beta_{0jk} R_{c(i)kt} + \beta_{1jk} LCC_i R_{c(i)kt}) \right] - \gamma \right) + v_{ijt}$$

- where v_{ijt} is distributed type I extreme value with scale parameter ξ_j and γ is Euler's constant
- The maximum net return on a parcel is a random variable with known distribution

Willingness to accept

- We assume that landowners are willing to accept the maximum net return from their parcel in exchange for returning their land to its native (pre-Euro-American settlement) cover
- WTA values are random and differentiated by starting use, county, and LCC values

Pre-Euroamerican Settlement Vegetation Cover

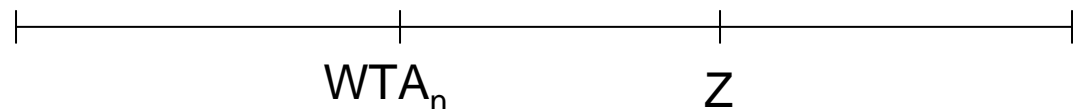


Native covers include prairie, emergent marsh, scrub/shrub, oak and other hardwoods, old-growth conifer, or riparian forest

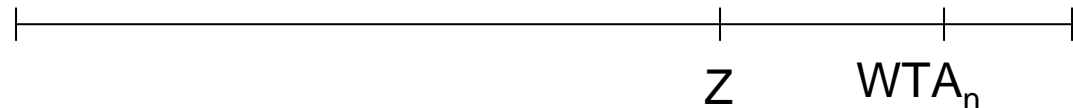
Simulating the spatial pattern of conservation

- Landowners are offered an annual per-acre payment Z
- For parcel n , we compute WTA_n by drawing values of all random variables.

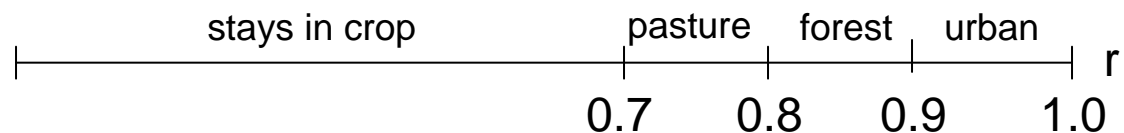
If $WTA_n < Z$, the parcel is conserved



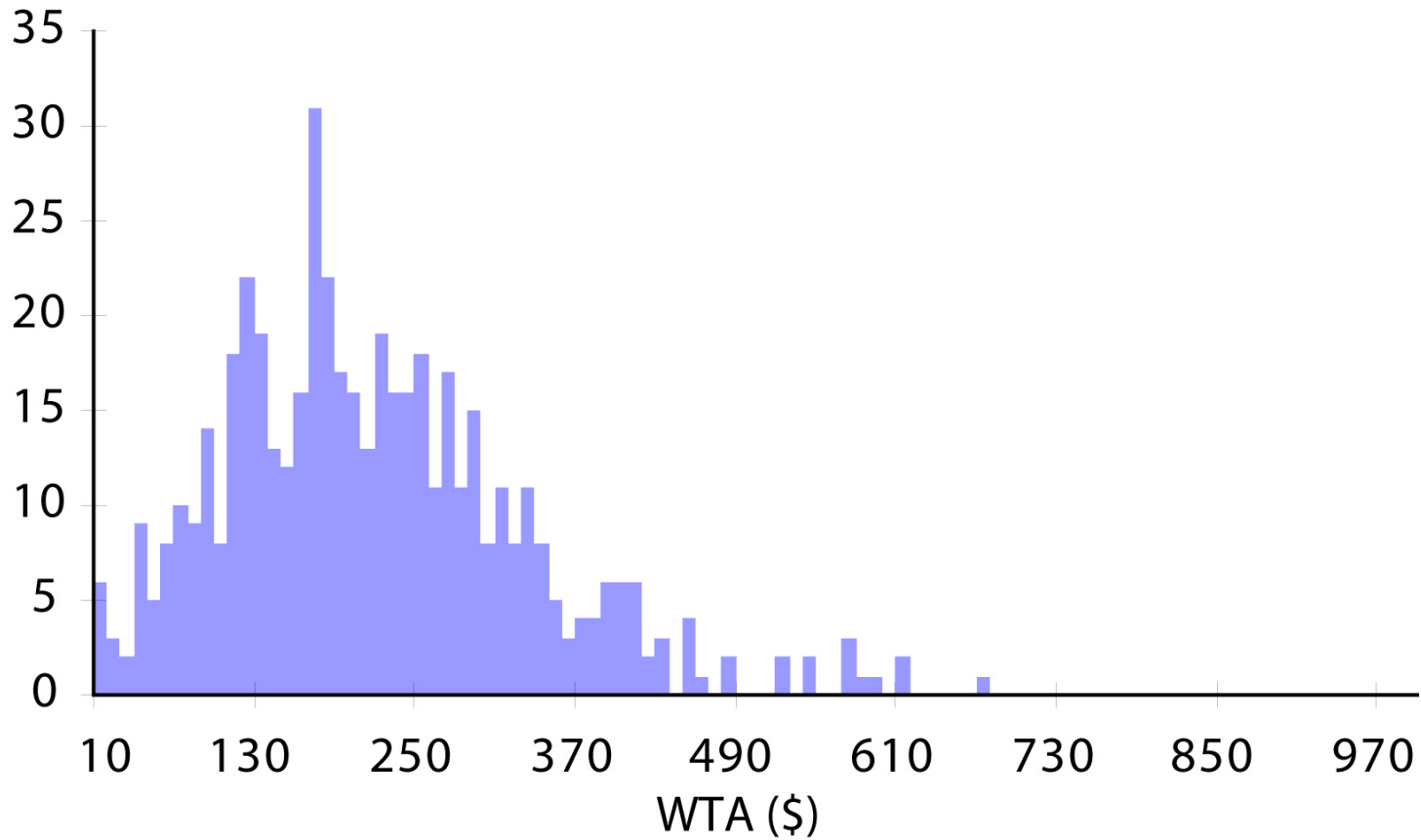
If $WTA_n > Z$, the parcel is not conserved and may remain in the same use or convert to an alternative use according to the transition probabilities



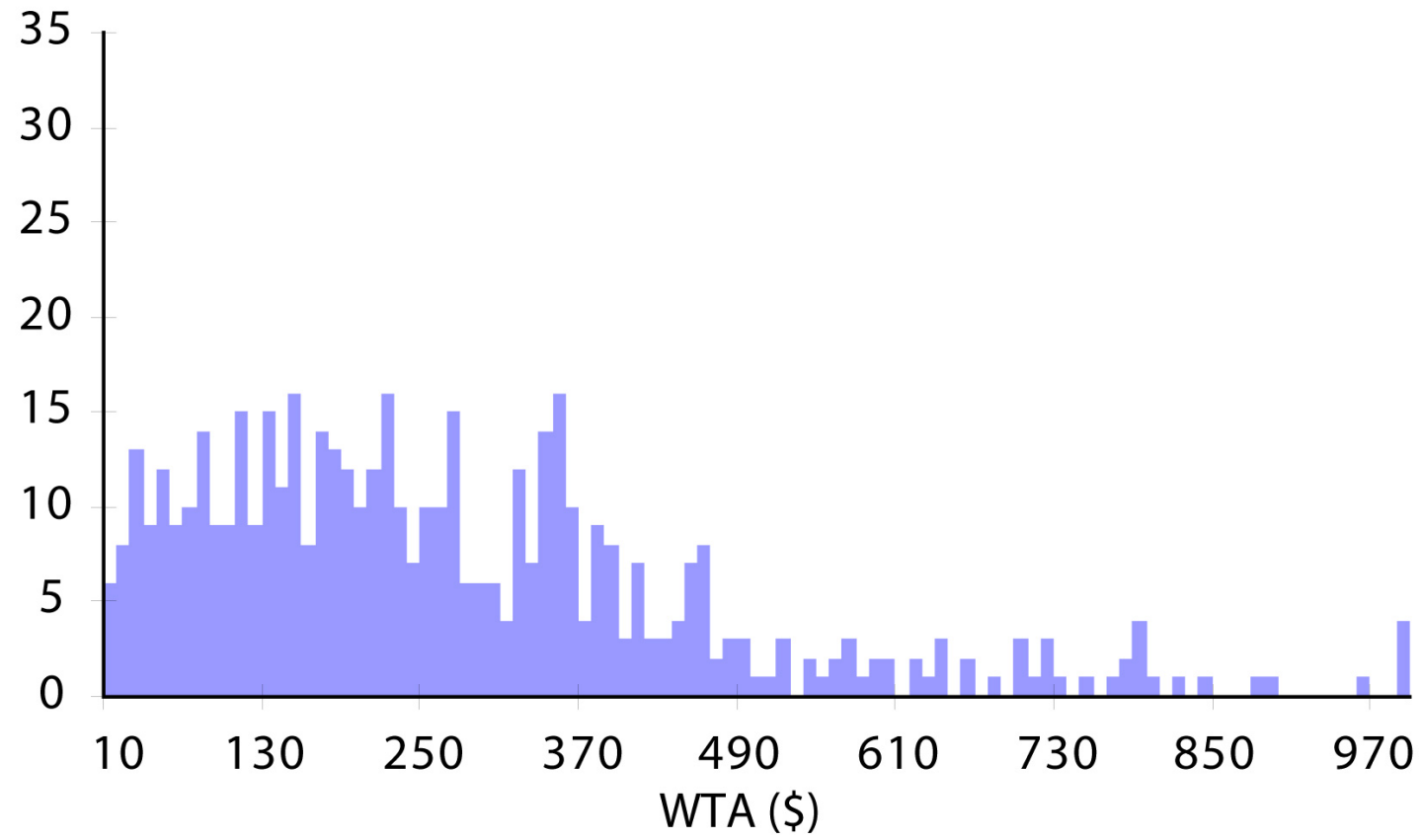
r is drawn from a $U(0,1)$. Its value determines the use of parcel n , as in the following example:



WTA distribution for crop parcels



WTA distribution for pasture parcels



Simulating the spatial pattern of conservation lands

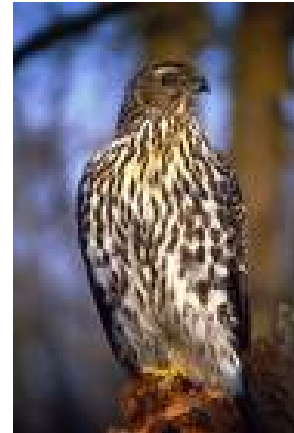
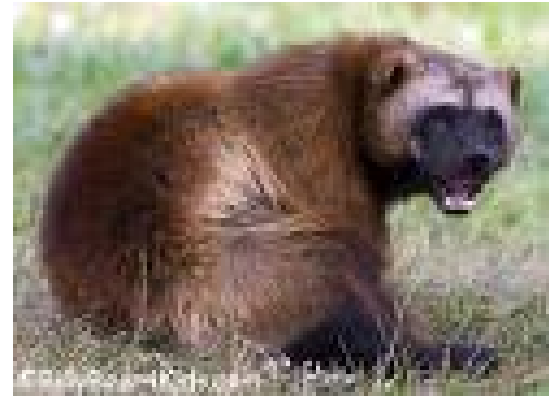
- We consider a range of different policies and different budget levels
- The regulator is assumed to know the distribution of WTA but not the WTA on any specific parcel
- For each policy/budget combination, the response to the conservation payment is simulated for each parcel
- Each round of the simulation produces a landscape consistent with the underlying WTA values and transition rules
- 500 landscapes are produced for each policy/budget level to characterize the range of potential spatial patterns
- The budget is the opportunity cost of the policy (not the cost to the government) computed as the sum of WTA for all conserved parcels. We consider budgets of \$1, \$5, \$10, \$20, and \$30 million per year.

Scoring the landscapes for species conservation

- Use the same biological model as in “Where to put things”
- Input land use pattern from policy simulations into biological model to get biological score for each simulation

Species modeled

- Information is available on 267 terrestrial vertebrate species in the Willamette Basin. We focus on 24 species that are 1) expected to decline in the baseline or 2) have small initial populations that can be increased by land-use change
- These species include: American Bittern, Canada Goose, Green-Winged Teal, Cinnamon Teal, Ruddy Duck, White-Tailed Kite, Bald Eagle, Osprey, Northern Goshawk, Red-Shouldered Hawk, Marbled Murrelet, Spotted Owl, Belted Kingfisher, Short-Eared Owl, Grasshopper Sparrow, Common Muskrat, Wolverine, White-Tailed Deer, Painted Turtle, Western Pond Turtle, Northern Harrier, Acorn Woodpecker, Western Meadowlark, and Fisher





The optimal landscape

- Objective: maximize the biological score for a given level of opportunity costs (measured by sum of WTA across conserved parcels)
- Assume that WTA for all parcels is known (full information)
- Spatial processes determining the biological score make explicit solution of this problem intractable
- We use heuristic methods to approximate the optimal solution



Policies considered: least-cost conservation policies

- *Uniform*: all parcels are eligible
- *Large*: only parcels greater in size than 800 acres
- *Rare Habitat*: only parcels whose natural state is prairie, oak savanna, wetland, or late-succession conifer forest
- *Agglomeration*: only parcels whose immediate neighbor accepts a conservation payment
- *Agglomeration-Rare Habitat*: combines eligibility for the *Rare Habitat* and *Agglomeration* policies
- *WHIP*: only parcels that score at least 100 points according to Oregon WHIP criteria
- *Rare Habitat-Large-Range*: only parcels with three or more of the following: i) satisfy the *Rare Habitat* eligibility, ii) greater than 400 acres, iii) greater than 800 acres, and iv) within the range of fourteen or more of our group of species

Policies considered:

benefit-cost conservation policies

- *Lot Size*: Parcels targeted according to ratio of lot size to expected cost
- *Lot Size-Rare Habitat*: same as *Lot Size* but eligibility limited to rare habitat parcels
- *Lot size-Agglomeration*: benefit index is the size of two adjacent conserved parcels
- *WHIP*: benefit index is Oregon WHIP points
- *Rare Habitat-Large-Range*: Benefit index computed by awarding one point for each of the following: i) satisfy the *Rare Habitat* eligibility, ii) greater than 400 acres, iii) greater than 800 acres, and iv) within the range of fourteen or more of our group of species.

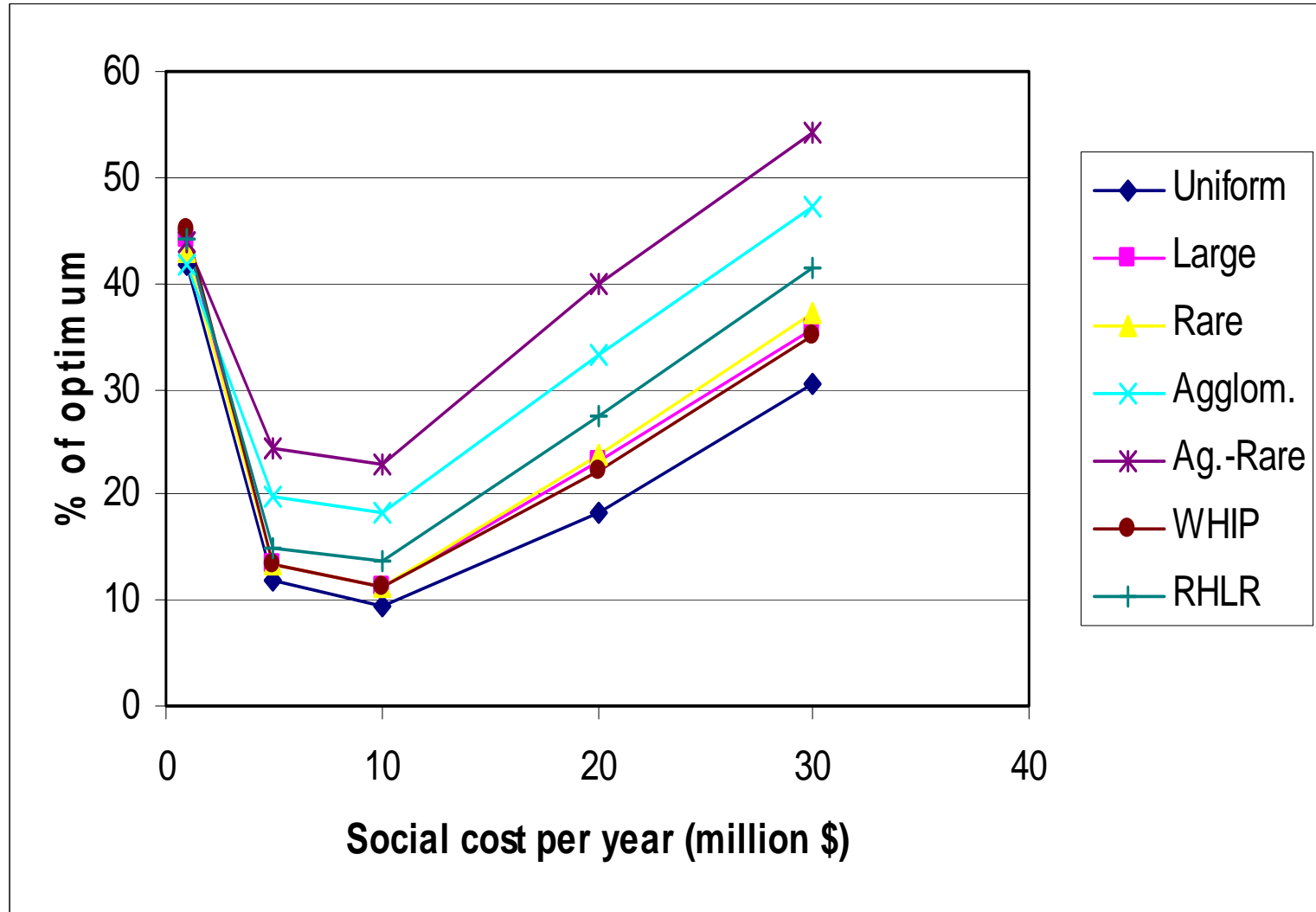
Table 4 – Estimated Mean Change in Biodiversity Score Relative to Baseline

	\$5m	\$10m	\$20m	\$30m
Approximate Optimal Policy	0.0840	0.2377	0.3289	0.3493
Uniform Policies				
<i>Simple Uniform</i>	0.0100 (11.92%)	0.0224 (9.43%)	0.0603 (18.35%)	0.1061 (30.37%)
<i>Large</i>	0.0112 (13.29%)	0.0267 (11.23%)	0.0759 (23.08%)	0.1242 (35.57%)
<i>Rare Habitat</i>	0.0112 (13.33%)	0.0271 (11.40%)	0.0781 (23.75%)	0.1300 (37.22%)
<i>Agglomeration</i>	0.0165 (19.65%)	0.0435 (18.32%)	0.1091 (33.17%)	0.1650 (47.23%)
<i>Agglomeration - Rare Habitat</i>	0.0203 (24.22%)	0.0545 (22.94%)	0.1314 (39.95%)	0.1899 (54.36%)
<i>WHIP</i>	0.0113 (13.52%)	0.0264 (11.12%)	0.0732 (22.26%)	0.1228 (35.15%)
<i>Rare Habitat – Large – Range</i>	0.0124 (14.81%)	0.0323 (13.59%)	0.0900 (27.38%)	0.1450 (41.51%)

Table 4 – Estimated Mean Change in Biodiversity Score Relative to Baseline

	\$5m	\$10m	\$20m	\$30m
Approximate Optimal Policy	0.0840	0.2377	0.3289	0.3493
Benefit-Cost Policies				
<i>Lot Size</i>	0.0019 (2.29%)	0.0082 (3.43%)	0.0644 (19.59%)	0.1181 (33.82%)
<i>Lot Size - Rare Habitat</i>	0.0027 (3.22%)	0.0105 (4.42%)	0.0822 (24.99%)	0.1274 (36.48%)
<i>Lot Size Agglomeration</i>	0.0060 (7.14%)	0.0686 (28.86%)	0.1278 (38.85%)	0.2254 (64.52%)
<i>WHIP</i>	0.0032 (3.76%)	0.0050 (2.12%)	0.0116 (3.54%)	0.0291 (8.34%)
<i>Rare Habitat – Large – Range</i>	0.0067 (7.94%)	0.0309 (13.00%)	0.2112 (64.23%)	0.3046 (87.20%)

Relative efficiency of least-cost conservation policies



Relative efficiency of benefit-cost conservation policies

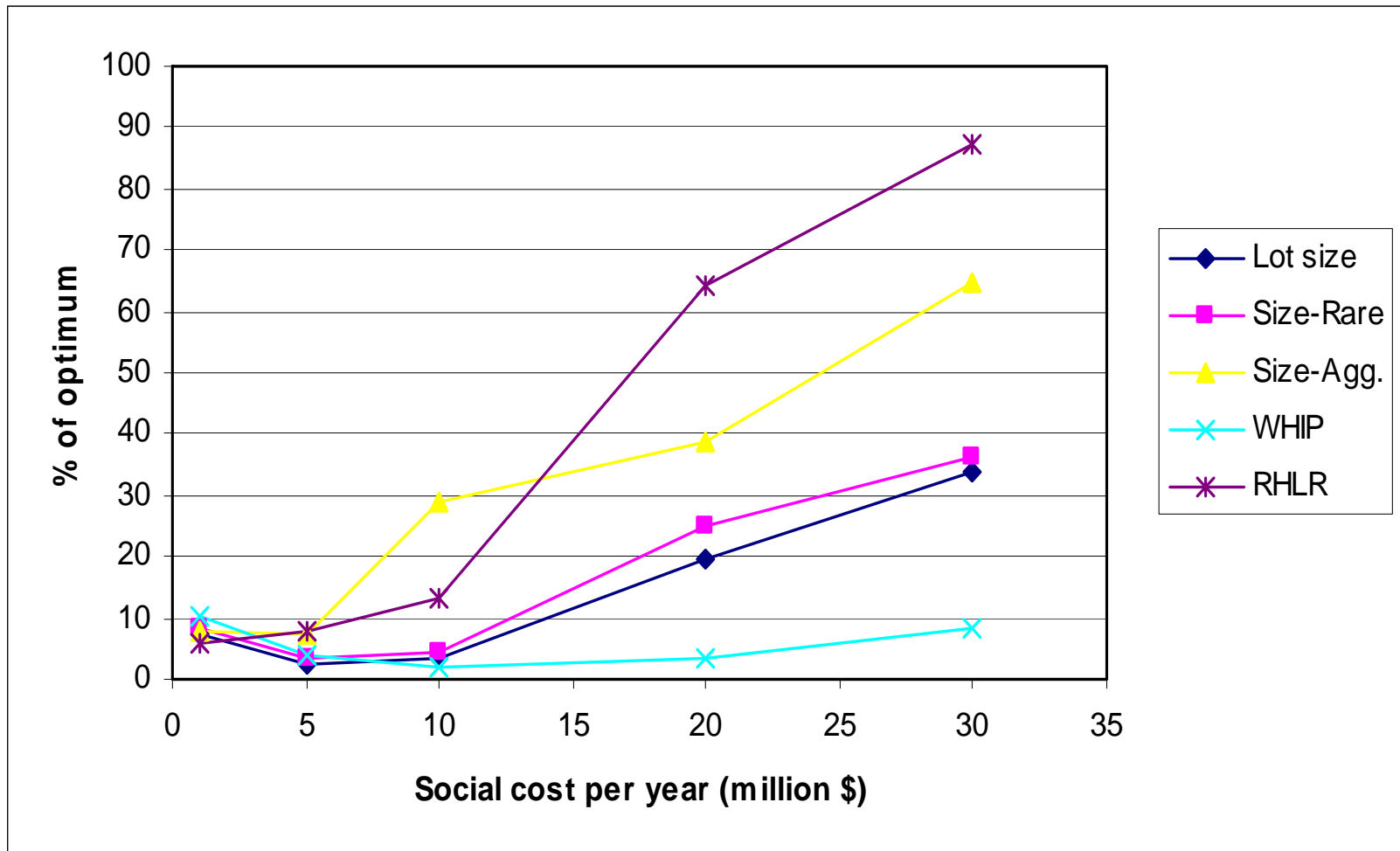


Fig. 3 - Frequency distributions of performance of alternative voluntary policies

a. Least-cost policies

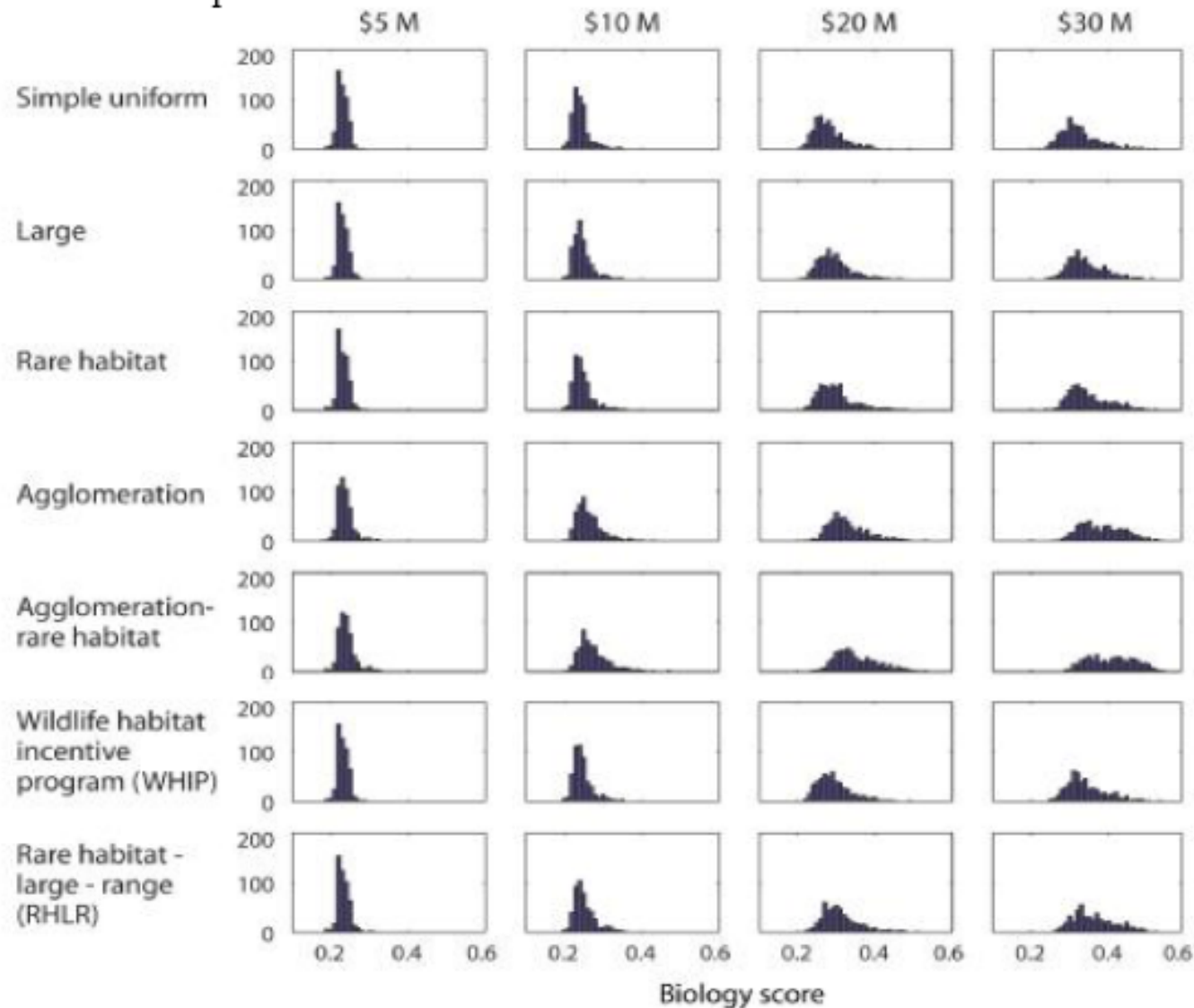
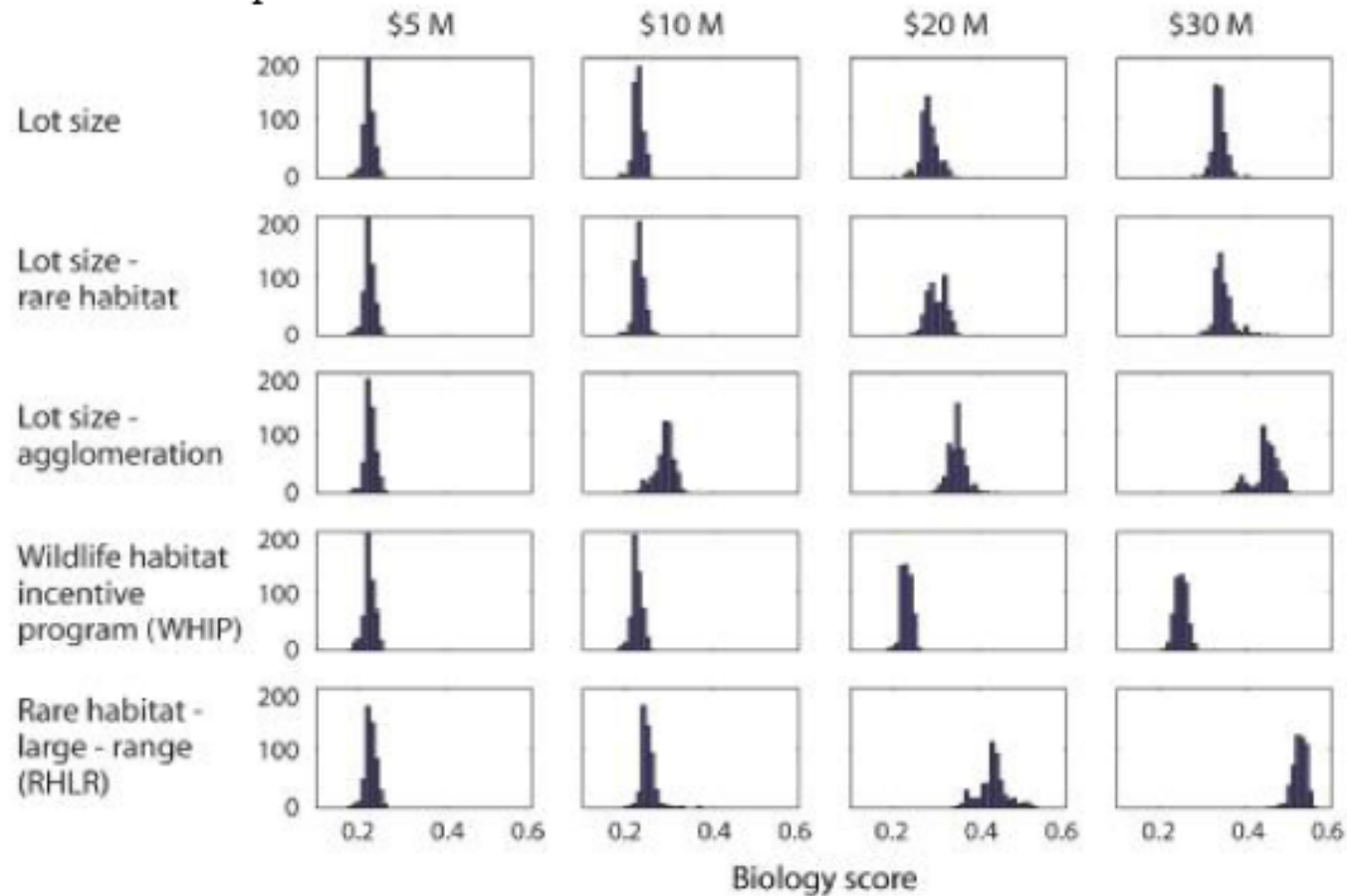


Fig. 3 - Frequency distributions of performance of alternative voluntary policies

b Benefit-cost policies



Discussion of results

- Large differences in the efficiency of alternative incentive-based policies
- At low budget levels:
 - No incentive-based policy performs particularly well compared to the estimated efficient solution
 - The simpler least-cost policies perform better than the benefit-cost policies
 - Premium for getting low cost land enrolled
- At high budget levels:
 - All incentive-based policies improve their performance vis-à-vis the estimated efficient solution
 - Some of the highly targeted benefit-cost policies perform extremely well (Lot-size – Agglomeration; Rare Habitat – Large – Range)

Discussion of results

- Economies of scale
 - Increasing returns to scale for all incentive-based policies at low to mid-budget levels
 - Increasing returns to scale throughout for some policies
 - Increased conservation decreasing fragmentation
 - Increased conservation allows species to attain critical thresholds of population that give large marginal benefit in terms of survival probabilities

Discussion of results

- Policies that target large parcels are relatively inefficient
- Agglomeration policies that create contiguous habitat do much better
- Targeting rare habitat does not do well on its own, but can be combined with other targeting criteria
- Adding more biological criteria does not necessarily improve the policy's performance, as seen with the WHIP policy
- Incorporating information on expected WTA can have a significant effect. Mechanisms that can elicit private information on WTA are worth exploring further.

Summary

- How efficient are voluntary incentive-based policies?
- Significant differences between outcomes on efficiency frontier and the incentive-based policy outcomes
- Incorporation of biological and economic information can significantly improve outcome
 - Economic information on WTA
 - Biological information on marginal benefit of conservation on parcel
 - Note: marginal benefit depends on spatial pattern of conservation

Summary: issues for future work

- Exploration of auctions and other mechanisms that reveal landowner WTA
- Exploration of mechanisms that tie acceptance into conservation program more closely to benefits per unit cost expended (where spatial pattern influences benefits)
- Studies of different regions with different benefit and cost patterns: do general patterns emerge?

A lush forest scene with a stream and mossy logs. The image shows a dense forest with tall trees and a stream flowing through it. In the foreground, several large logs covered in moss are scattered across the ground. The water in the stream is white and foamy, suggesting a small waterfall or rapids. The overall atmosphere is serene and natural.

Thank you