

Climate Change and Ecosystem Services: Impacts and Adaptation

Steve Polasky
University of Minnesota
& Natural Capital Project

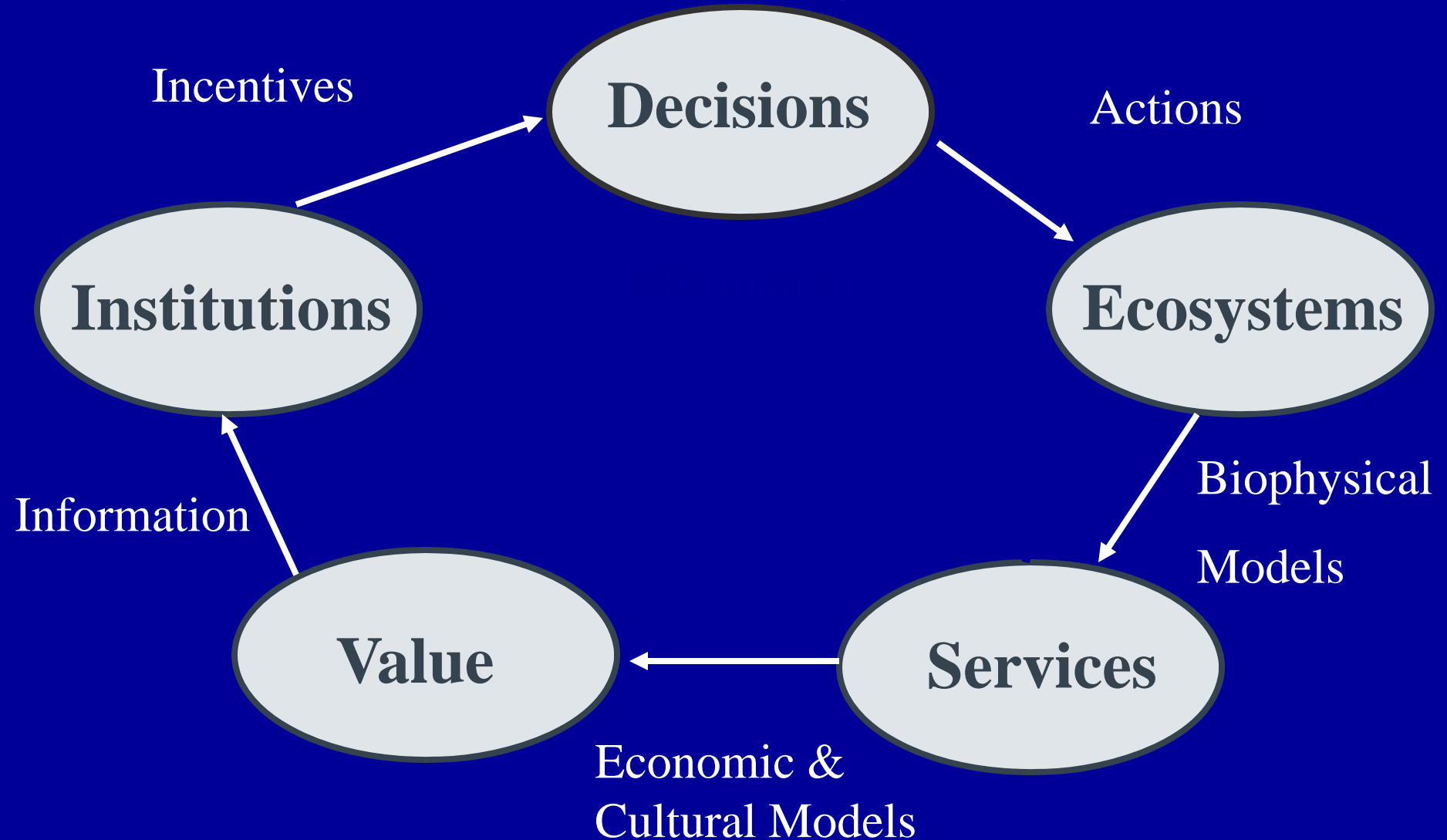
Introduction

- Ecosystems provide a wide array of goods and services of value to people (“ecosystem services”)
- Human actions affect ecosystems and the services they provide:
 - Land use
 - Water use
 - Climate change
- The 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

Introduction

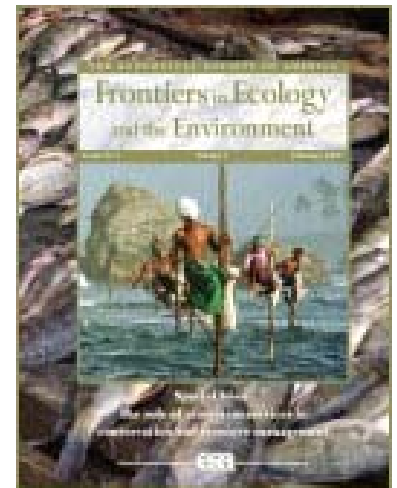
- Three main tasks for bringing ecosystem services into decision-making
 1. Understanding the provision of ecosystem services and how they change under different conditions (Quantification)
 2. Understanding the benefits to human well-being from ecosystem services (Valuation)
 3. Creating incentives for sustainable provision of ecosystem services (Institutions/policy)

Ecosystem services: research agenda



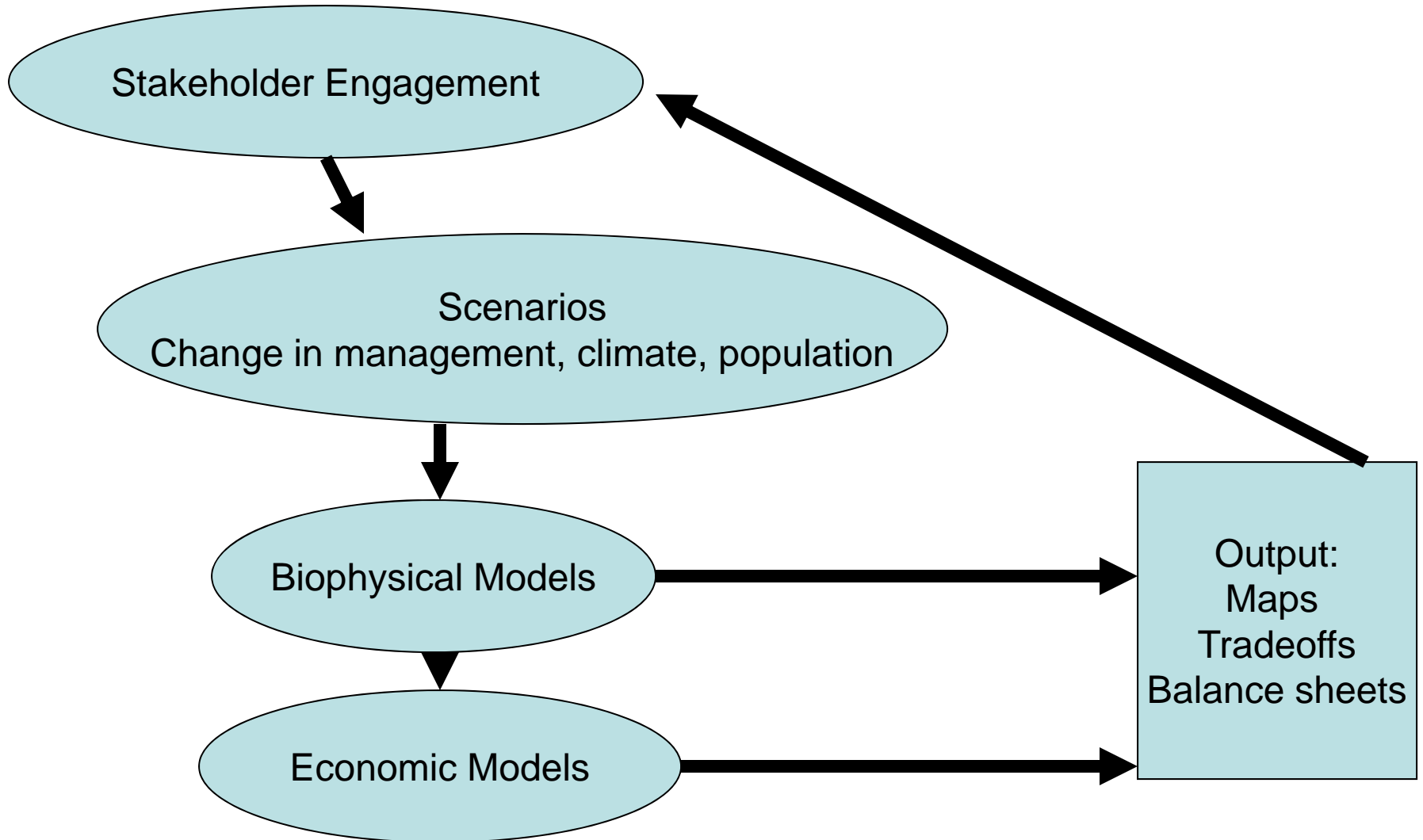
“InVEST”
Integrated Valuation of **E**cosystem
Services and **T**radeoffs

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



Frontiers of Ecology
and Environment
Feb 2009

InVEST process



Putting InVEST to work

- Examples of applications of ecosystem services approach
 - Willamette Basin, Oregon
 - Minnesota
- Closing thoughts on ecosystem services and climate change

Modeling multiple ecosystem services and tradeoffs at landscape scales



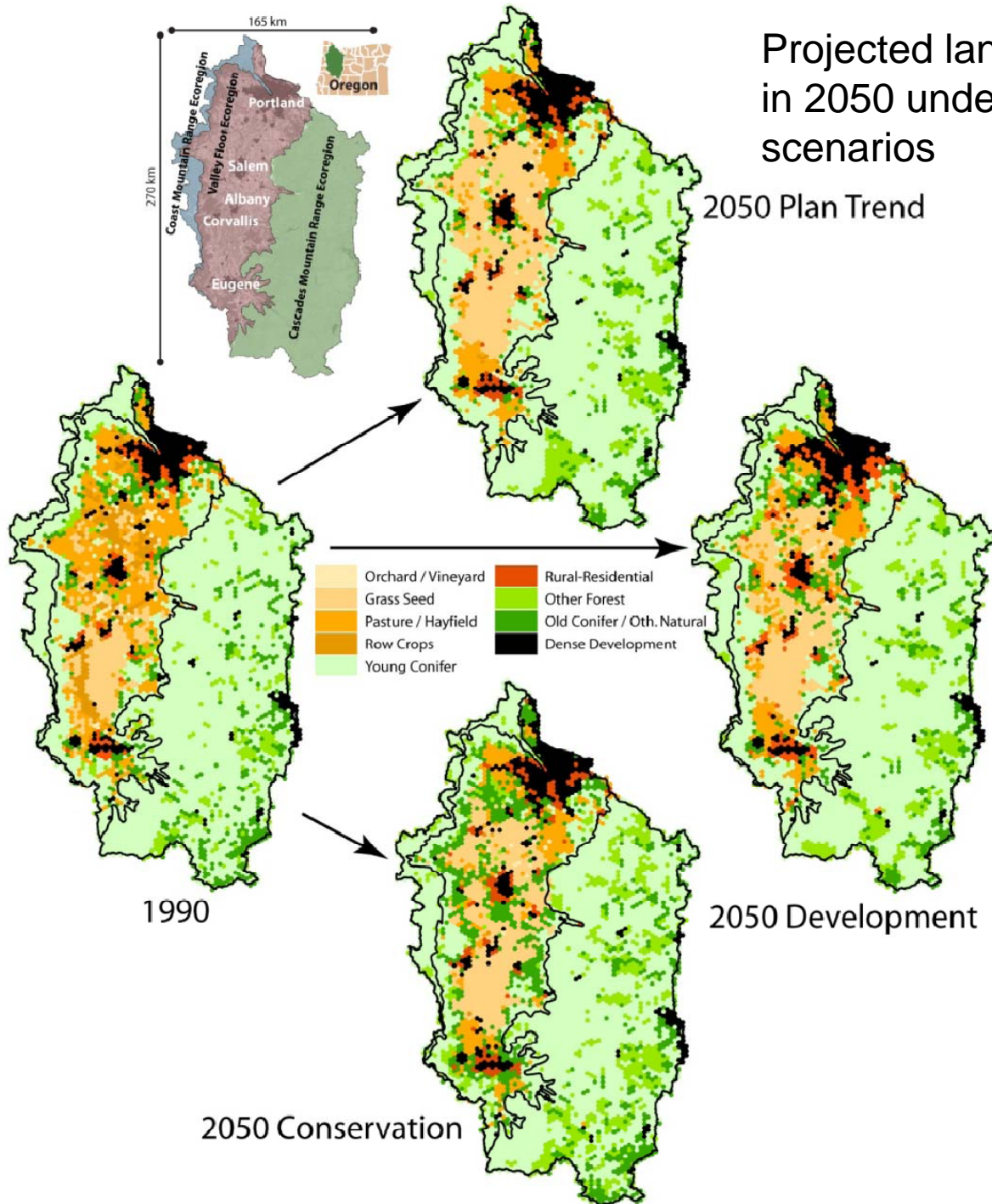
Nelson et al. 2009. *Frontiers in Ecology and Environment* 7(1): 4–11.

Getting started: model inputs

- Applying InVEST requires
 - Scenarios
 - Set of services included
 - Data inputs to calculate services as a function of the scenario
- InVEST ecosystem services modules use data to calculate flow of ecosystem service under each scenario

Alternative land use scenarios

- Three scenarios of land use / land cover change for the Willamette Basin (1990 – 2050) developed by the Pacific Northwest Ecosystem Research Consortium
 - Plan trend (business as usual)
 - Development
 - Conservation



Projected land use change in 2050 under the three scenarios

1990

2050 Plan Trend

2050 Development

2050 Conservation

Generating scenarios

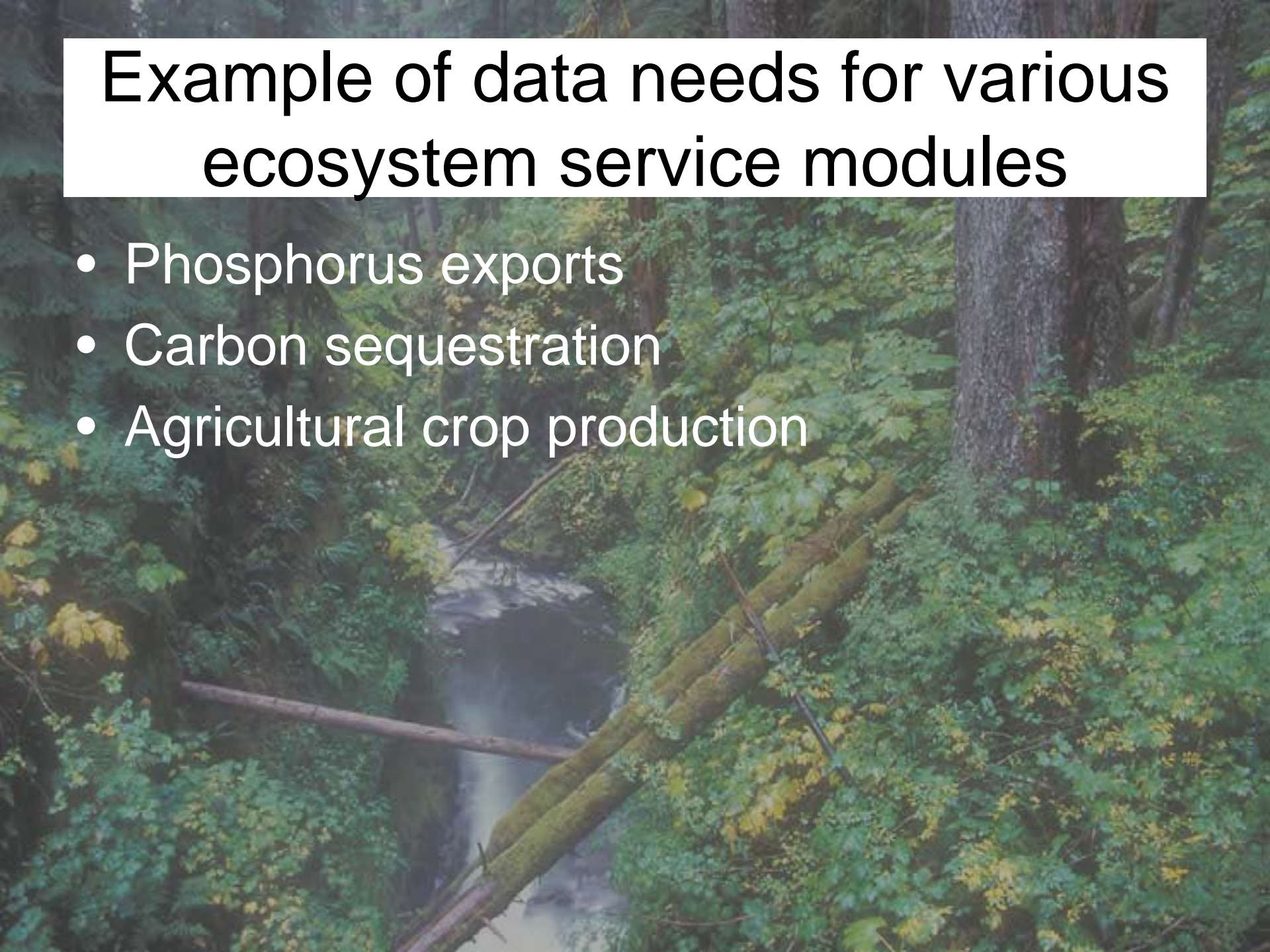
- Alternative ways to generate scenarios:
- Use of existing scenarios:
 - Land use scenarios (as in this example)
 - IPCC climate change scenarios
- Stakeholder process
- Model of landowner behavior (or other decision-makers) to determine evolution of land use (or other scenario inputs)
- Application of optimization tools to maximize desired outcomes

Multiple ecosystem services

- Set of services included in this application
 - Water quality (phosphorus exports)
 - Storm peak mitigation
 - Soil conservation (sediment retention)
 - Climate stabilization (carbon sequestration)
 - Biodiversity (species conservation)
 - Market returns to landowners (agricultural crop production, timber harvest and housing values)

Example of data needs for various ecosystem service modules

- Phosphorus exports
- Carbon sequestration
- Agricultural crop production



Phosphorus exports (water quality) model

- Prediction of annual export of phosphorus to mouth of a watershed
- Export of phosphorus from a parcel depends on:
 - Phosphorus levels and loadings
 - Ability of land cover to retain phosphorus
 - Quantity of water export (depends on precipitation, evapotranspiration)
- Use digital elevation maps to route water through watershed

Carbon sequestration model

- Carbon model tracks carbon storage on each parcel – report output in either tons of carbon or monetary value
- Carbon storage in four carbon pools: soil, below-ground biomass, above-ground biomass and harvested wood products
- Tier 1 (“simple”): IPCC data on carbon sequestered for ecoregion by land-use class
- Tier 2 (“more refined”): region-specific data for the Willamette Basin that uses detailed parcel-level characteristics
 - Carbon sequestration is a function of the mix of softwood and hardwood trees, tree stand age, canopy density, soil type, elevation, initial and final land use on the parcel, and the timing of the transition

Carbon sequestration model

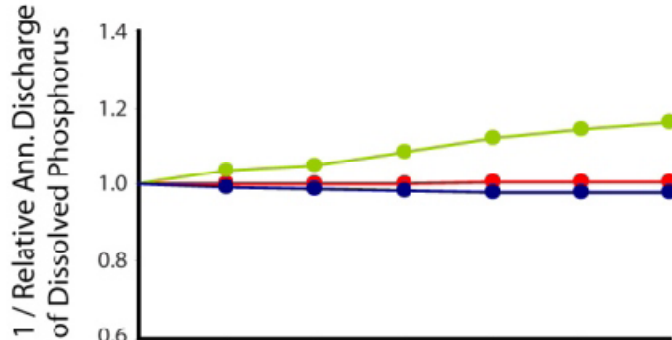
- Valuation of carbon sequestration: social cost of carbon
 - Social cost of carbon equals the marginal damage associated with the release of an additional metric ton of carbon into the atmosphere
 - By sequestration, avoid imposing cost
- Tol (2005) survey of literature –\$43 per Mg of carbon

Agricultural crop production model

- Monetary returns for a parcel in agricultural production
- Agricultural returns depend on
 - Crop type
 - Crop yield (soil quality, irrigation, fertilizer and other inputs)
 - Crop price
 - Production cost

Outputs through time

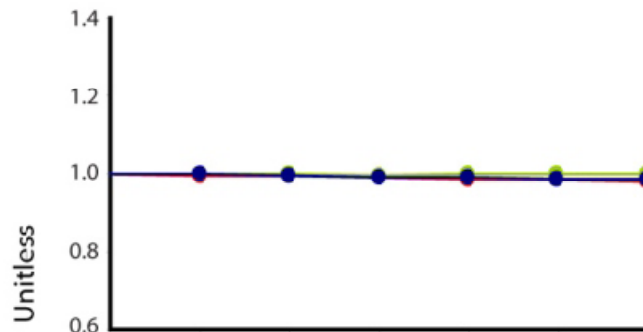
Water Quality



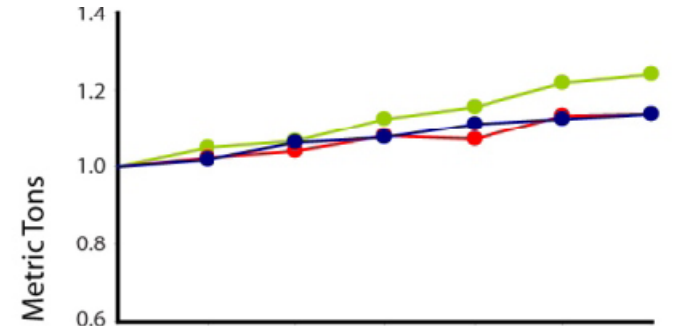
Potential Soil Conservation



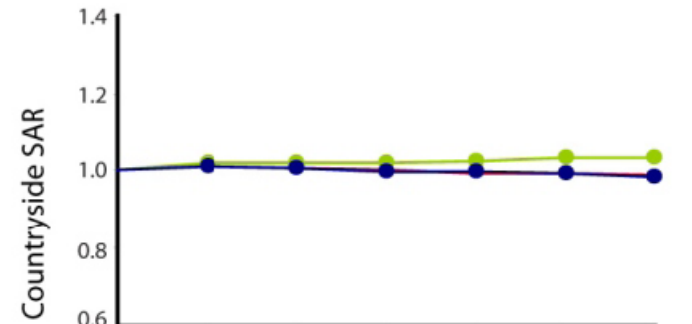
Storm Peak Management



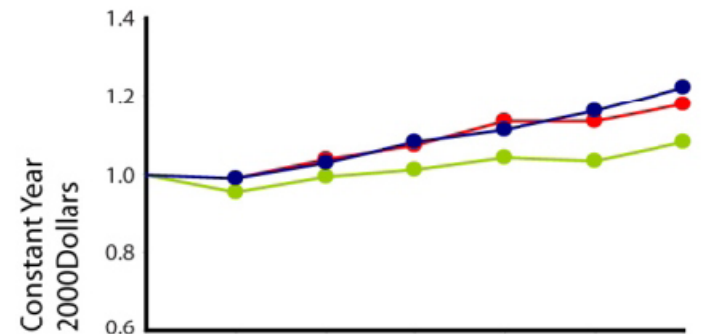
Carbon Sequestration



Biodiversity



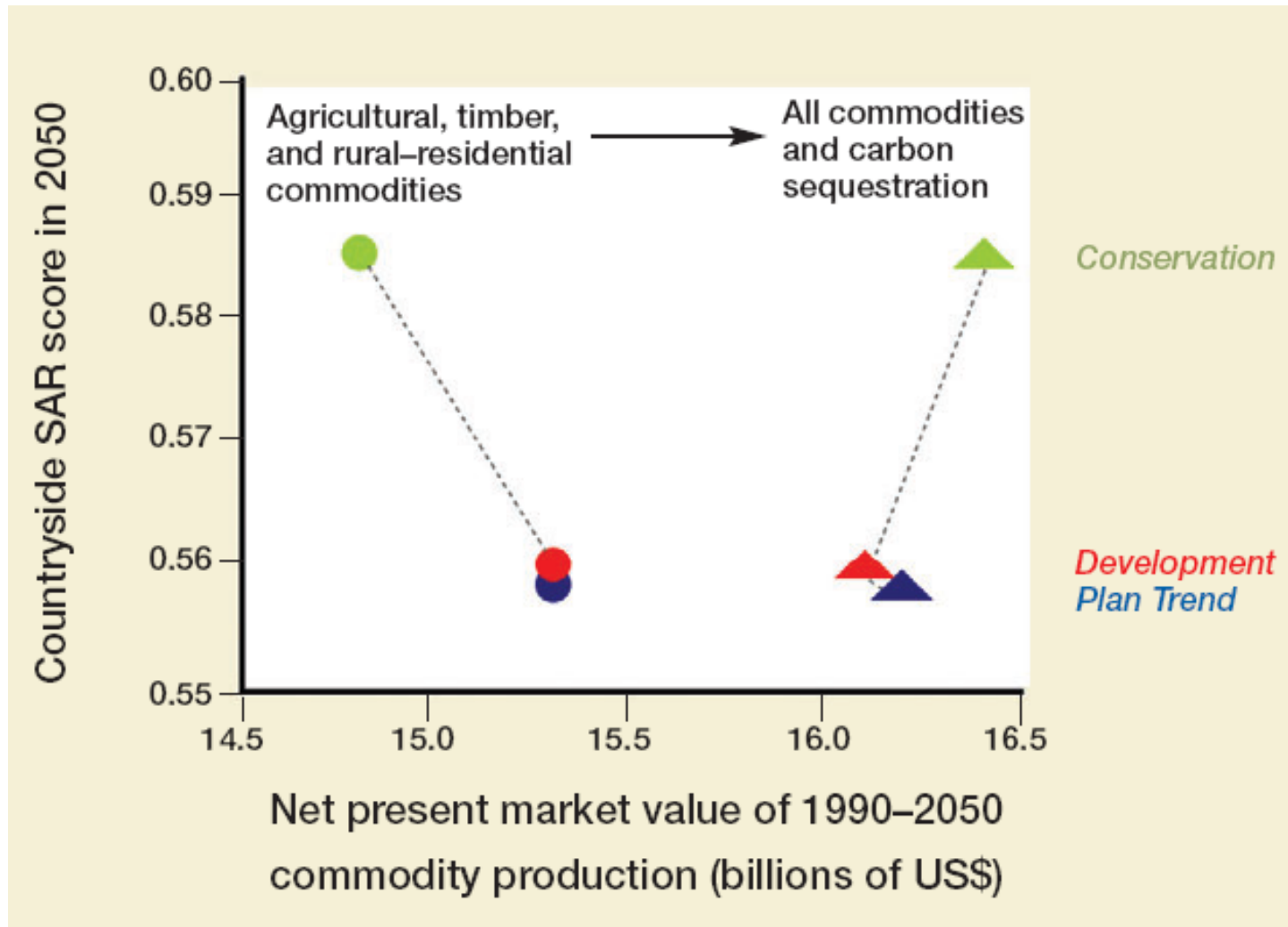
Market Value



1990 2000 2010 2020 2030 2040 2050

● Plan Trend ● Development ● Conservation

Ranking of scenarios depends on set of ecosystem services considered



Summary

- Spatially explicit analysis of multiple ecosystem services and biodiversity conservation
- Joint provision of services: one landscape, many consequences
 - Tradeoffs among services under alternative management
- Tools to address three related tasks of
 - Quantification of services
 - Valuation of services
 - Policies for provision of services

The Impact of Land Use Change on Ecosystem Services, Biodiversity and Returns to Landowners: A Case Study in the State of Minnesota



Polasky et al. Forthcoming. *Environmental and Resource Economics*

Introduction

- Compare the impact on ecosystem services & biodiversity from:
 - Actual land use change from 1992- 2001
 - Alternative land use change scenarios

Land use scenarios

- Use National Land Cover Database (NCLD) for 1992 to 2001 for data on actual land use change in Minnesota
- Alternative land use scenarios:
 - No agricultural expansion
 - No urban expansion
 - Agricultural expansion into highly productive soils
 - Forestry expansion into highly productive forest parcels
 - Conservation: low productivity ag land and ag land within a 100 m buffer of waterways in MN River watershed were converted to pre-settlement vegetation

Land use change 1992 to 2001

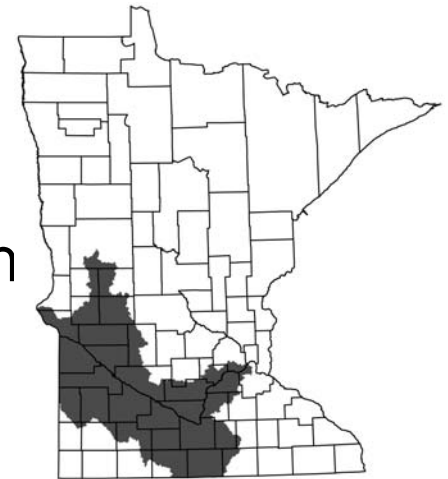
Table 1: Baseline 1992 to 2001 LULC Change

		To...							
	Change in Acres	Agriculture	Barren	Forest	Grassland / Shrub	Open Water	Urban	Wetlands	1992 Totals
From...	Agriculture	24,120,804	2,021	97,638	32,365	86,360	43,362	110,464	24,493,015
	Barren	120	63,541	1,458	182	3,807	31	897	70,036
	Forest	89,799	6,689	14,393,111	19,130	14,044	22,424	112,967	14,658,164
	Grassland / Shrub	36,275	149	88,885	2,093,448	382	9,278	21,756	2,250,173
	Open Water	12,487	3,127	21,627	3,287	3,032,070	742	25,059	3,098,400
	Urban	6,523	13	2,189	661	3,134	2,656,976	4,360	2,673,857
	Wetlands	71,394	557	167,702	23,349	17,577	6,966	6,453,303	6,740,849
	2001 Totals	24,337,402	76,098	14,772,610	2,172,424	3,157,374	2,739,779	6,728,806	

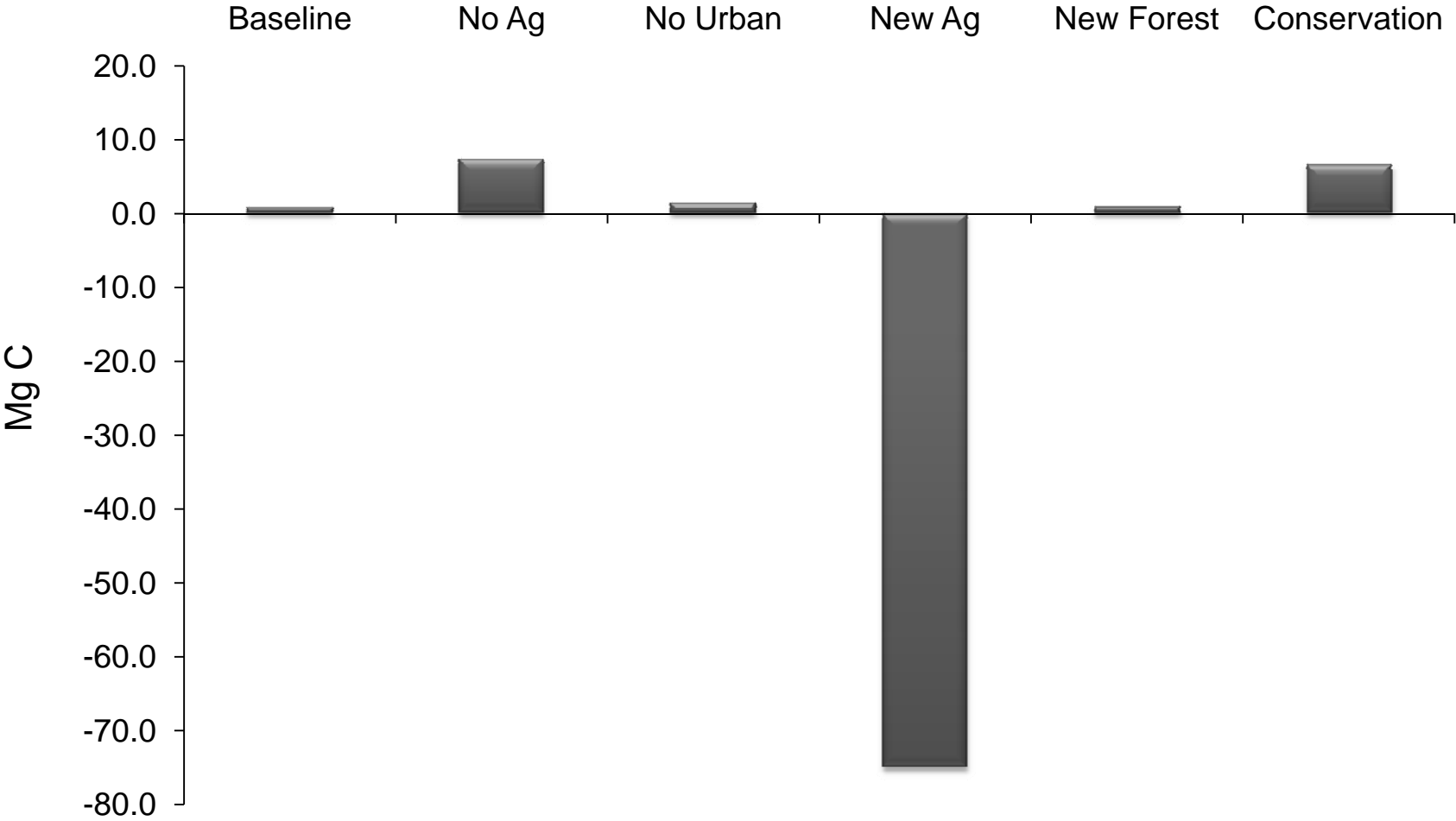
	Ag	Urban
Lost	372,211	16,880
Gained	216,598	82,803
Total	-155,613	65,923

Outputs of analysis

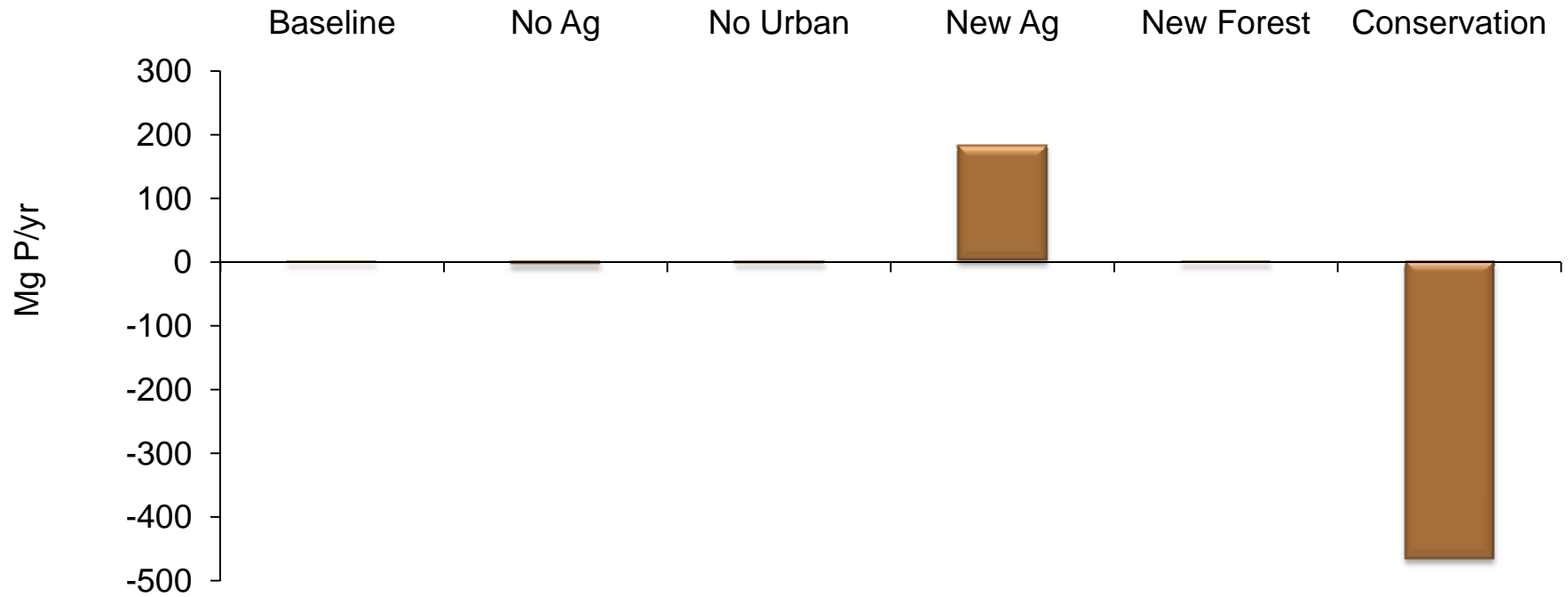
- We modeled impact of land use decisions on:
 - Carbon sequestration
 - Water quality (phosphorus): done only for the Minnesota River Basin not statewide
 - Conservation of terrestrial vertebrates (forest birds, grassland birds)
 - Value of agricultural production
 - Value of timber production
 - Value of land use in urban development



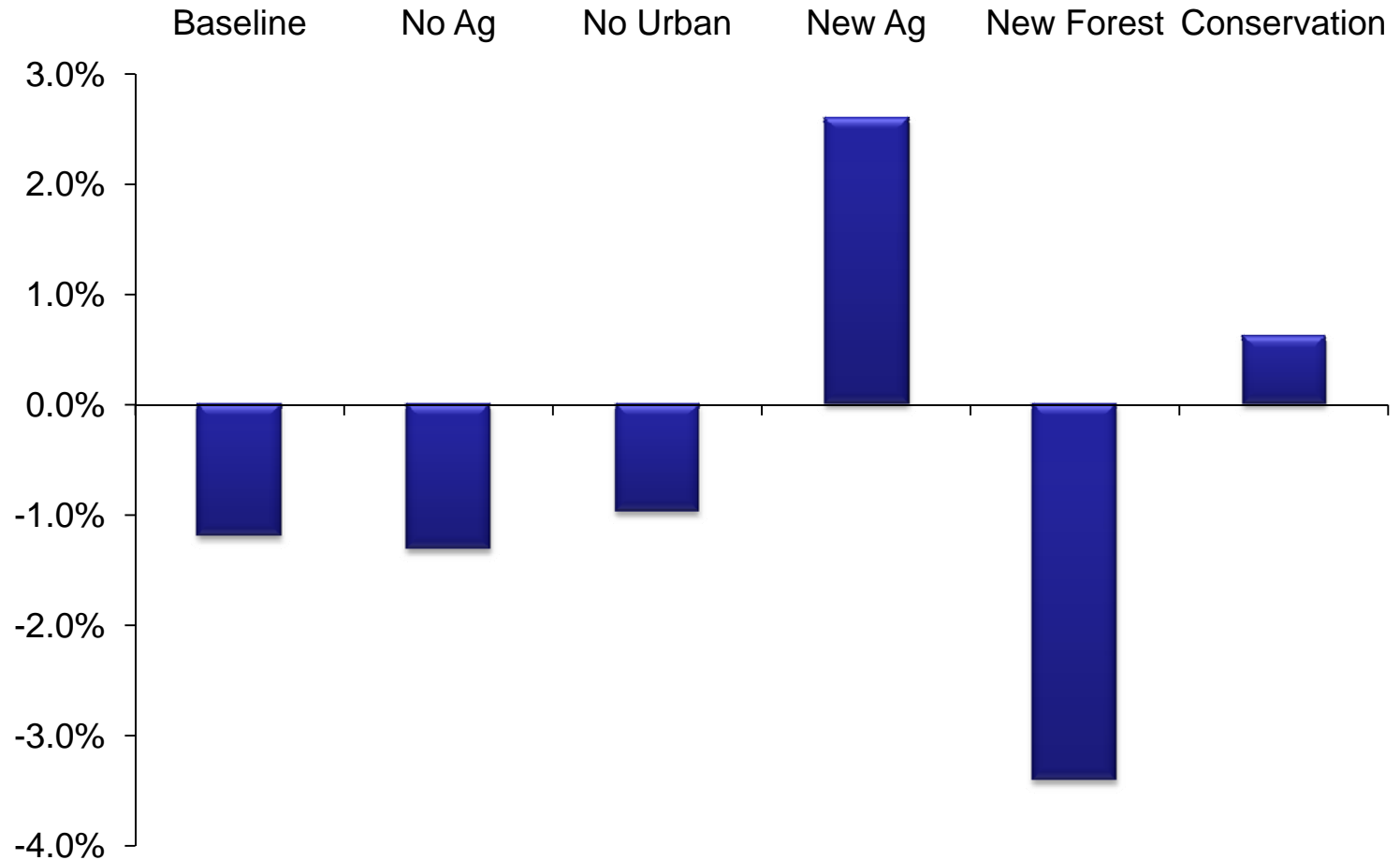
Change from 1992 to 2001 by scenario: carbon sequestration



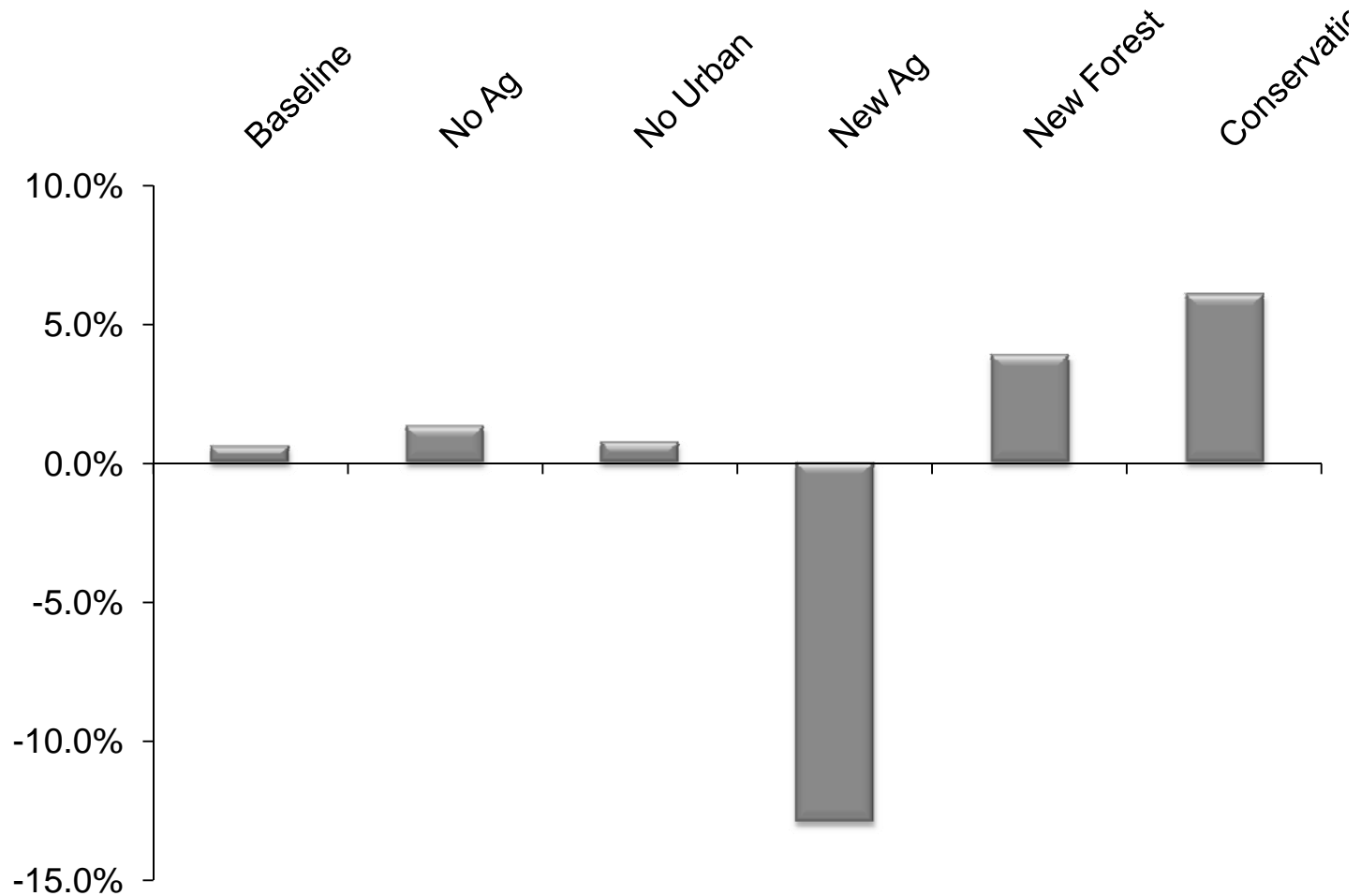
Change in phosphorus exports to mouth of Minnesota River



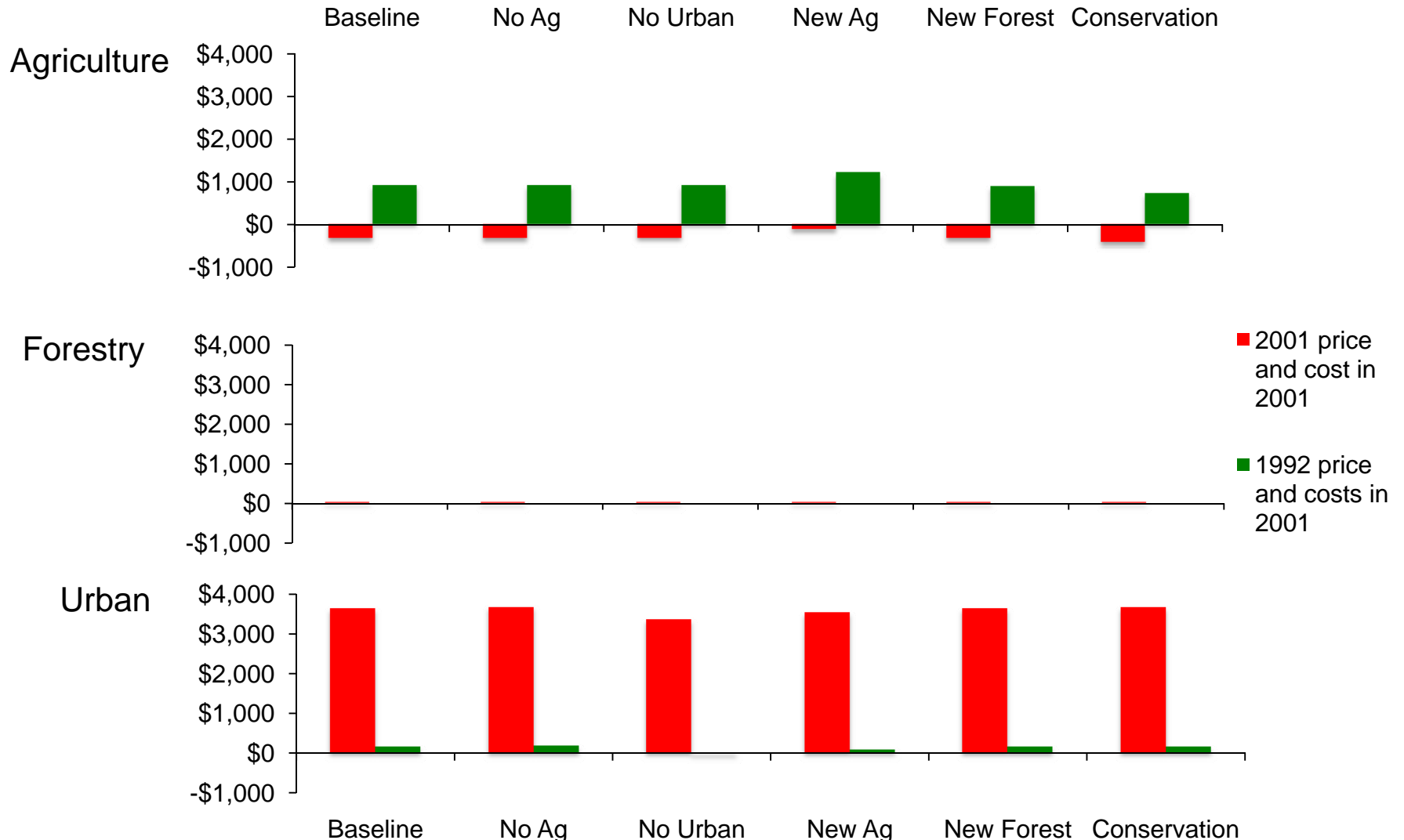
Percentage change in habitat quality for grassland breeding birds



Percentage change in habitat quality for forest breeding birds





Change from 1992 to 2001 by scenario: market returns to agriculture, forestry, urban



Million 1992 US \$

Annual value from land use change scenarios 1992-2001

	Actual land use	No ag expansion 	No urban expansion	Ag expansion	Forest expansion	Conser- vation
Change in total value: carbon, water quality, ag & forest production, urban using actual prices (M1992 \$)	\$3,328	\$3,407	\$3,040	\$2,742	\$3,300	\$3,380
Change in returns to landowners: ag & forest production, urban using actual prices (M1992 \$)	\$3,320	\$3,343	\$3,027	\$3,418 	\$3,292	\$3,221

Summary

- The failure to incorporate the value of ecosystem services in land use planning can result in poor outcomes
 - Low level of ecosystem services
 - Low value of total goods and services from landscape
- Agricultural land use change had a bigger effect on ecosystem service value and biodiversity than urbanization
 - Result is largely due to the fact that there is far more agricultural land than urban land
 - Urban land: generates negative externalities but the direct value of urban land use is high
 - Agriculture: generates negative externalities but with lower direct land use value

Adapting to climate change

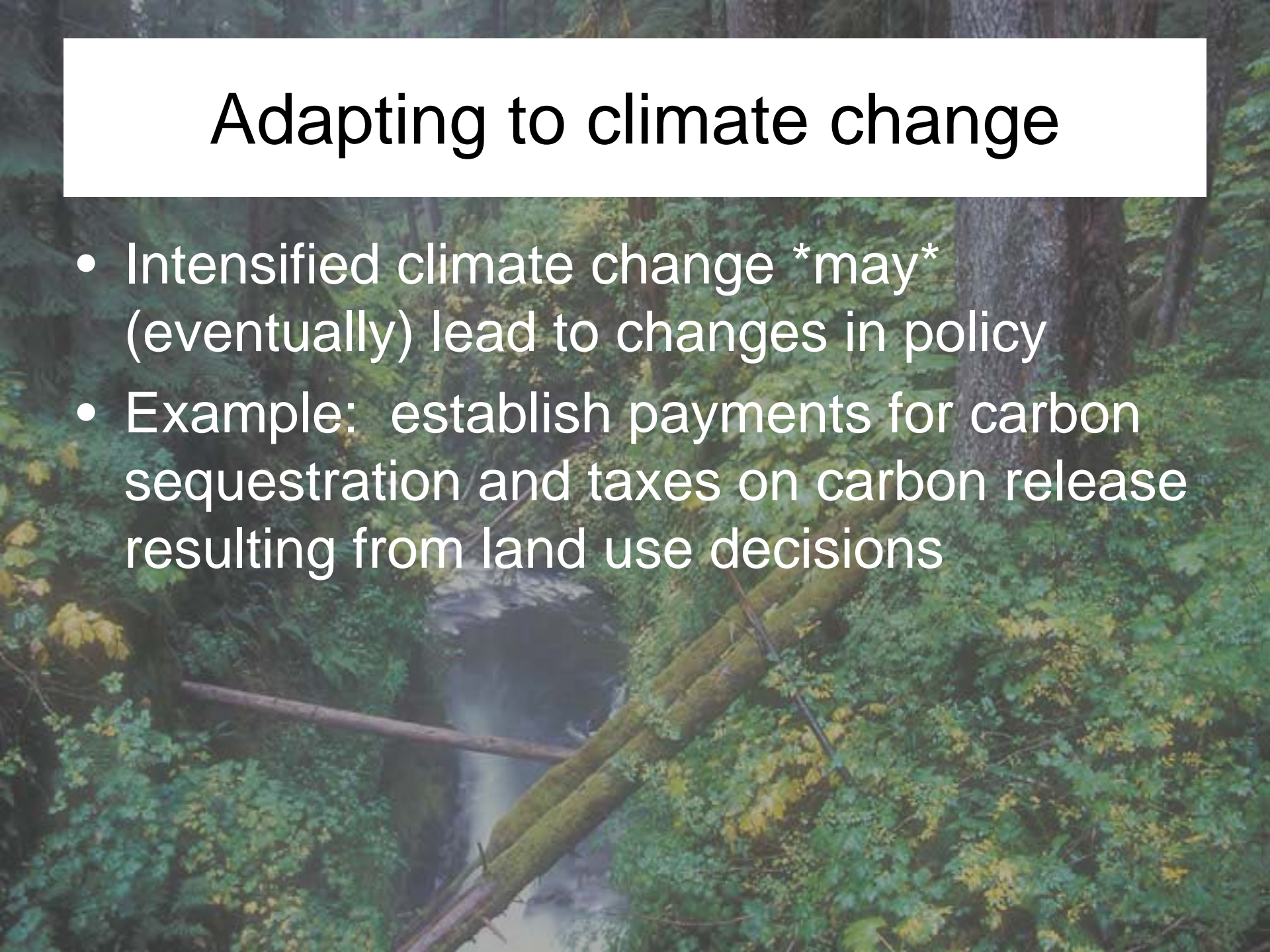
- Climate change will have direct effects on ecological production functions and the provision of services
- Example: change in precipitation patterns
 - Water quantity and water quality effects
 - Change in water availability to agricultural production (rainfall, irrigation)
 - Shifts in natural vegetation patterns and effects on biodiversity
 - Flooding patterns

Adapting to climate change

- Further effects caused by climate change through changes in human behavior
- Example: change in precipitation patterns on agriculture
 - Change in profitability of agriculture in various ecoregion
 - Shift in agricultural production to more productive zones
 - Changes in relative prices will also cause shifts in what is grown where
- intensified climate change – affect crop prices, carbon prices

Adapting to climate change

- Intensified climate change *may* (eventually) lead to changes in policy
- Example: establish payments for carbon sequestration and taxes on carbon release resulting from land use decisions



Adapting to climate change

- Climate change increases uncertainty about future flow of ecosystem services
- Decision-making under uncertainty: robust or resilient outcomes that do well under a wide range of potential future states
- Building in adaptive capacity to respond to future unknown events

Moving ahead

- We do not know enough BUT...
- We know enough to improve on current performance
- Pressing need to begin to mainstream ecosystem services into societal decisions
- The long road rather than the quick fix: adaptive process to improve governance of socio-ecological systems

A lush forest scene with a stream and fallen logs. The image shows a dense forest with tall trees and a stream flowing through it. Several large logs are lying on the ground, partially submerged in the water. The foliage is vibrant green, and the overall atmosphere is serene and natural.

Thank you