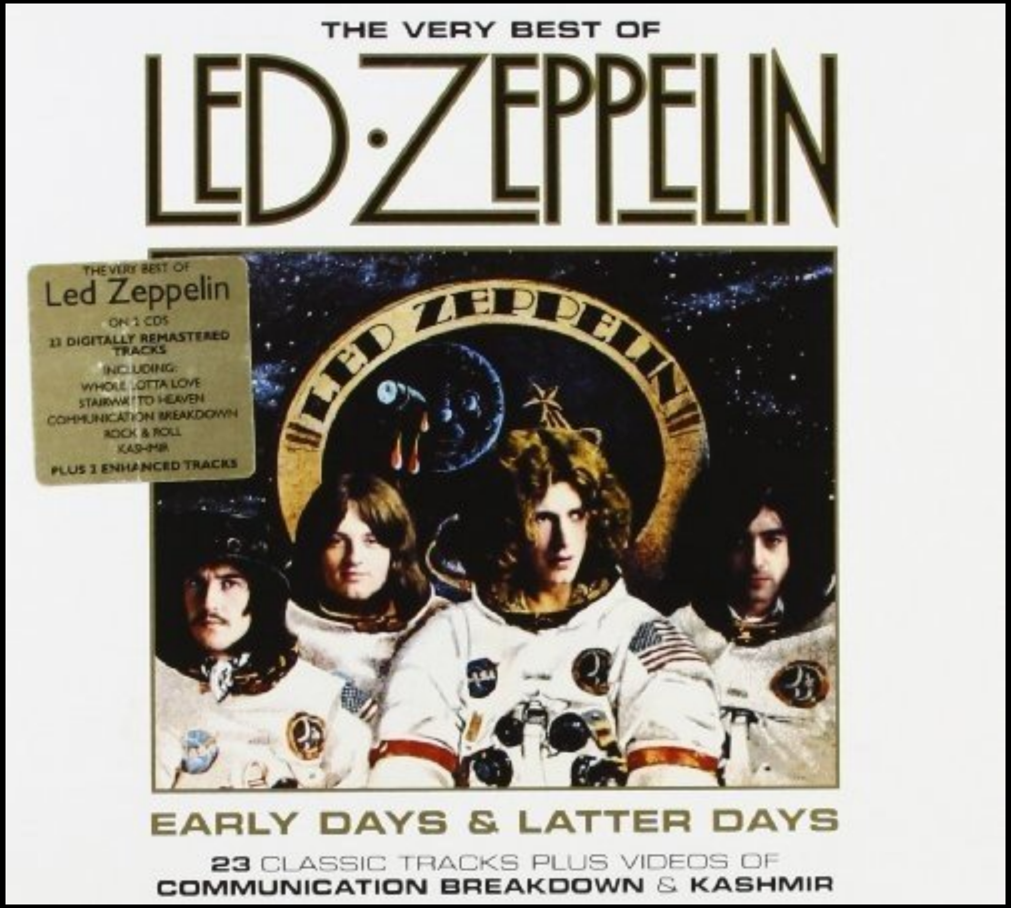
Making Nature Count at Micro to Macro Scales

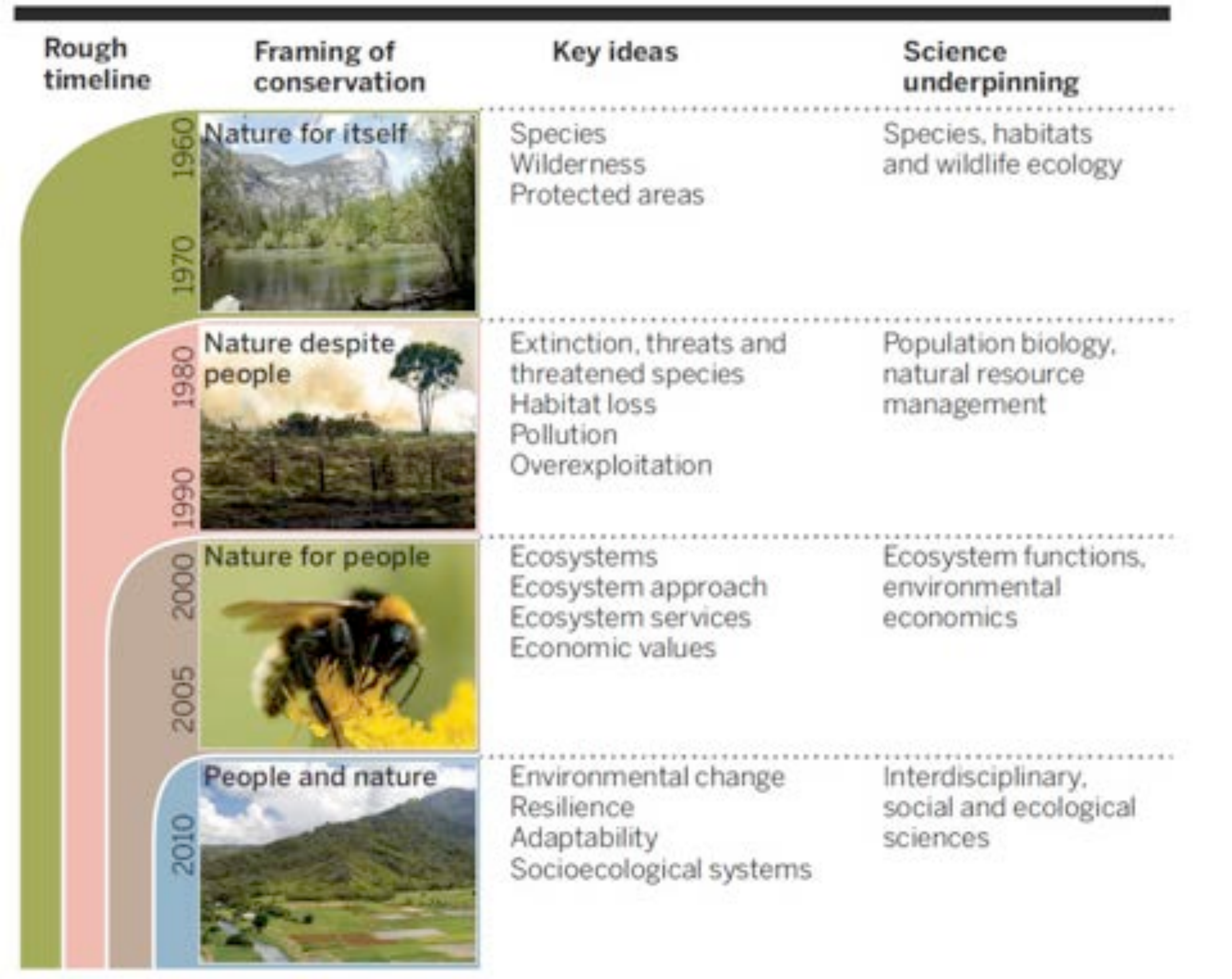
Stephen Polasky
University of Minnesota

Rock-and-roll theme



- Wow – Led Zeppelin. I always wanted to be a rock star!
- Great hits
  - Stairway to Heaven
  - Whole Lotta Love
- But other songs…
- Dazed and Confused
- Fool in the Rain
- Communication Breakdown
- Ramble On

Evolution of conservation



Rough timeline	Framing of conservation	Key ideas	Science underpinning
1960–1970	Nature for itself	Species Wilderness Protected areas	Species, habitats and wildlife ecology
1980–1990	Nature despite people	Extinction, threats and threatened species Habitat loss Pollution Overexploitation	Population biology, natural resource management
2000–2005	Nature for people	Ecosystems Ecosystem approach Ecosystem services Economic values	Ecosystem functions, environmental economics
2010	People and nature	Environmental change Resilience Adaptability Socioecological systems	Interdisciplinary, social and ecological sciences

Mace. 2014. Whose Conservation? *Science* 345 (6204): 1558-1560


Natural Capital Club Pre Ian and LEEP

Natural Capital Club Post Ian’s Rock and Roll Revolution

Young Ian?

Photo credit: www.abc.net.au/triplej/events/one_night_stand_07

Sustainable development challenge

- "The central challenge of the 21st century is to develop economic, social, and governance systems capable of ending poverty and achieving sustainable levels of population and consumption while securing the life-support systems underpinning current and future human well-being"

June 16, 2015 Special Issue of PNAS

Guerry, A., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G.C. Daily, R. Griffin, M.H. Ruckelshaus, I.J. Bateman, A. Duraiappah, T. Elmqvist, M.W. Feldman, C. Folke, J. Hoekstra, P. Kareiva, B. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *PNAS* 112: 7348-7355

The big questions

1. Conserving nature: maintain natural capital that sustains biodiversity and provides numerous contributions to human well-being
   - 1 million of ~8 million species at risk of extinction (IPBES Global Assessment 2019)
   - 14 of 18 categories of nature's contributions to people have declined over the past 50 years (IPBES Global Assessment 2019)

2. Economic development: alleviate poverty and improve material standard-of-living
   - Over three billion people live on less than $2.50 a day
   - ~ 800 million people are malnourished
   - Desire of billions of people to live a good life

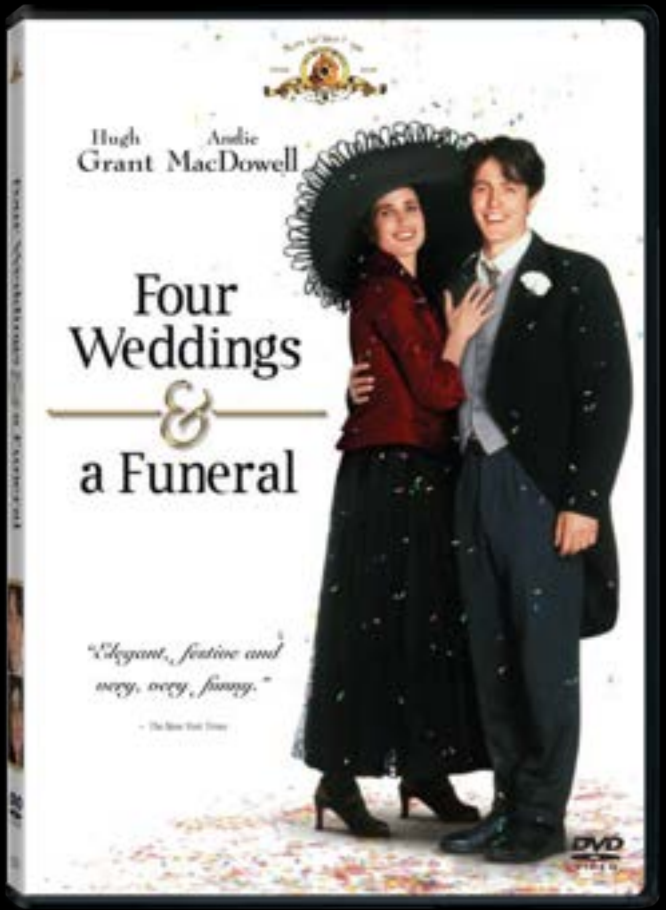
Challenge of integrated thinking

- Integrate development and conservation to simultaneously reduce poverty, improve well-being, and enhance natural capital
- Economic development that does not account for natural capital risks being unsustainable
- Conservation that does not account for human well-being risks being irrelevant

Challenge of ecosystem management

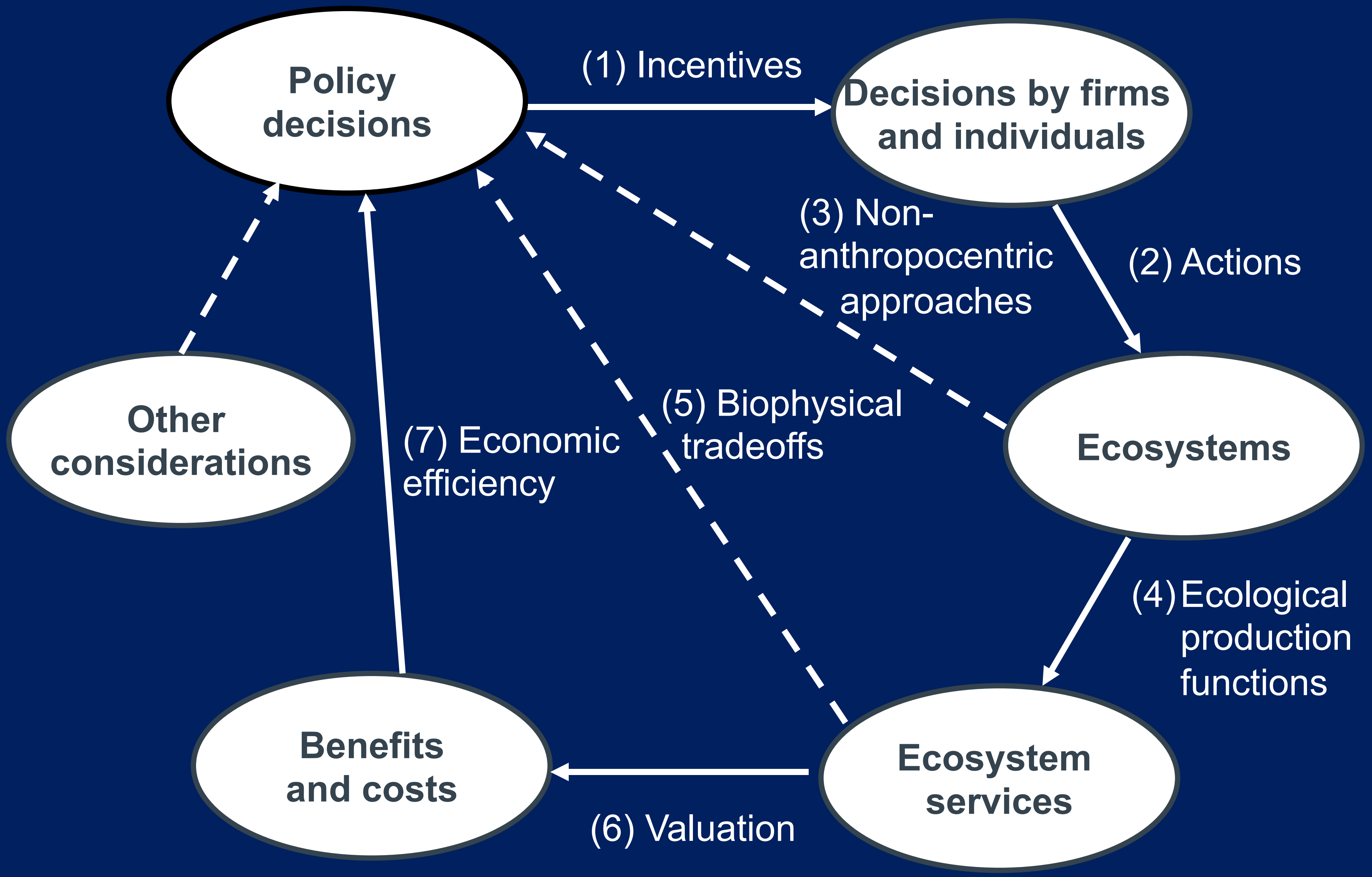
- Four questions and an objective
- Objective: manage ecosystems to conserve biodiversity and maintain/enhance the flow of benefits to people

1. Natural science question: what can be done to achieve the objective? (linking management action to objective)
2. Economic question: what are the benefits and costs of potential management actions?
3. Political question: who wins and who loses under a management action (and by how much)?
4. Implementation question: how to design institutions or policies so that winners have enough power to carry out the management action?



How was the talk?
It was elegant, festive and very, very funny

A research agenda for ecosystem services



Polasky & Segerson *Annual Review of Resource Economics* 1: 409-434.

natural capital PROJECT

ALIGNING ECONOMIC FORCES WITH CONSERVATION

“InVEST”

Integrated **V**aluation of **E**cosystem **S**ervices and **T**radeoffs

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

Frontiers of Ecology and Environment Feb 2009

Micro to Macro Scales

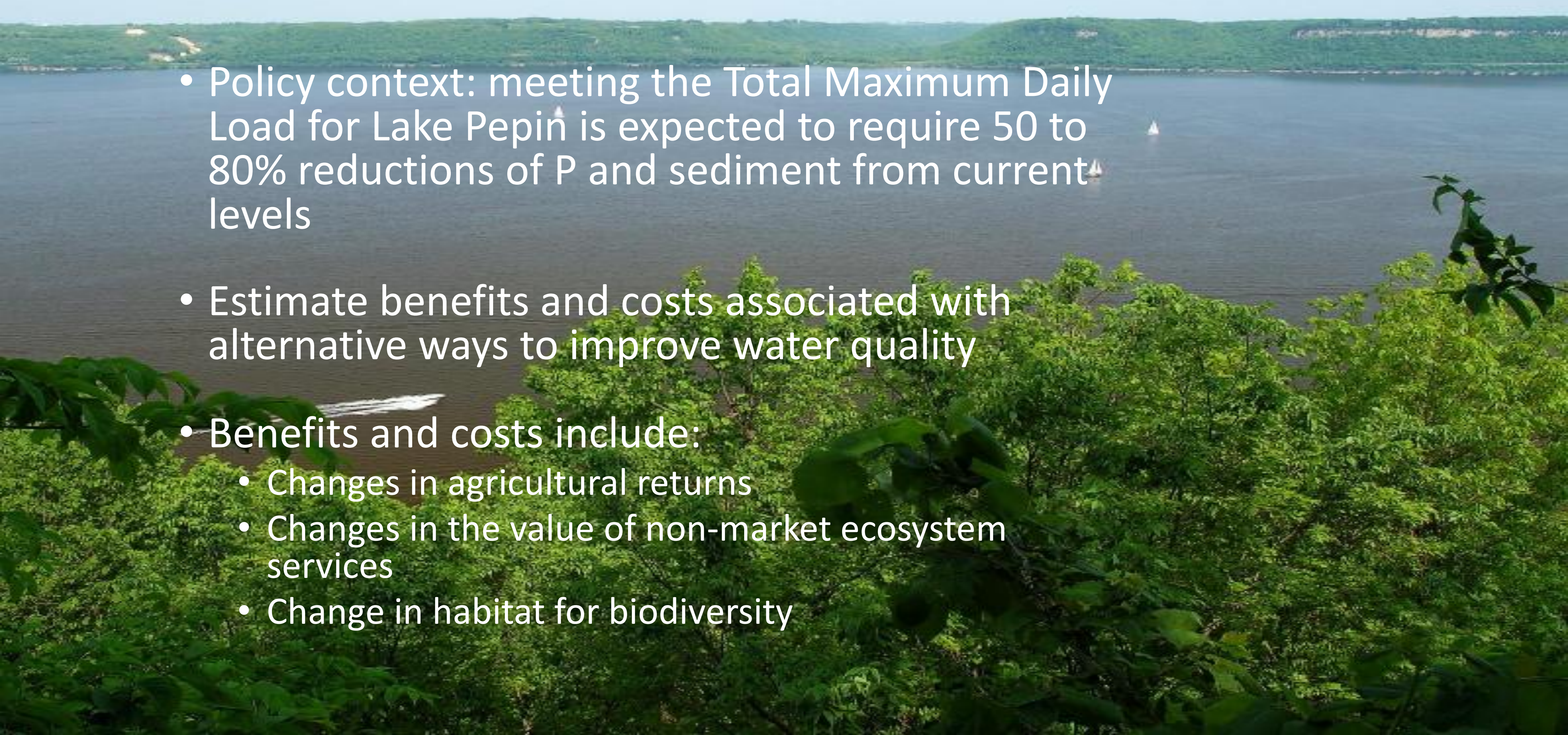
- Micro-scale analysis
  - Analysis of alternative land use and management
  - Benefit-cost analysis
- Local-scale analysis
  - Example: Minnesota watershed
- National-scale analysis
  - Example: Continental US
- Macro-scale analysis
  - National income and wealth accounting
  - Example: Gross Ecosystem Product in China
- Global-scale analysis
  - Example: Global vision for conservation and human well-being
- Concluding thoughts: economic and policy challenges

Cost effective land use planning: Optimizing land use and land management patterns to maximize social benefits

Pennington, et al. 2017. *Ecological Economics* 139: 75-90.

Lake Pepin Photo by Guy Schmickle

Context

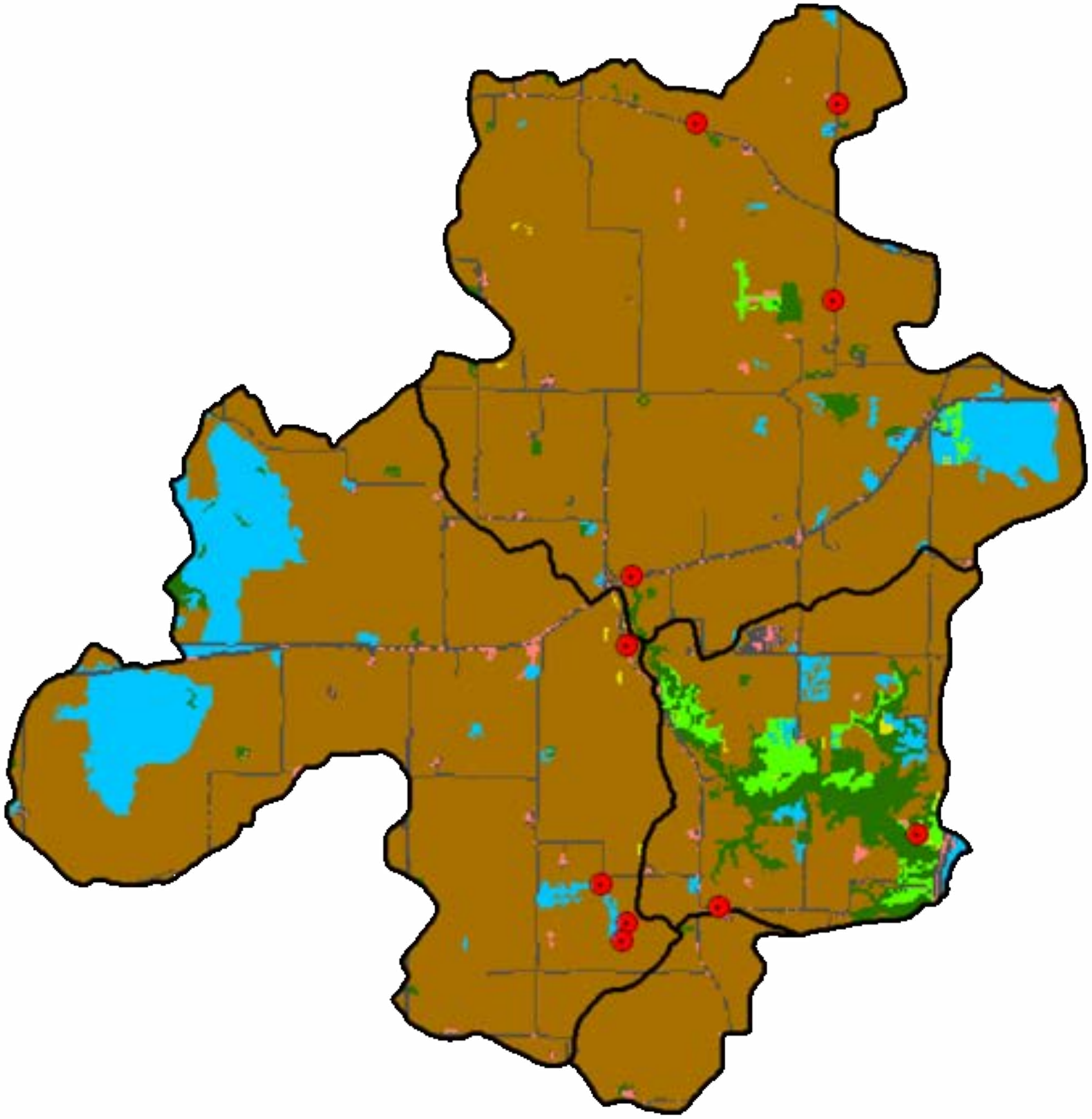


- Policy context: meeting the Total Maximum Daily Load for Lake Pepin is expected to require 50 to 80% reductions of P and sediment from current levels

- Estimate benefits and costs associated with alternative ways to improve water quality

- Benefits and costs include:
  - Changes in agricultural returns
  - Changes in the value of non-market ecosystem services
  - Change in habitat for biodiversity

Seven Mile Creek Land Use



Water/wetlands
Roads
Residential/developed
Forest
Hay/Pasture
Row Crops

Source: NLCD 2001

Model Inputs

- National Land Cover Database (NLCD) 2001 for data on baseline land use

Table 1. Selected land-management and land-cover types.

Land-management practices	Land-cover types
Chemical application of N and P	Row crops – e.g., corn, soybeans, sugar beets, grapes
Manure application of N and P	Alfalfa hay and pasture
Tillage practices – conservation and conventional	Short-rotation woody perennial – hybrid poplar
Buffer strips – 25 m and 250 m	Short-rotation herbaceous perennial - switchgrass
	Deciduous forest
	Grassland – mixed species
	Wetland
	Cover crops - ryegrass

Model outputs

- Ecosystem Services:
  - Water Quality (SWAT, InVEST, Additional modeling for streambank erosion)
    - Phosphorous Loading
    - Sediment Loading
  - Carbon Sequestration (InVEST)
  - Agriculture production and profitability (SWAT and InVEST)

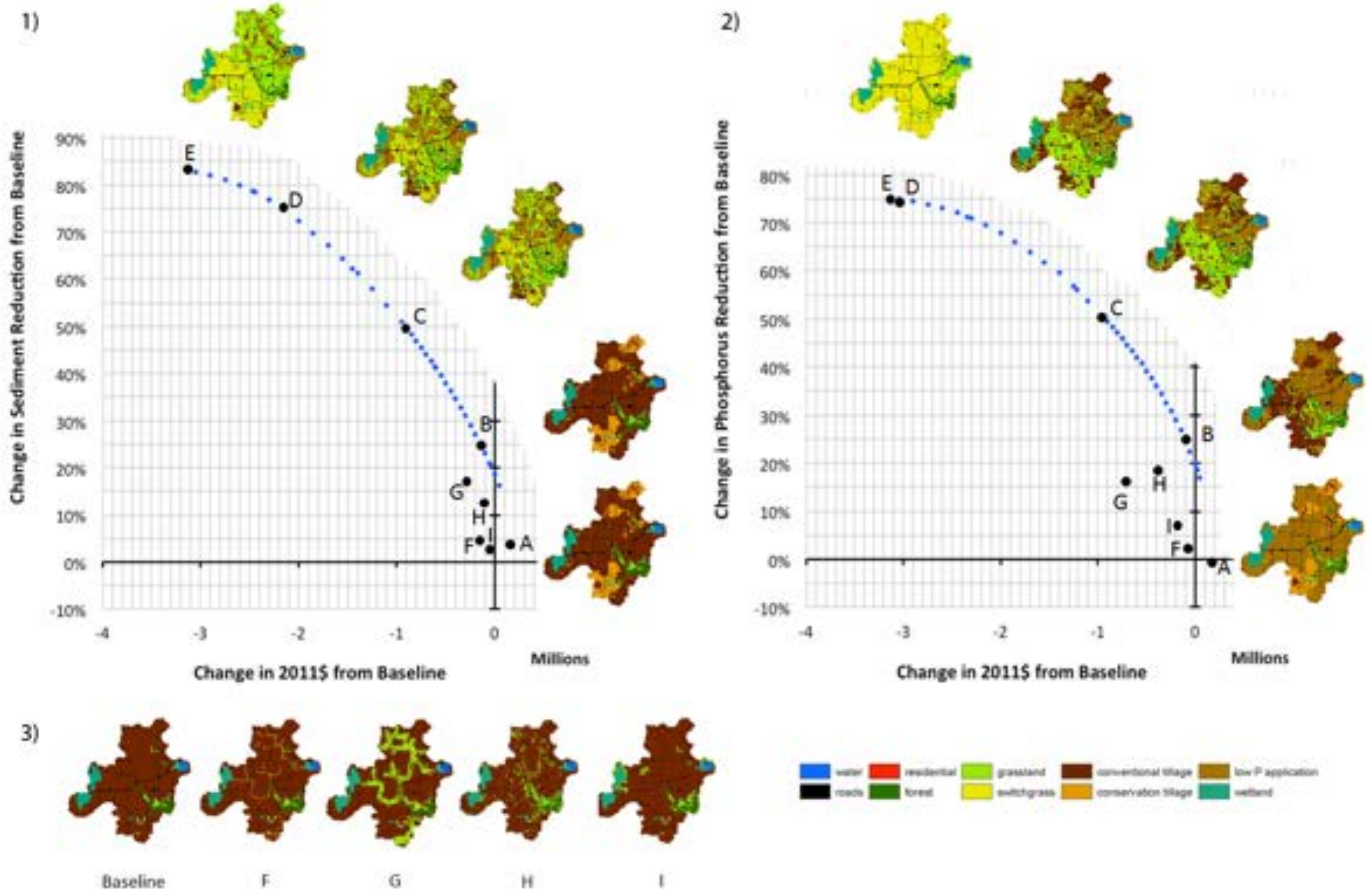
- Biodiversity Conservation (InVEST)
  - Habitat quality for grassland birds
  - Habitat quality for forest birds

Efficiency frontier

- The goal of the analysis is to find land-use patterns that maximize phosphorus reductions for a given economic return

- Frontiers
  - With and without value of ecosystem services
  - "Current market returns" based on 2007-2011 price and cost data
  - "Historic market returns" based on 2002-2006 price and cost data

Efficiency frontiers for sediment and phosphorus reduction



Projected land-use change impacts on ecosystem services in the U.S.

Lawler et al. 2014. *Proceedings of the National Academy of Sciences* 111(20): 7492-7497.

Long-term projections of land-use change in the U.S. from 2001 to 2051

- How can policies alter land-use change projections?

- How do land-use changes affect the provision of important ecosystem services?
  - Carbon storage
  - Habitat for various groups of species
  - Agricultural crop and timber production

Land-use change scenarios

- Forecast land-use changes from 2001 to 2051 for two baseline economic scenarios:
  - 1990s Trend Scenario (1992-1997)
  - High Crop Demand Scenario (2007 to 2012)

Three alternative policy scenarios

- Forest Incentives - payment for afforestation and reduced deforestation ($100/acre)
- Natural Habitats - incentives for conservation of forest and range ($100/acre)
- Urban Containment - prohibition on urban land expansion in all rural areas

Three alternative policy scenarios

- Five land use categories
  - Crops
  - Pasture
  - Forest
  - Range
  - Urban
- Observed land uses for 1992 and 1997 for 844,000 sample points

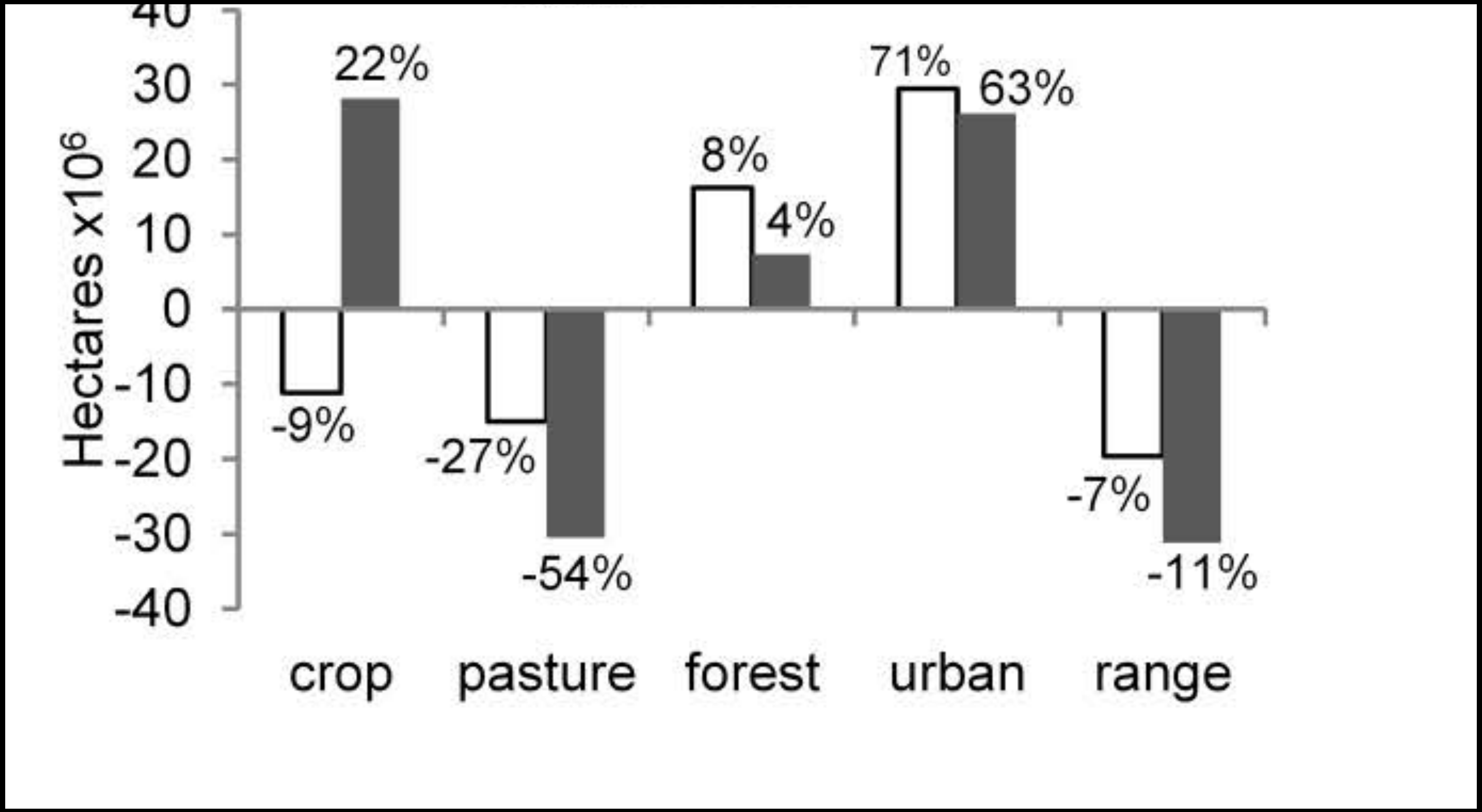
Econometric land-use change model

- Discrete choice model: predict the probability of conversion from one land type to any other land type
- The probability is a function of:
  - Starting land-use type
  - County level returns for each land-use type
  - Plot level soil characteristics (which modify returns)

Land-use change simulations

- Use econometric model results to simulate land-use transitions for a five year period
  - Repeat 10 times to generate a 50 year land-use projection (from 2001 to 2051)
- Alternative policy simulations
  - Tax/subsidy policies affect relative returns: modifies the transitions probabilities
  - Urban containment: constrain land use in rural areas
  - Re-run 50 year land-use projections with new probabilities

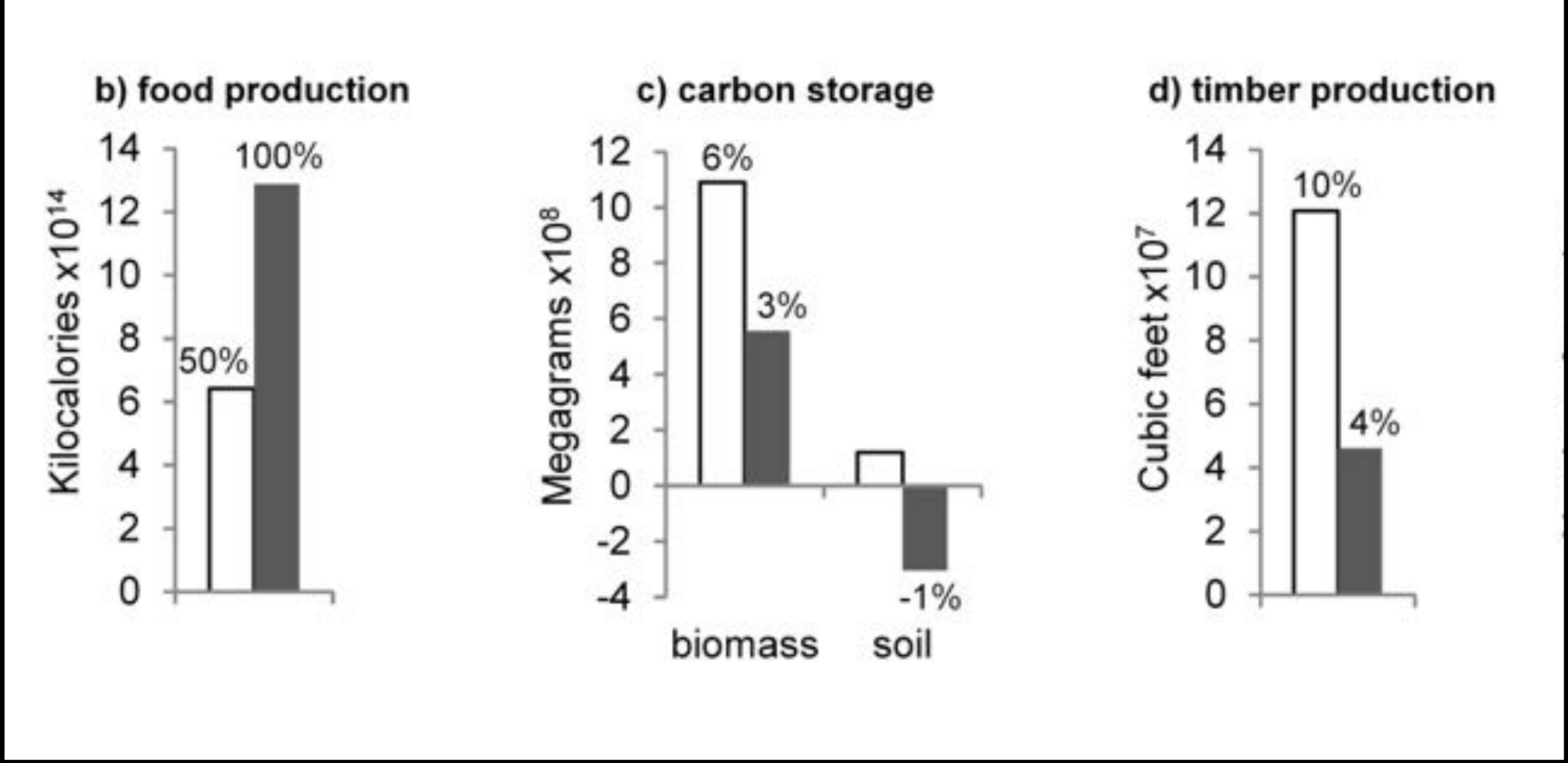
Projected land cover changes between 2001 and 2051



1990s Trend scenario

High Crop Demand scenario

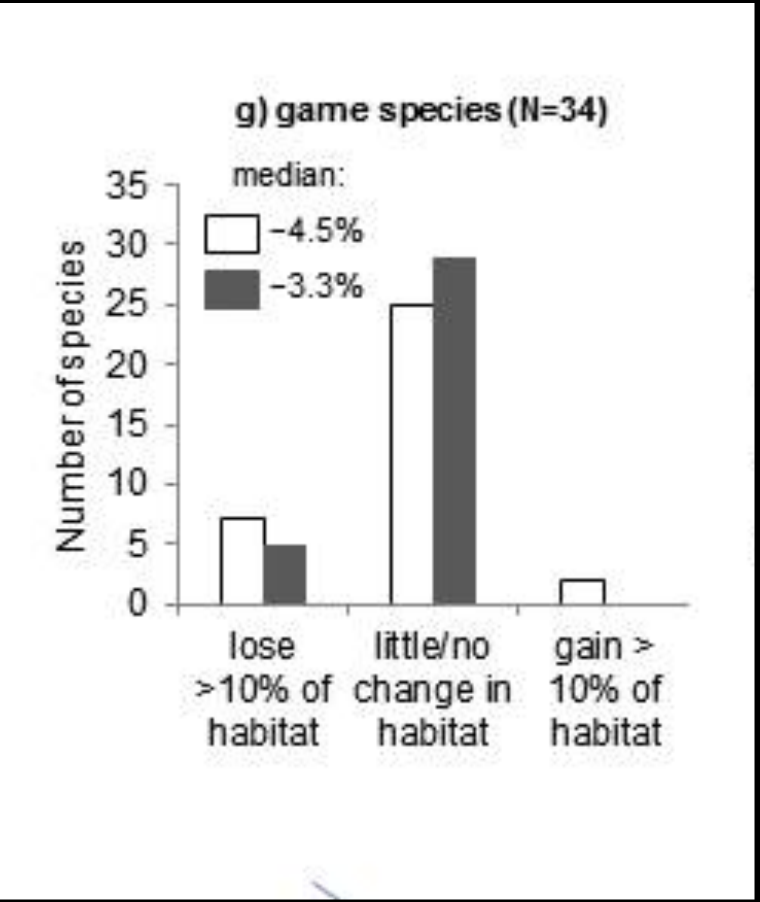
Projected changes in ecosystem services from 2001 to 2051

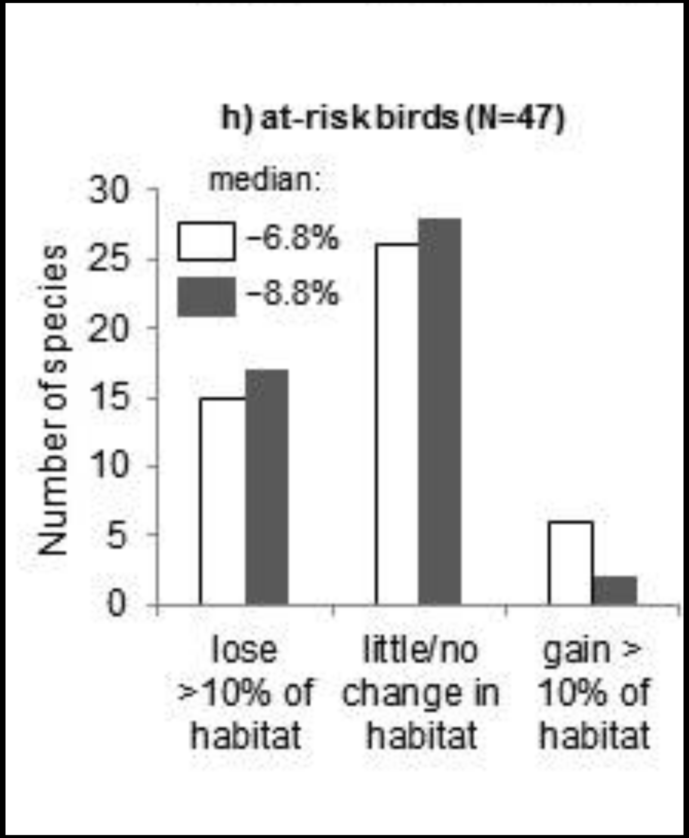


1990s Trend scenario

High Crop Demand scenario

Projected changes in habitat

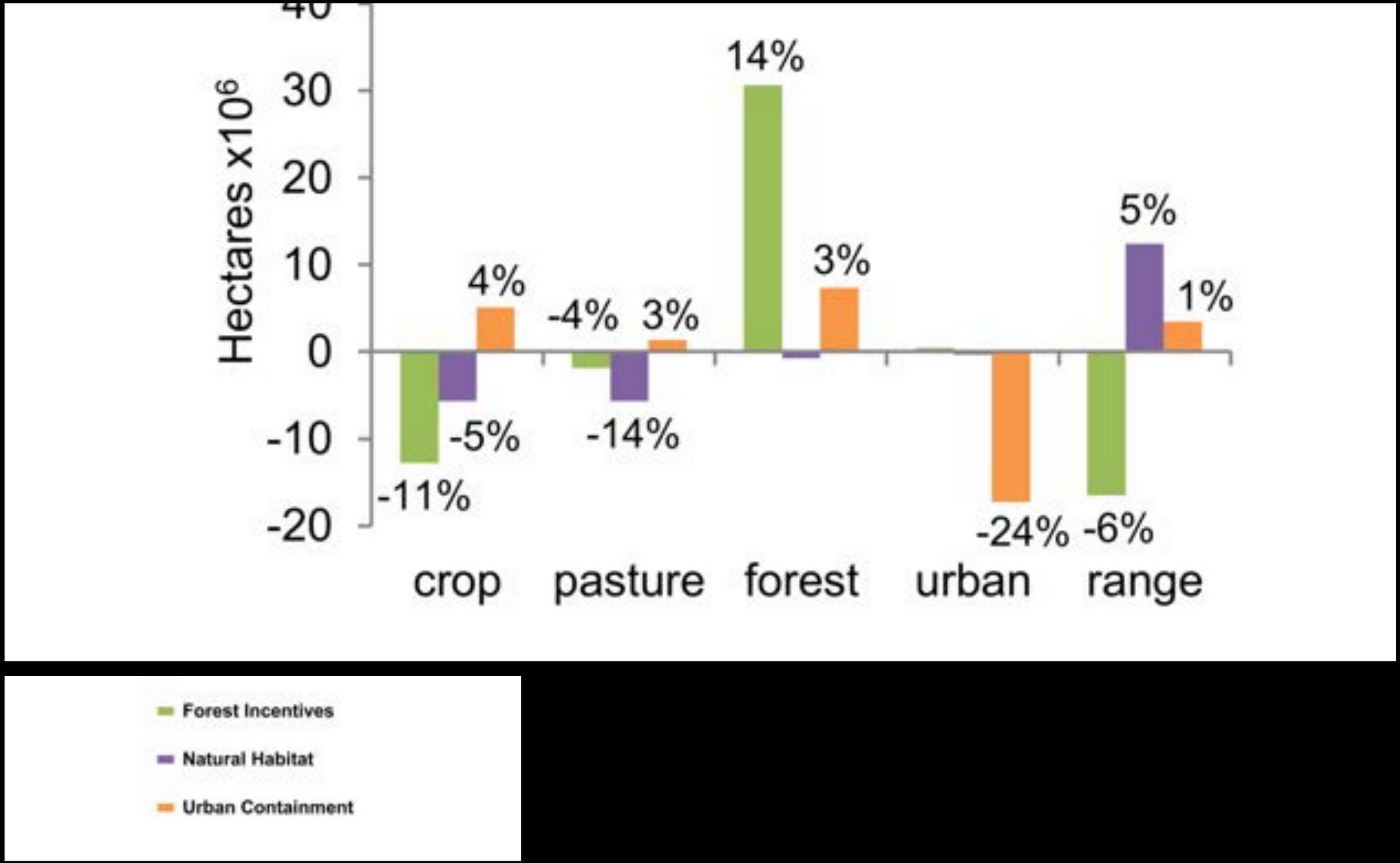




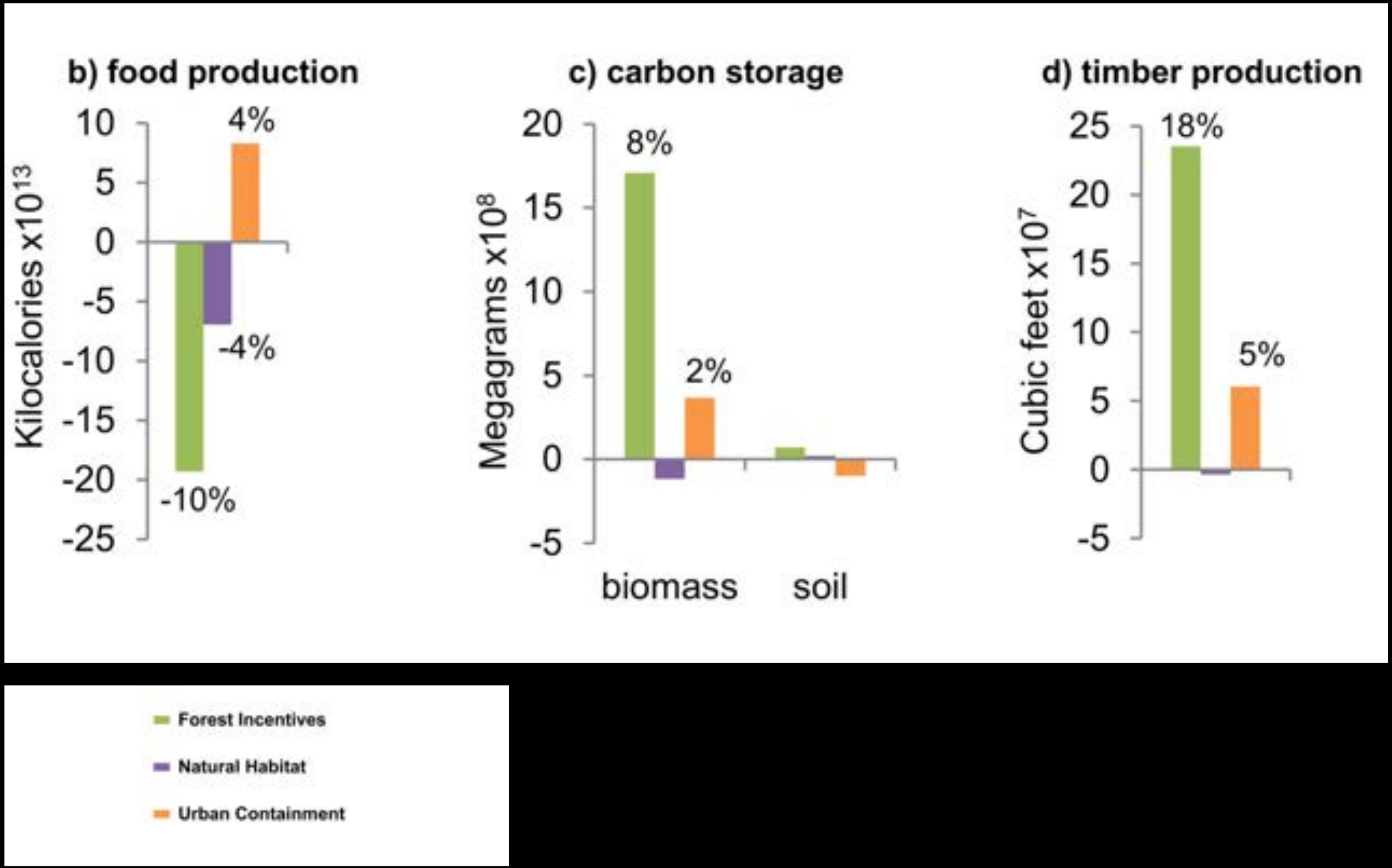
1990s Trend scenario

High Crop Demand scenario

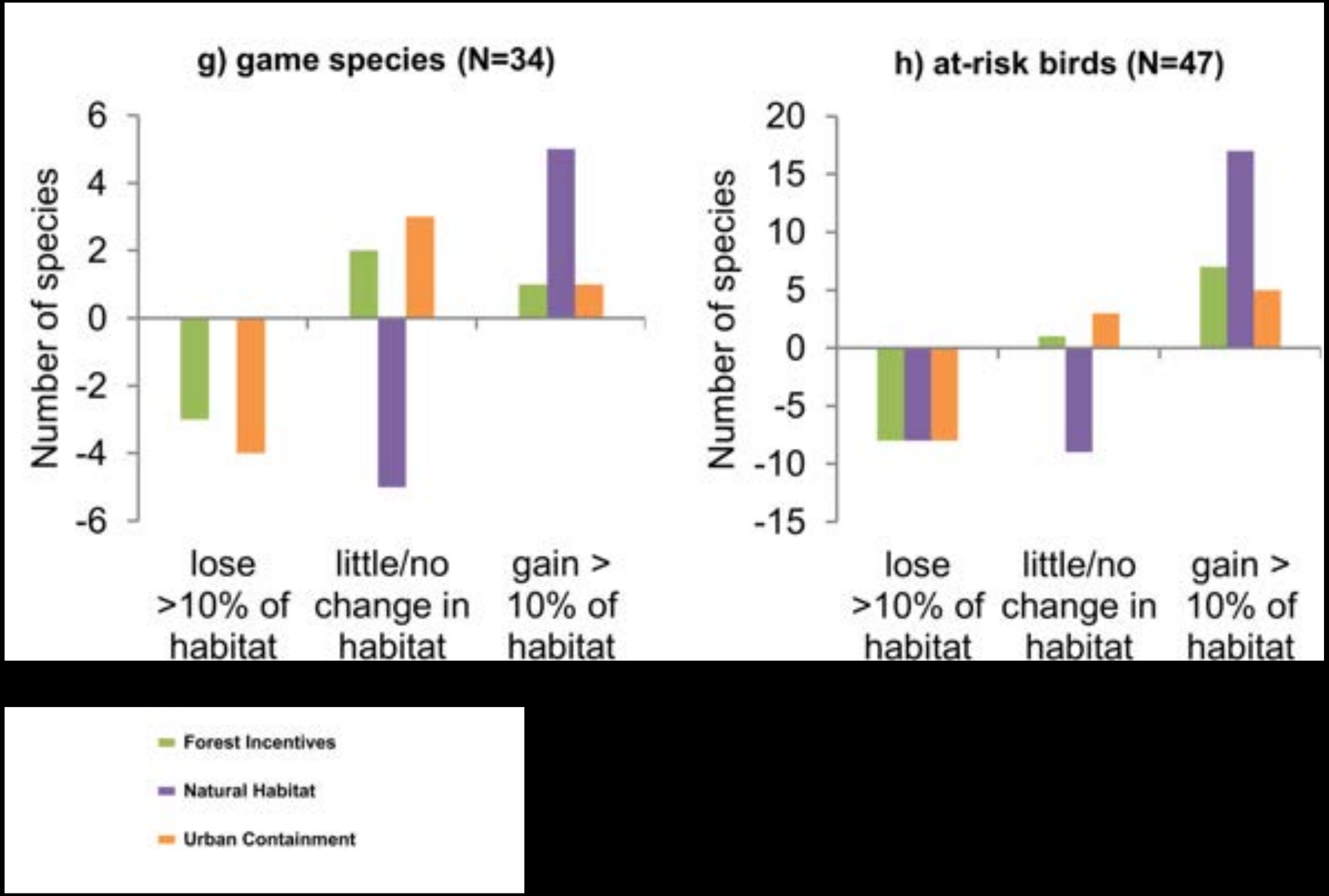
Policy simulation results: difference in land cover between policy scenarios and 1990s trend scenario



Projected changes in food production, carbon storage and timber production



Projected changes in habitat

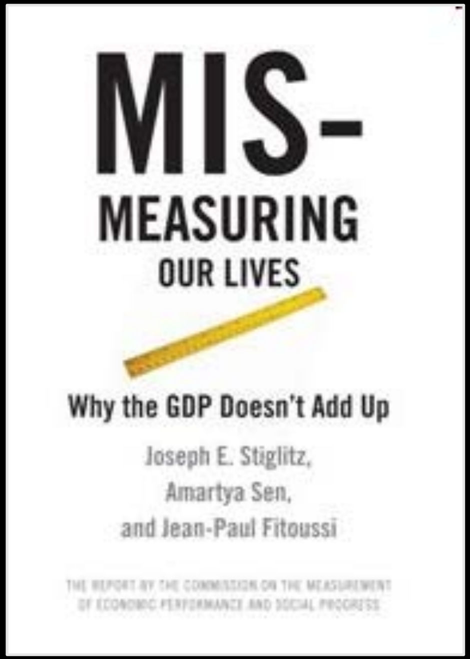


Gross Ecosystem Product (GEP) for Sustainable Development

Ouyang et al. 2019. In review

Moving beyond GDP

- Widespread recognition of the need to move beyond GDP
- Need measures of ecological, economic, and social performance

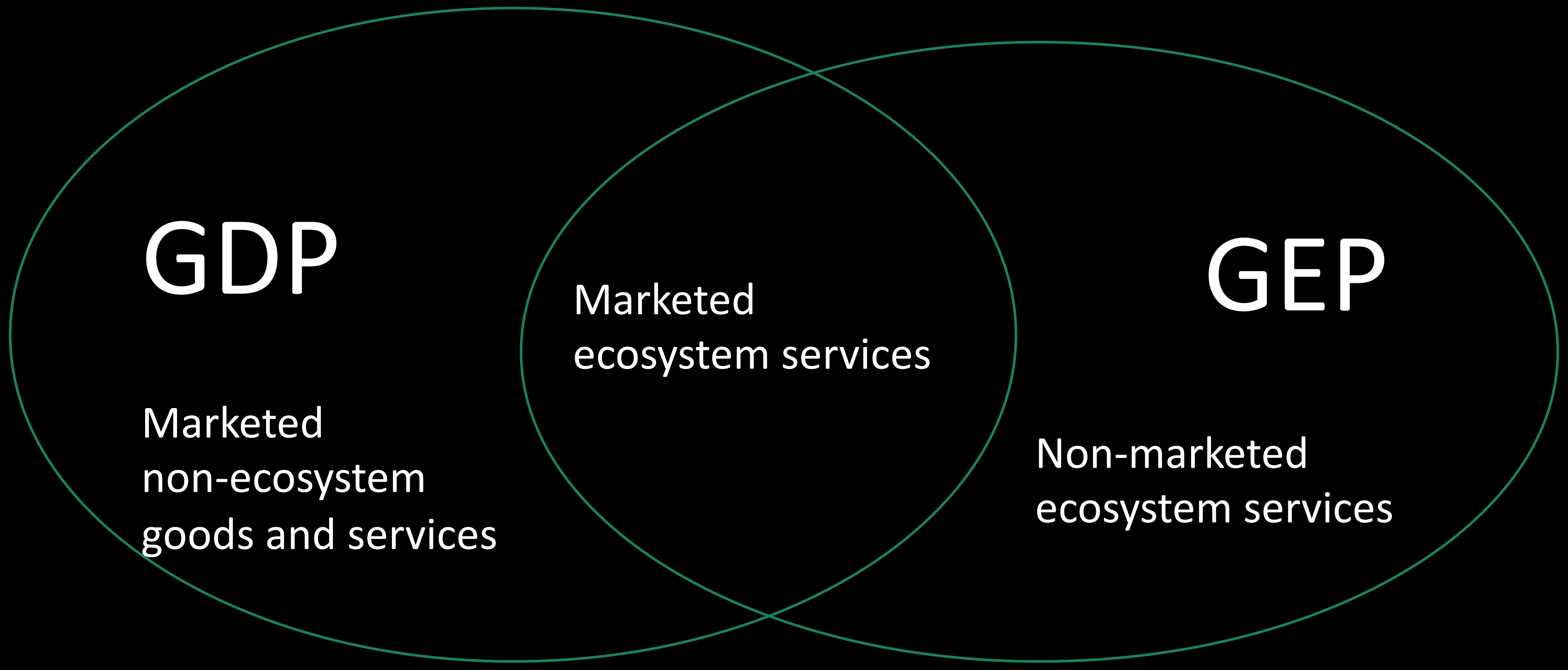


Need for GEP

- GDP provides clear and easily understood signal of economic performance (“headline number”)
- Currently lack an equivalent clear and easily understood signal of ecological performance
- Uses of GEP in China:
  - Reveal the contribution of ecosystems to the economy and human well-being
  - Show the ecological connections among regions
  - Provide the basis for compensation from beneficiaries to suppliers of ecosystem services
  - Serve as a performance metric for government officials

GEP and GDP

- GDP: summary statistic that measures the flow of income from marketed goods and services
- GEP: summary statistics that measures the flow of value from ecosystem goods and services



GEP and ecological assets

- Creating ecological asset and ecosystem service accounts:

1. Tracking the magnitude and condition of biophysical stocks of natural capital (lands, waters, and their biodiversity)
2. Translating these stocks into flows of ecosystem goods and services
3. Pricing ecosystem goods and service flows
4. Aggregating into GEP

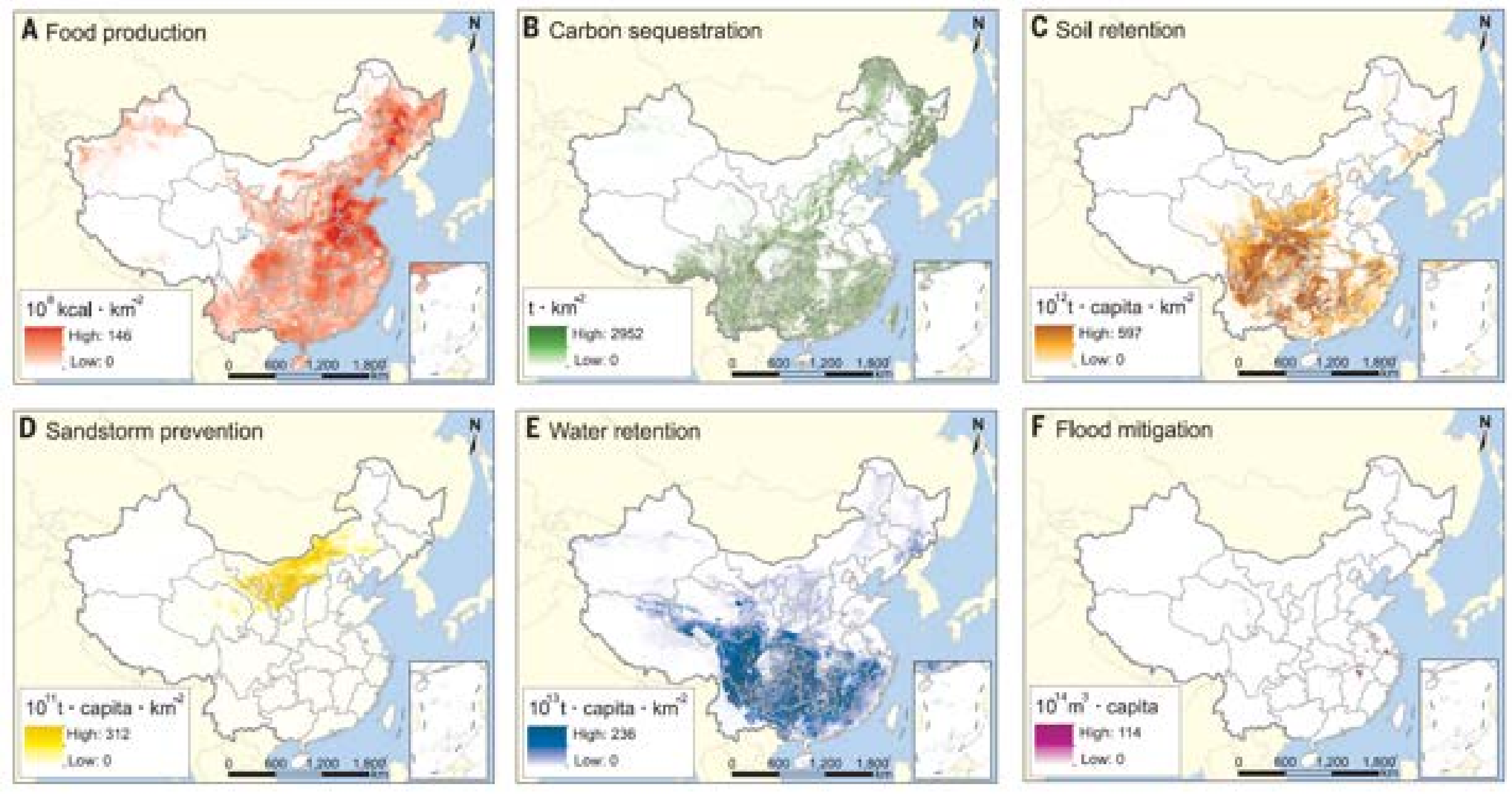
1. Tracking the magnitude and condition of biophysical stocks of ecological assets

- China Ecosystem Assessment (CEA): systematic measurement of ecological assets
- The CEA: 5-year cycle supported by a 1.76 billion yuan investment in China’s Digital Earth (Guo 2018)

2. Translating ecological assets into flows of ecosystem goods and services

- Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST; Sharp et al. 2018)
  - Use land cover and other biophysical data as inputs
  - Models calculate measure of flow of ecosystem services

Ouyang et al. 2016. Improvements in ecosystem services from investments in natural capital. *Science* 352: 1455-1459.



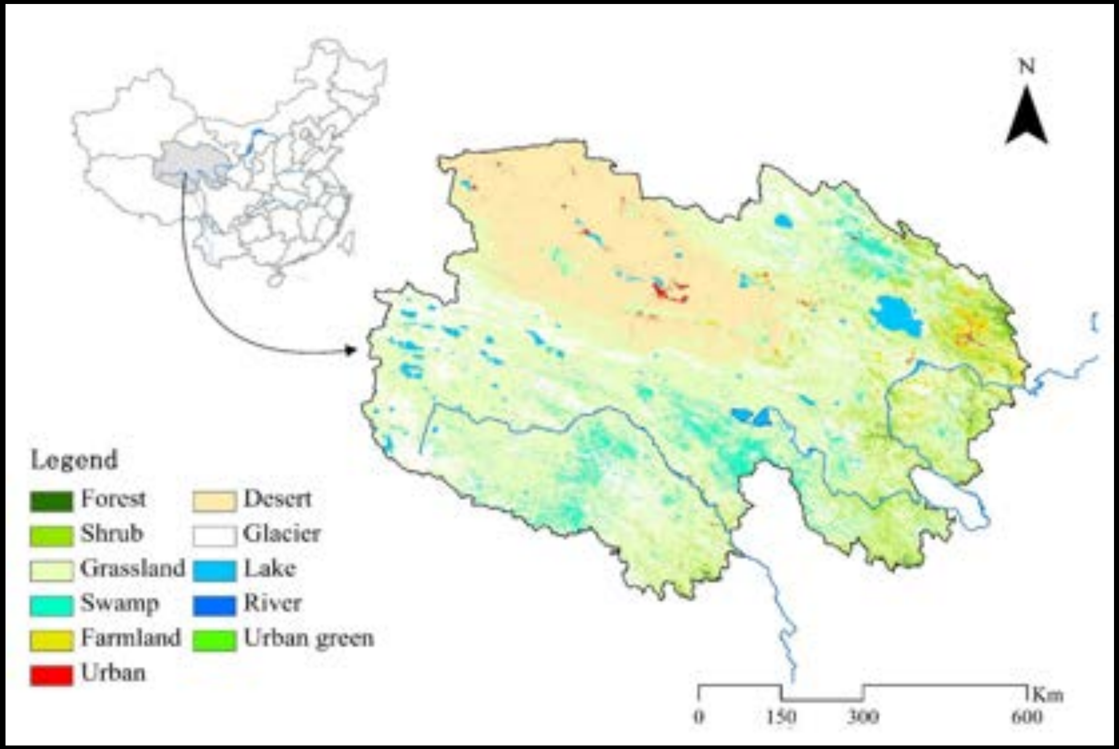
3. Pricing ecosystem goods and services

- Many ecosystem goods and services do not have a readily observable market price and are excluded from GDP
- GEP estimates price analogues for non-market ecosystem goods and services
- Most common valuation methods: imputed values for inputs and replacement cost (some travel cost, not much else in terms of standard non-market valuation techniques)

4. Aggregating into GEP

- Aggregate the values of ecosystem goods and services into a single GEP metric (taking care not to double count…)

Case study: Qinghai Province



Yellow River

Yangtze River

Mekong River

Case study: Qinghai Province

- Calculate GEP for an important set of ecosystem services
- Two time periods: 2000 and 2015

Set of ecosystem goods and services

- Provisioning goods (and services)
  - Crop and animal agricultural production, forest products, fishery production, nursery production, water supply
- Regulating (goods and) services
  - Soil retention, sandstorm prevention, flood mitigation, air purification, water purification, carbon sequestration
- Cultural (goods and) services
  - Ecotourism

GEP accounting in Qinghai in 2000 and 2015: provisioning services

		2000		2015	
		Biophysical value	Monetary value (billion yuan)	Biophysical value	Monetary value (million yuan)
Provisioning goods and services	Agricultural products (thousand tons)	1652	2.491	3091	14.5
	Forestry products (thousand m^3)	1800	0.151	825	0.743
	Husbandry products (thousand tons)	459	3.049	724	15.8
	Fishery products (thousand tons)	1.2	0.008	10.58	0.278
	Nursery products (million plants)	300	0.180	1100	0.742
	Water supply (billion m^3)	46.44	66.8	46.47	130.8

GEP accounting in Qinghai in 2000 and 2015: regulating services

		2000		2015	
		Biophysical value	Monetary value (billion yuan)	Biophysical value	Monetary value (billion yuan)
Regulating goods and services	Soil retention (million tons)	382	4.821	390	6.968
	Sandstorm prevention (million tons)	330	6.968	448	9.912
	Flood mitigation (million m^3)	700	0.022	410	0.031
	Water purification: COD (thousand tons)	33	0.023	104	0.146
	Water purification: NH-N (thousand tons)	4	0.003	10	0.018
	Air purification: SO2 (thousand tons)	32	0.02	151	0.19
	Air purification: Dust (thousand tons)	106	0.016	246	0.037
	Carbon sequestration (million tons)	131	1.96	219	4.651

GEP accounting in Qinghai in 2000 and 2015 cultural services

	2000		2015	
	Biophysical value	Monetary value (billion yuan)	Biophysical value	Monetary value (billion yuan)
Ecotourism (thousand people)	3210	2.998	23154	21.624
Total GEP		89.6		206.6
Total GDP		26.0		241.7

Summary of Qinghai Province case study

- GEP rivals GDP in value
- Importance of water supply services:
  - Provides 63% of value of GEP in Qinghai
- Other important services
  - Recreation and tourism 10.5%
  - Animal agriculture: 7.7%
  - Crop production: 7.1%
- Adding water supply value to GDP increases GDP in Qinghai by 54%

Conclusion

- The Great Depression in the 1930s led society to realize the urgent need for better economic performance metrics, such as GDP, to help guide economic policy
- The current "Great Degradation" in natural capital and ecosystem services should lead society to realize the urgent need for better metrics of ecosystem services and natural capital to help guide sustainable development

An attainable global vision for conservation and human well-being

Heather Tallis, Peter Hawthorne, Steve Polasky, Joseph Reid, Mike Beck, Kate Brauman, Jeff Bielicki, Seth Binder, Matt Burgess, Emily Cassidy, Adam Clark, Chris Costello, Joe Fargione, Eddie Game, James Gerber, Forest Isbell, Joe Kiesecker, Rob McDonald, Jen Molnar, Nathan Mueller, Daniel Ovando, Tim Boucher, Brian McPeek

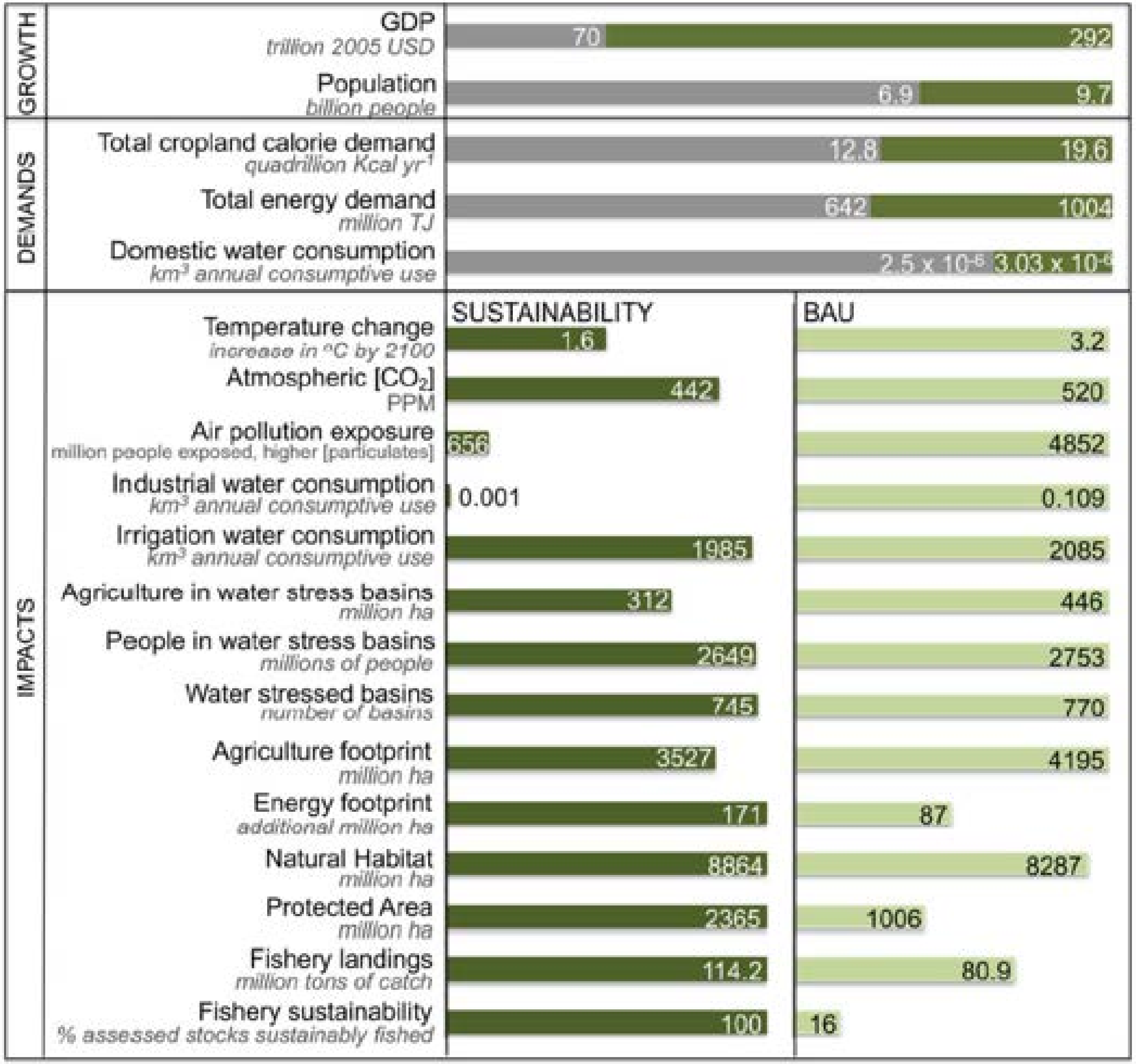
Frontiers of Ecology and Environment 16(10): 563–570. 2018

Meeting Sustainable Development Challenges

- How can we "make it fit"?
- Can we meet demands of a growing and increasingly wealthy population AND
  - Reduce greenhouse gas emissions to prevent dangerous anthropogenic climate change
  - Stop habitat and biodiversity loss
  - Reduce water stress and air pollution

Comparing Two Paths

- Business-as-usual (BAU) scenario
  - Follows current trends in technology and demand
  - Meets economic objectives
  - Does not meet environmental objectives
- Sustainability scenario
  - Consider changes in how and where to produce food, energy, and other goods
  - Meets economic objectives
  - Achieve multiple environment objectives



GROWTH
GDP
trillion 2005 USD
70
292
Population
billion people
6.9
9.7
DEMANDS
Total cropland calorie demand
quadrillion Kcal yr-1
12.8
19.6
Total energy demand
million TJ
642
1004
Domestic water consumption
km3 annual consumptive use
2.5 x 10-5
3.03 x 10
IMPACTS
SUSTAINABILITY
BAU
Temperature change
increase in °C by 2100
1.6
3.2
Atmospheric [CO2]
PPM
442
520
Air pollution exposure
million people exposed, higher [particulates]
656
4852
Industrial water consumption
km3 annual consumptive use
0.001
0.109
Irrigation water consumption
km3 annual consumptive use
1985
2085
Agriculture in water stress basins
million ha
312
446
People in water stress basins
millions of people
2649
2753
Water stressed basins
number of basins
745
770
Agriculture footprint
million ha
3527
4195
Energy footprint
additional million ha
171
87
Natural Habitat
million ha
8864
8287
Protected Area
million ha
2365
1006
Fishery landings
million tons of catch
114.2
80.9
Fishery sustainability
% assessed stocks sustainably fished
100
16

Sustainable Development

Sustainable development requires major shifts in how and where economic activity occurs

- Sustainability scenario shows a feasible pathway to sustainable development that achieves environmental goals even with large-scale increases in economic activity from a growing human population with higher per capita income
- Important shifts include
  - Transforming energy production from fossil-fuel dominated to renewable and nuclear energy
  - Offsetting habitat impacts from new energy infrastructure
  - Shifting agricultural production to areas with higher yields and lower water stress
  - Sustainably managing fisheries

Sustainable Development

HOW WE GET THERE IS THE NEXT BIG QUESTION

Meeting the sustainable development challenge

- Complex interaction of social, economic, and political considerations along with biophysical constraints make sustainable development a daunting challenge

Challenge for economists

Sackler Colloquium on "Economics, Environment, and Sustainable Development"

Role of economics in analyzing the environment and sustainable development

Stephen Polasky[a,b,1], Catherine L. Kling[c,d], Simon A. Levin[a,c,e], Stephen R. Carpenter[a,f], Gretchen C. Daily[a,g,h,i], Paul R. Ehrlich[a,g], Geoffrey M. Heal[j], and Jane Lubchenco[a,k]

PNAS | March 19, 2019 | vol. 116 | no. 12 | 5233–5238

Challenge for economists

- “The discipline of economics arguably should play a central role in meeting the sustainable development challenge.”
- “The core question at the heart of sustainable development is how to allocate the finite resources of the planet to meet ‘the needs of the present, without compromising the ability of future generations to meet their own needs’ (Brundtland Report 1987)”
- “The application of economic principles and empirical findings should be a central component in the quest to meet the aspirations of humanity for a good life given the finite resources of the earth.”

Challenge for economists

- Extensive work by economists that integrates other natural and social sciences into a policy-relevant framework on sustainable development challenges
- Some positive examples:
  - Climate change integrated assessment models
  - Sustainable use of common property resources
  - Ecosystem services and natural capital modeling

Challenge for economists

- "Despite these examples…the center of gravity in the analysis of sustainable development remains in the natural sciences, and the center of gravity in economics remains far removed from the challenge of sustainable development."
- "While natural science understanding is insufficient on its own to achieve sustainable development, the same is true of economics. Economists alone do not have the knowledge base supplied by the natural sciences necessary to understand the complex ecological systems within which the economic system operates and on which economic activity causes impacts. Progress in sustainable development requires collaboration between social scientists, including economists and natural scientists."

Challenge for economists: Improvement needed

- No economists involved in a special section on “Ecosystem Earth” (*Science* April 2017) that contained discussions of population, consumption, agricultural production, land use, human behavior, collective action, and policy
- Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
  - Three co-chairs: zero economists
  - 25 coordinating lead authors: two economists (Alex Pfaff, myself)
  - Bob Watson: chair of IPBES said it was a shame there was not more economics in the assessment

Challenge for economists: Improvements needed in the economics profession

- The fields of ecological, environmental, and resource economics are not core fields within economics
  - Only a small minority of the top economics departments have fields in ecological, environmental, or resource economics
- Few ecological, environmental, or resource economics publications in flagship journals
  - *American Economic Review* in 2018: only two papers listed classification codes for renewable resources and conservation, nonrenewable resources and conservation, energy economics, or environmental economics (one of these was "Narrative sign restrictions for SVARs")
- "Though all disciplines are in someway insular. . .this trait peculiarly characterizes economics" (Fourcade et al. 2015 *Journal of Economic Perspectives* 29: 89-114)
  - The percentage of within-field citations in economics: 81%, versus 59% for political science, 53% for anthropology, and 52% for sociology (Jacobs 2013. *In Defense of Disciplines: Interdisciplinarity and Specialization in the Research University.* Univ of Chicago Press)

Challenge for economists

- The challenge of achieving sustainable development is large and pressing
- Need economists to play a larger role
- Need more and better economics to integrate with other natural and social sciences to do policy-relevant research on sustainable development

Natural Capital Club Post Ian's Rock and Roll Revolution

Young Ian!

Photo credit: www.abc.net.au/triplej/events/one_night_stand_07

EAERE Plenary Session circa 2025

Thank you

Questions?