NatCap TEEMs First Annual Workshop

Natural Capital Project:
The Earth-Economy Modelers

25 September 2025

Motivation for NatCap TEEMs

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 Proceedings
of the National Academy of Science

Guerry, Polasky, Lubchenco, et al. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112: 7348-7355

Motivation for Earth-Economy modeling

- Biodiversity is vital natural capital that supports all life including human life ("life support system")
- Essential infrastructure on which the economy and human wellbeing depend (the economy happens on earth)
- When an article published in *Nature* estimated the total annual value of Earth's ecosystem services was $33 trillion, Mike Toman said it was "serious underestimate of infinity"

Biosphere 2

By Johndedios - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=16883643

Motivation for Earth-Economy modeling

- Human actions affect ecosystems and the benefits they provide
- The provision of these benefits often is not factored into important economic and financial decisions that affect ecosystems
- Distortions in decision-making damage the provision of these benefits making human society and the environment poorer

Mission

- *NatCap TEEMs integrates ecological, climate, and economic data in Earth-Economy models to inform decision-making for sustainable development.*

Interdisciplinary center housed in the Department of Applied Economics

- 12 people partially/fully funded by NatCap TEEMs
- 54 affiliated members: faculty, researchers, post-docs, graduate students
- We welcome more!

NatCap TEEMs
The Earth-Economy Modelers

UNIVERSITY OF MINNESOTA

The Natural Capital Project & NatCap TEEMs

Stanford University

natural capital PROJECT

NatCap TEEMs
The Earth-Economy Modelers
UNIVERSITY OF MINNESOTA

Research Center for
Eco-Environmental Sciences
Chinese Academy of Sciences

WWF

The Nature Conservancy

Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems

Current research agenda: Two examples

- Gross Ecosystem Product (GEP)
- Linking earth systems and macro-economy models (GTAP-InVEST)

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Gross Ecosystem Product (GEP)

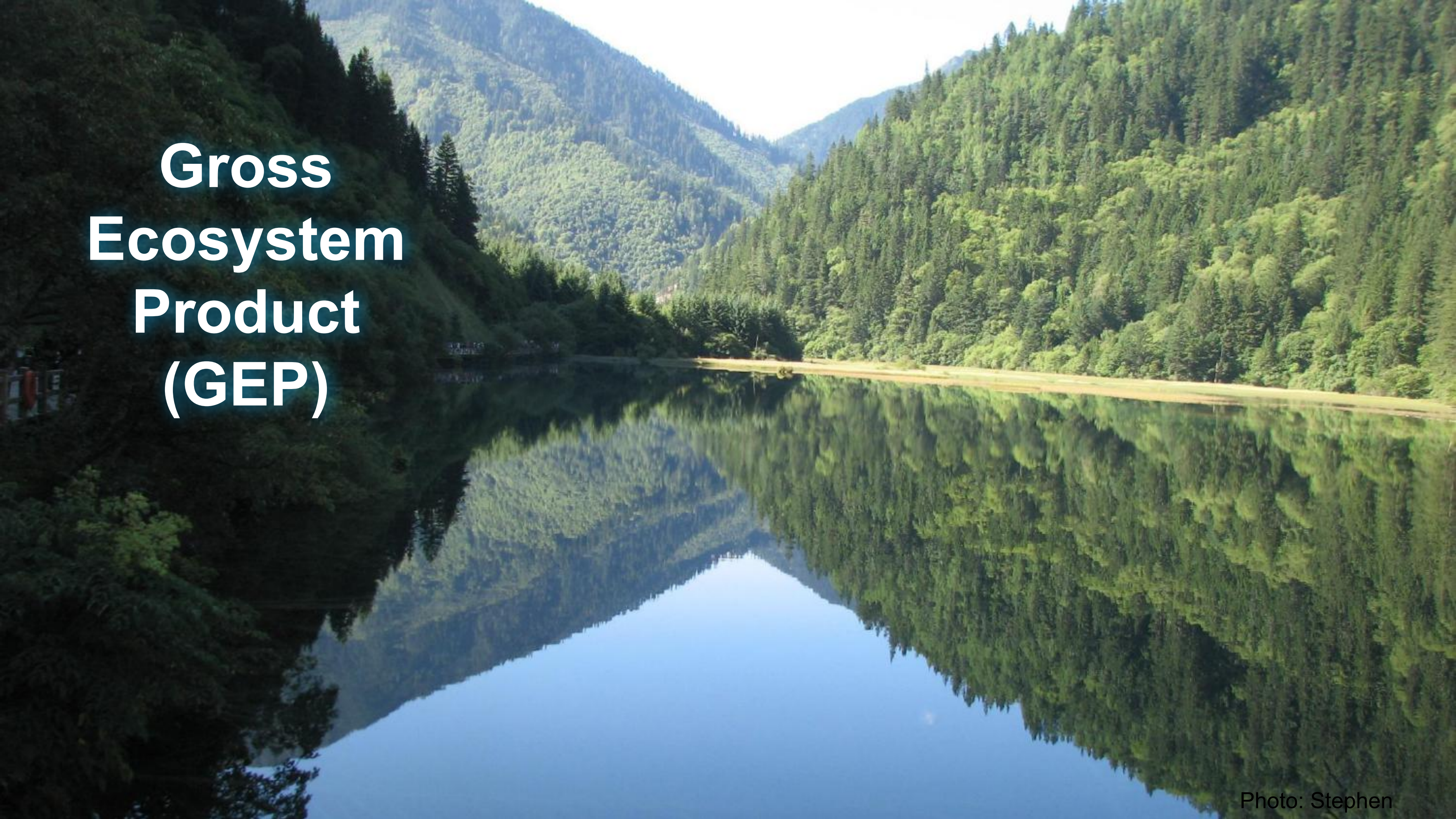
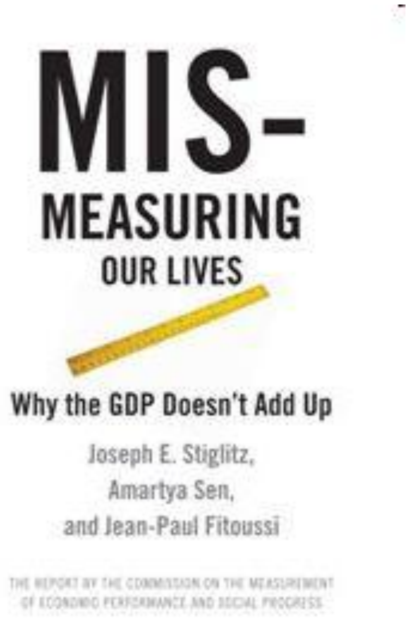


Photo: Stephen

Moving beyond GDP

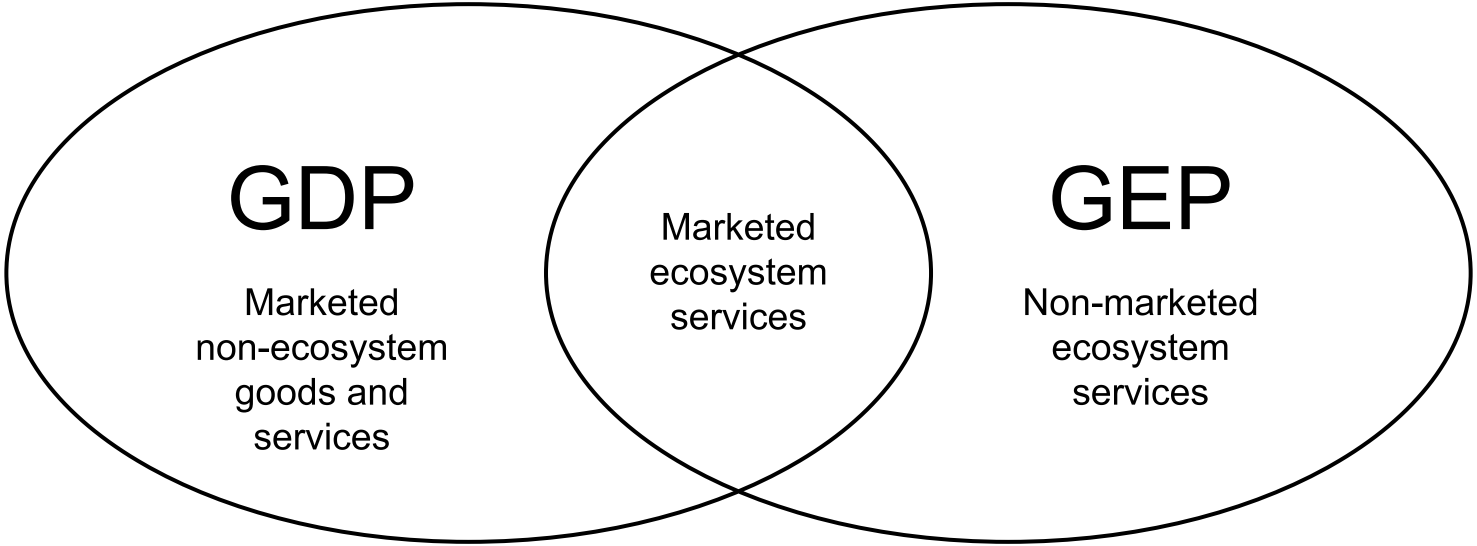
- GDP provides clear and easily understood signal of narrow economic performance
- Widespread recognition of the need to move beyond GDP for more complete performance measures of the ecological, economic, and social systems supporting human wellbeing

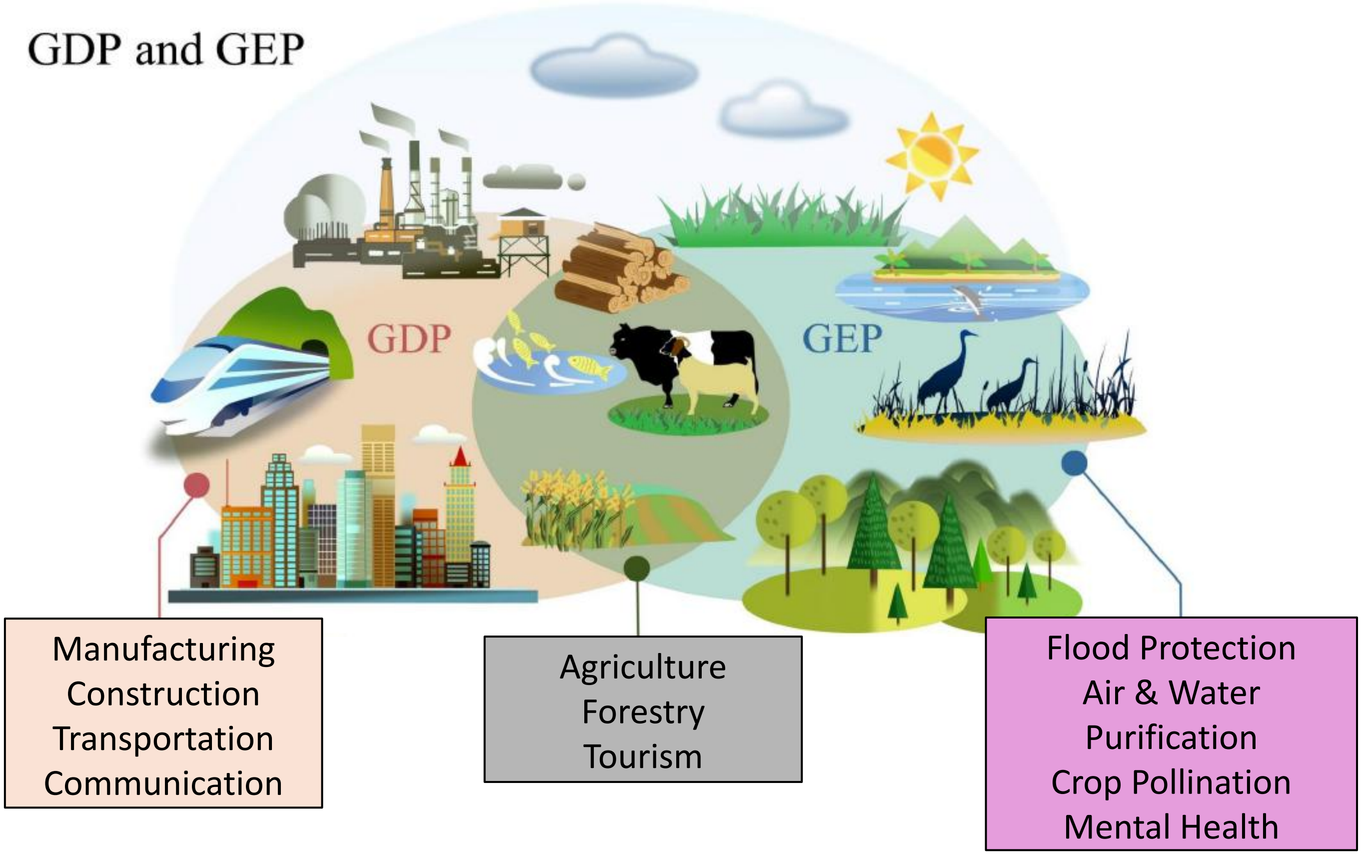


GDP and GEP defined

- GDP: summary statistic that measures the flow of income from marketed goods and services in a region in an accounting period (e.g. measured annually for a country)

- GEP: summary statistic that measures the flow of value from ecosystem goods and services. GEP is a measure of the aggregate monetary value of ecosystem-related goods and services in a given region in an accounting period





Zheng et al. 2023 Ambio

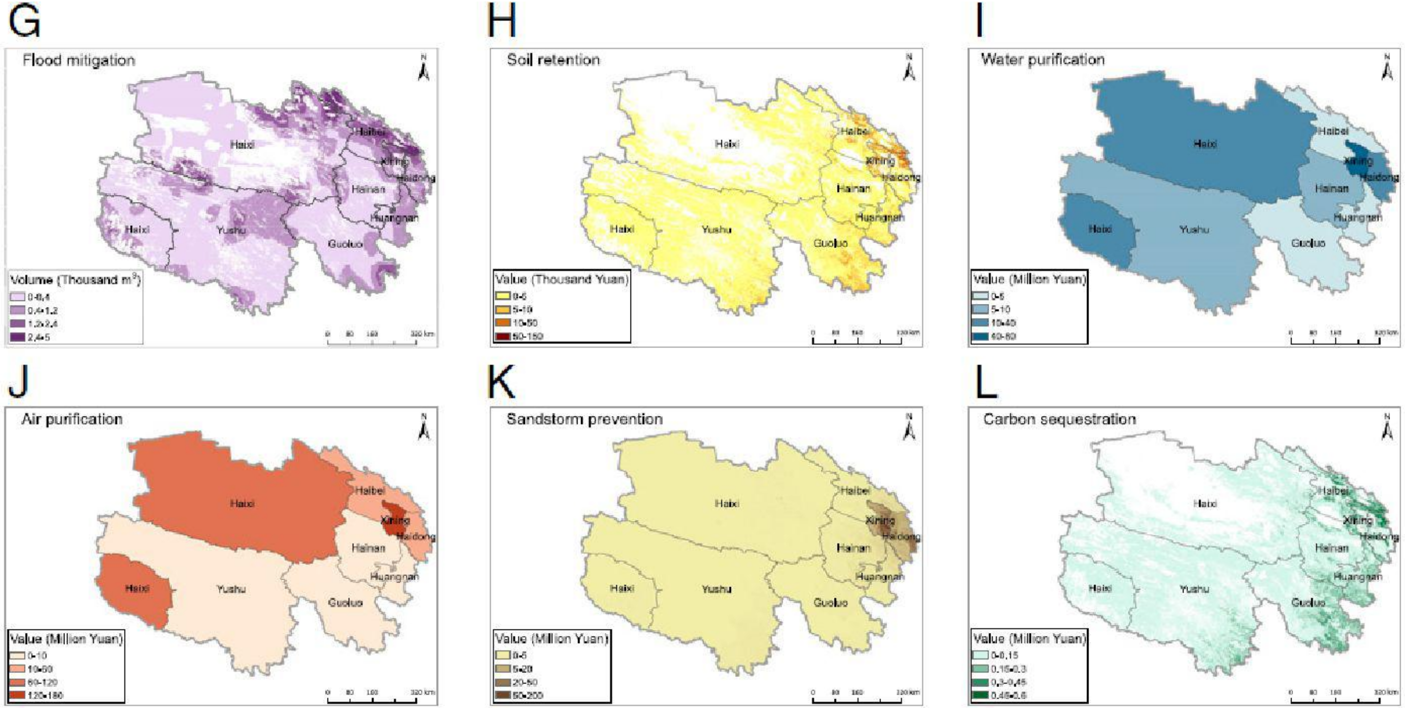
Current GEP project

- Calculate GEP for all countries around the world for 2019
- 33 ecosystem services
  - Regulating services: pollination, carbon sequestration, flood control…
  - Material services biotic: timber, agricultural crops…
  - Material services abiotic: minerals, solar and wind power,…
  - Non-material services: recreation and tourism, mental and physical health

Example of ecosystem services included: Regulating services

Ecosystem service	Methods writeup	Software code
Commercial crop pollination	Complete draft	Python code
Carbon sequestration (terrestrial)	Complete draft	Python code
Carbon sequestration (marine)	Complete draft	
Other greenhouse gases	In progress	Python code
Air quality (including dust)	Complete draft	R script
Coastal protection	Complete draft	Python code
Riverine flooding	In progress	-
Wildfires	Complete draft	R script
Landslide mitigation	Complete draft	In progress
Urban cooling	Complete draft	In progress
Urban flooding	In progress	In progress
Water quality and purification	Complete draft	In progress
Biological pest control	Complete draft	R script
Regional moisture recycling	-	-

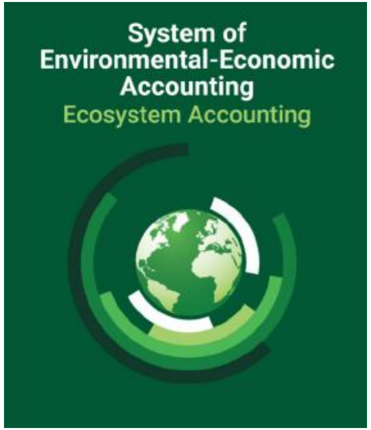
Example output: Regulating service provision in Qinghai Province, China

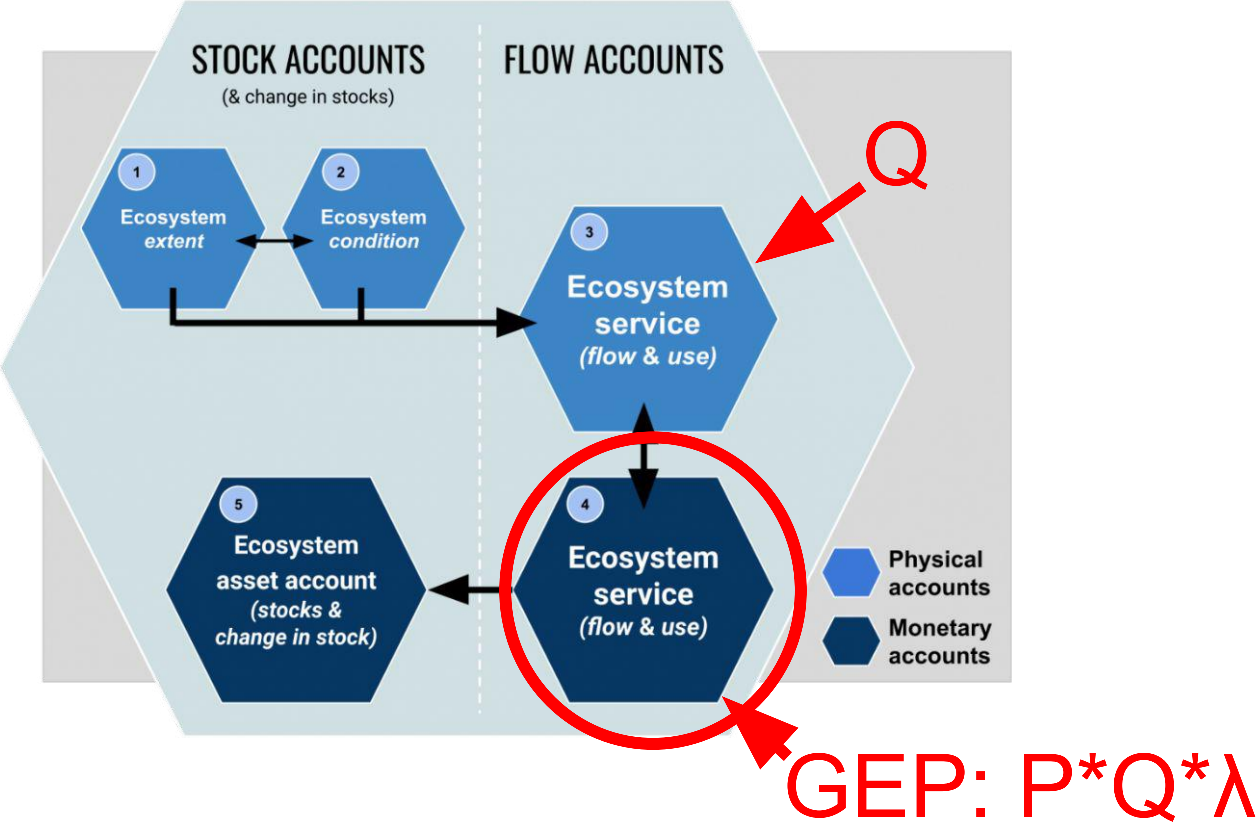


GEP Accounting in Qinghai (2000 – 2015)

Types of service	Category of ecosystem services	Accounting items	2000			2015			2000-2015 (constant price)		2000-2015 (current price)	
			Bio-physical quantity	Monetary value (Billion Yuan)	% of total value	Bio-physical quantity	Monetary value (Billion Yuan)	% of total value	Amount of change (Billion Yuan)	% change	Amount of change (Billion Yuan)	% change
Material services	Production of ecosystem goods	Agricultural crop production ($x10^3$t)	1652.1	1.0	1.2	3091.2	5.6	3.0	4.2	310.6	4.6	482.1
		Animal husbandry production ($x10^3$t)	458.7	1.1	1.4	724	5.8	3.1	4.2	266.4	4.7	419.4
		Fishery production ($x10^3$t)	1.2	0.01	0.01	10.6	0.3	0.1	0.3	2351.5	0.3	3375.0
		Forestry production ($x10^3m^3$)	1800	0.2	0.2	825	0.7	0.4	0.5	247.1	0.6	392.1
		Plant nursery production ($x10^9$)	0.3	0.2	0.2	11	0.7	0.4	0.5	190.8	0.6	312.2
		Total		2.5	3.0		13.1	7.1	9.7	284.1	10.7	444.5
	Water supply	Water use in downstream agricultural irrigation ($x10^9$ m^3)		11.8	14.5		15.0	8.1	-1.5	-9.3	3.2	26.8
		Water use in households ($x10^9m^3$)		5.3	6.5		13.8	7.4	6.4	86.5	8.5	160.4
		Water use in industry ($x10^9m^3$)		19.4	23.8		29.2	15.8	2.2	8.1	9.8	50.5
		Hydropower production ($x10^9$ kwh)	21.3	11.3	13.9	92	48.8	26.3	37.5	331.6	37.5	331.6
		Total		47.8	58.7		106.7	57.6	44.5	71.6	58.9	123.3
Regulating services	Flood mitigation	Flood mitigation ($x10^9m^3$)	0.07	0.02	0.03	0.07	0.03	0.02	0.001	2.3	0.01	45.0
	Soil retention and non-point pollution prevention	Retained soil ($x10^9$ t)	0.4	4.8	5.9	0.4	7.0	3.8	0.13	1.9	2.1	44.5
		Retained N ($x10^3$ t)	9.8	0.01	0.01	10	0.02	0.01	0.0003	1.9	0.01	103.9
		Retained P ($x10^3$t)	0.7	0.002	0.002	0.7	0.002	0.001	0.00004	2.0	0.00004	2.0
	Water purification (wetland)	COD purification ($x10^3$ t)	33.2	0.02	0.03	104.3	0.1	0.1	0.10	214.0	0.1	528.0
		NH-N purification ($x10^3$ t)	3.5	0.00	0.004	10	0.02	0.01	0.01	186.8	0.01	473.6
		TP purification ($x10^3$ t)	-	-	-	0.9	0.003	0.001	-	-	-	-
	Air purification	SO_2 purification ($x10^3$ t)	32.0	0.02	0.02	150.8	0.2	0.1	0.15	370.9	0.2	841.8
		NO_x purification ($x10^3$ t)	-	-	-	117.9	0.1	0.1	-	-	-	-
		Dust purification ($x10^3$ t)	105.5	0.02	0.02	246	0.04	0.02	0.02	133.3	0.02	133.3
	Sandstorm prevention	Sand retention ($x10^9$t)	0.3	21.4	26.2	0.5	31.7	17.1	1.5	4.9	10.3	48.2
	Carbon sequestration	Carbon sequestration ($x10^9$ t)	0.01	2.0	2.4	0.02	4.7	2.5	1.9	67.4	2.7	137.3
		Total		28.3	34.7		43.9	23.7	3.9	9.8	15.6	55.3
Non-material services	Eco-tourism	Tourists ($x10^6$ persons)	3.2	3.0	3.7	23.2	21.6	11.7	21.2	4988.4	18.6	621.3
Grand Total				81.5	100.0		185.4	100.0	79.3	74.9	103.9	127.5

Relationship to UN SEEA





Final thought

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

Global Earth-Economy Modeling

PNAS

RESEARCH ARTICLE | ECONOMIC SCIENCES ENVIRONMENTAL SCIENCES

Investing in nature can improve equity and economic returns

Justin Andrew Johnson[a,1], Uris Lantz Baldos[b], Erwin Corong[b], Thomas Hertel[b], Stephen Polasky[a,1], Raffaello Cervigni[c], Toby Roxburgh[d], Giovanni Ruta[c], Colette Salemi[e], and Sumil Thakrar[a]

Earth-Economy Models

- Earth-economy models integrate earth system models (ecosystem services) with general equilibrium models to analyze integrated socio-economic-ecological system
- We have linked Global Trade Analysis Project (GTAP)-computable general equilibrium model of the economy with the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

The Global Earth-Economy Model in a nutshell

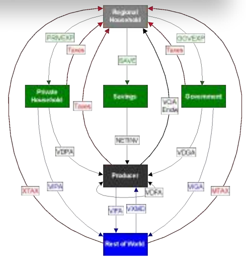
Policy changes

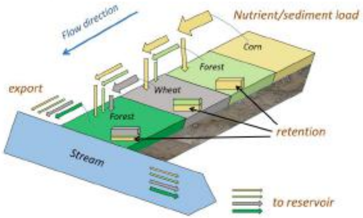
- Fiscal reform
- Expansion of PES
- Intensification of agriculture
- Trade policies

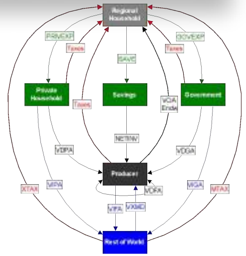
1. *Pollination*
2. *Timber*
3. *Fisheries*
4. *Carbon…*

- **GDP**
- **Welfare**
- **Factor use**

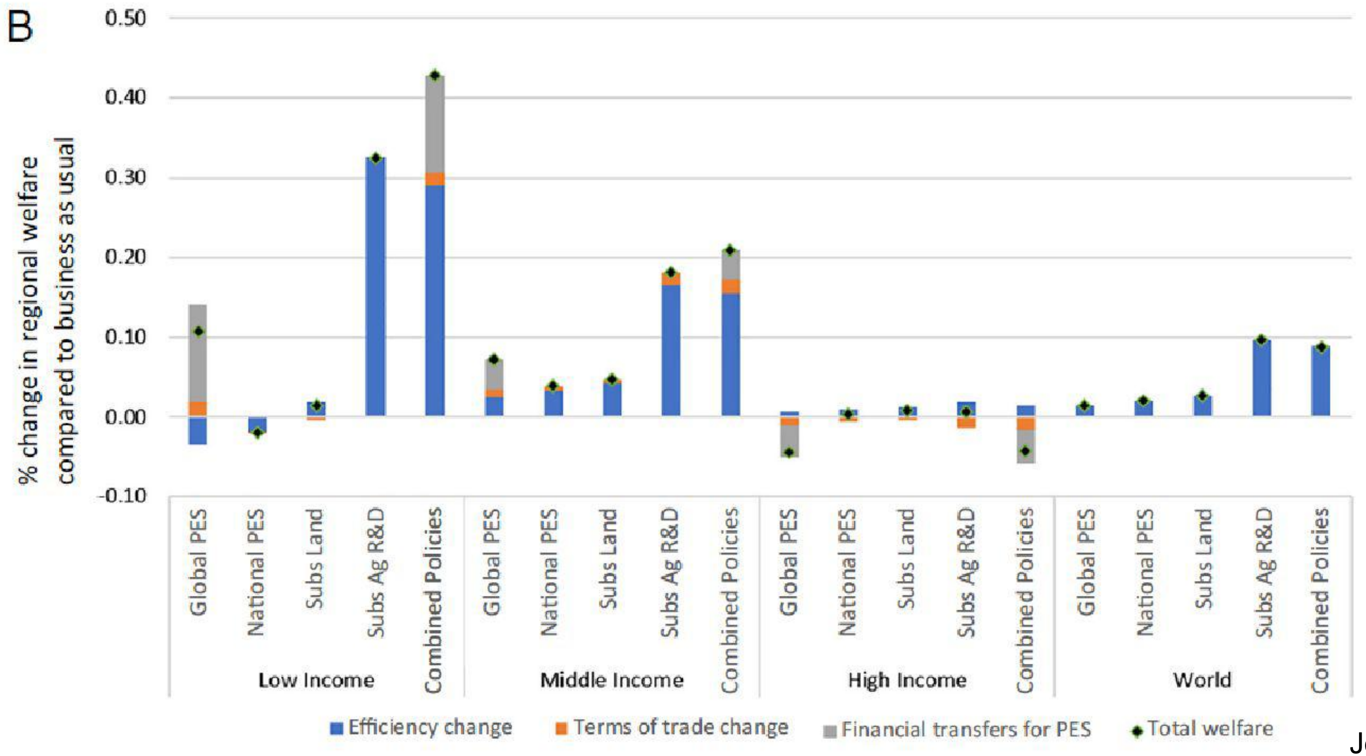
CGE Economic Model (without ES) → **Change in land use** → Natural Capital → Ecosystem Services Model → CGE Economic Model







Gains/losses to different income groups under alternative policies



Johnson et al. PNAS 2003

Future directions

- Dynamic-recursive earth-economy model
- Simulate evolution of ecosystems, climate, economy through time
- Analyze policy options and how this shifts outcomes (natural capital, ecosystem services, climate, income, trade employment, GDP & GEP)

Data and software

- Expand and improve the data
- Professionalize our software
- Goal: make it easy to bring nature and climate into all economic, financial decisions to help achieve sustainable development

Linking to implementing partners

- Government agencies (local, state, national)
- NGOs (IUCN, WCMC, TNC, WWF…)
- International institutions and development banks (World Bank, IMF, IDB, ADB…)
- Central banks and financial institutions (Chilean Central Bank, NGFS…)
- Accounting: UN SEEA
- Businesses and investors (TNFD)

Path ahead

- Huge demand for analytical capabilities of integrated earth-economy models
- Many next steps in research, data, software, training, implementation to meet this demand
- Mainstream value of nature and bring values into sharp focus to push forward on the path towards a sustainable future

Sign along park trail in China:
“Life is embraced with green
Human is coexist with ecology”

From Vision to Value

Reflecting on Year One and Looking Ahead

Lunch

Voices from the Field

What makes academic research actionable?

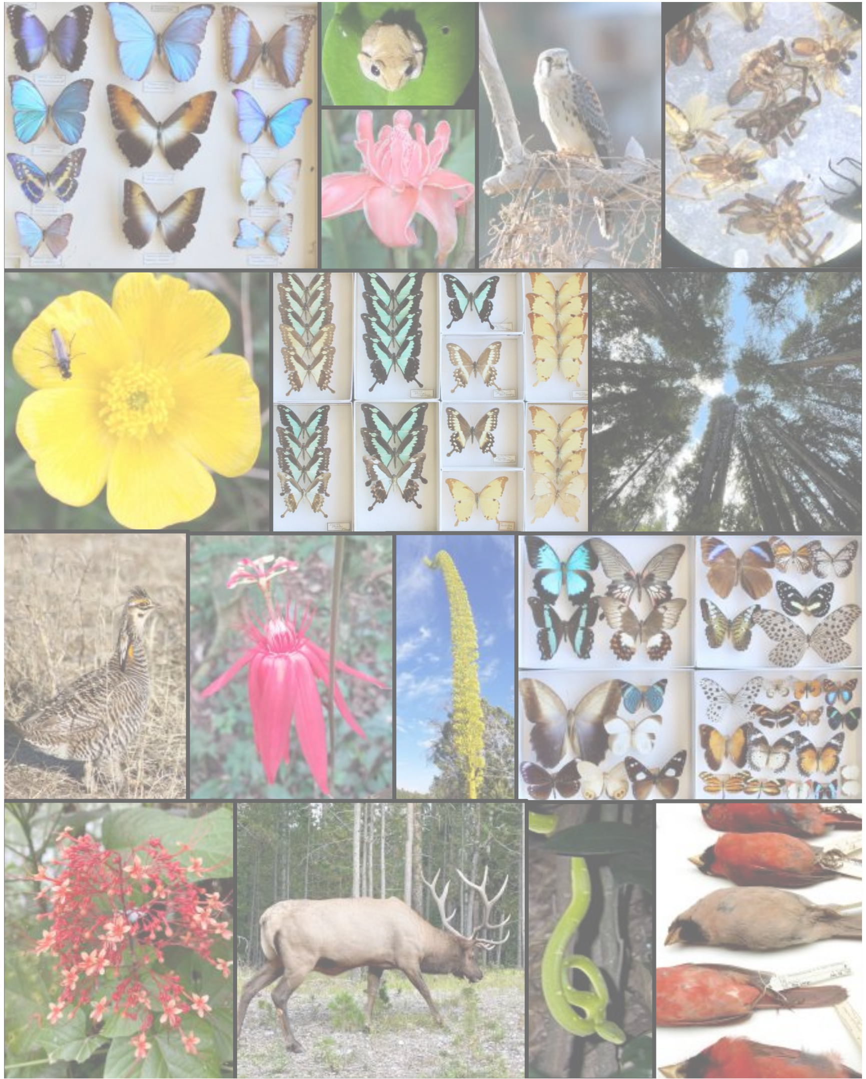
Bringing Ideas to Actionable Research

Funding the Future of Earth-Economy Science

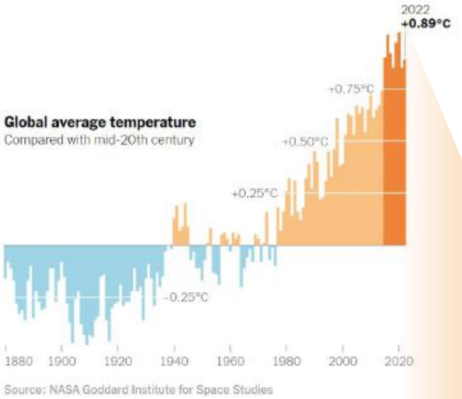
5-minute pitches

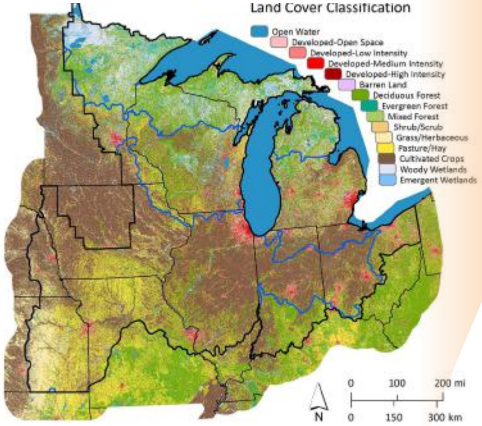
Improving biodiversity models across scales: **back to the basics**

Colleen R. Miller & Megan E. Barkdull

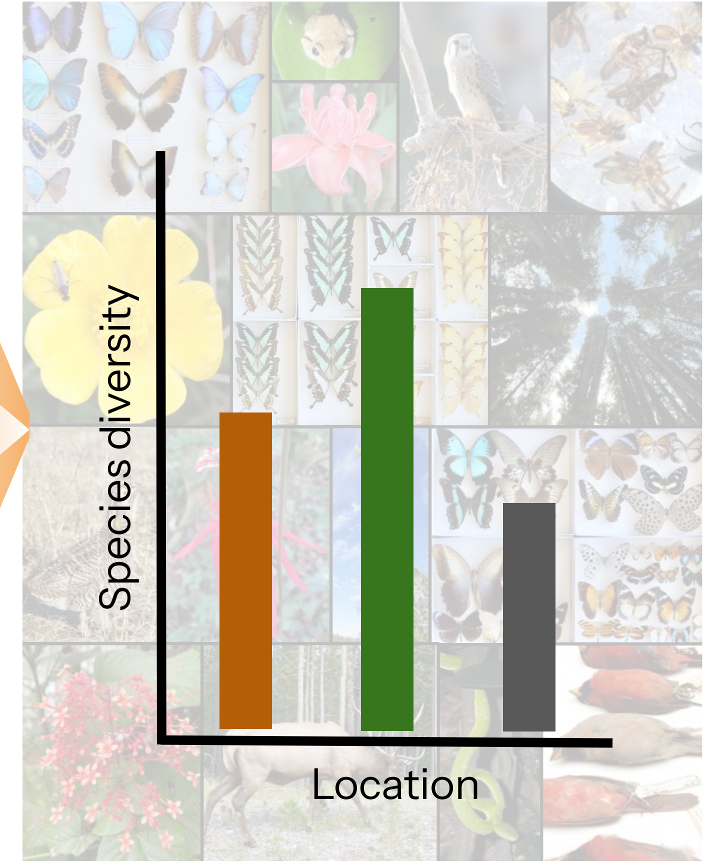


Improving biodiversity models across scales: **back to the basics**



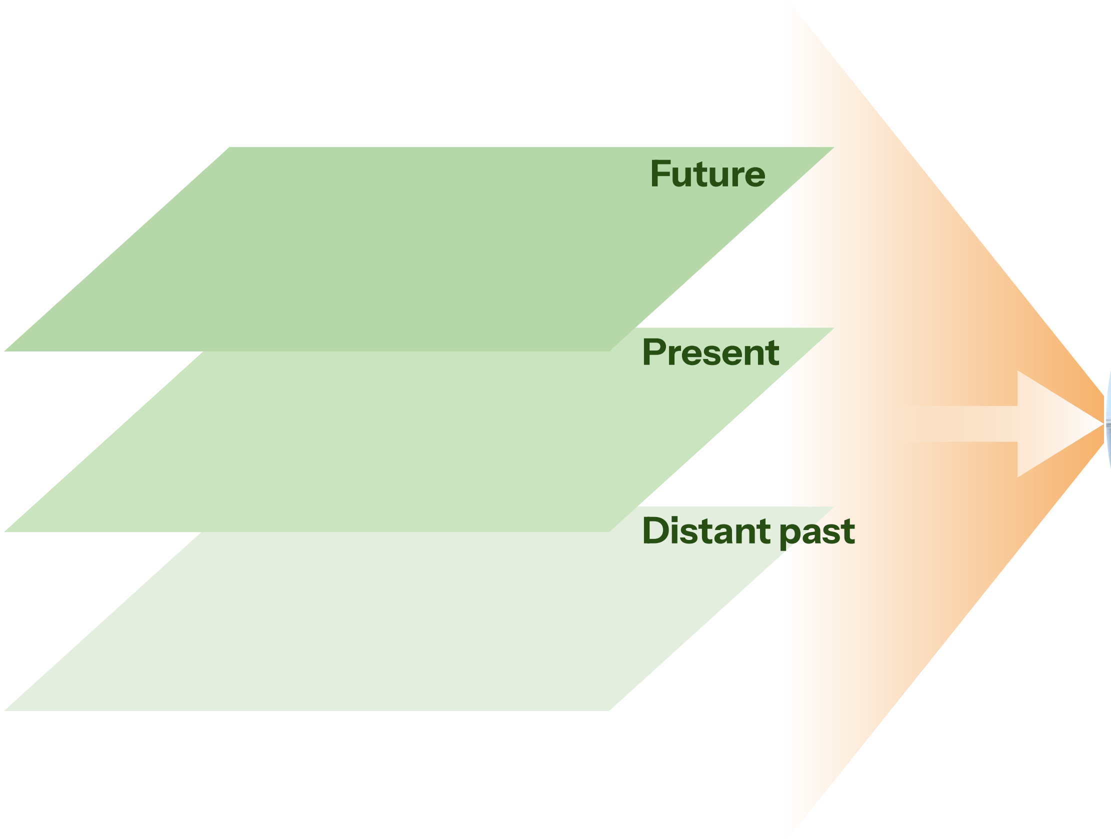


Upper Mississippi/ Great Lakes Joint Venture

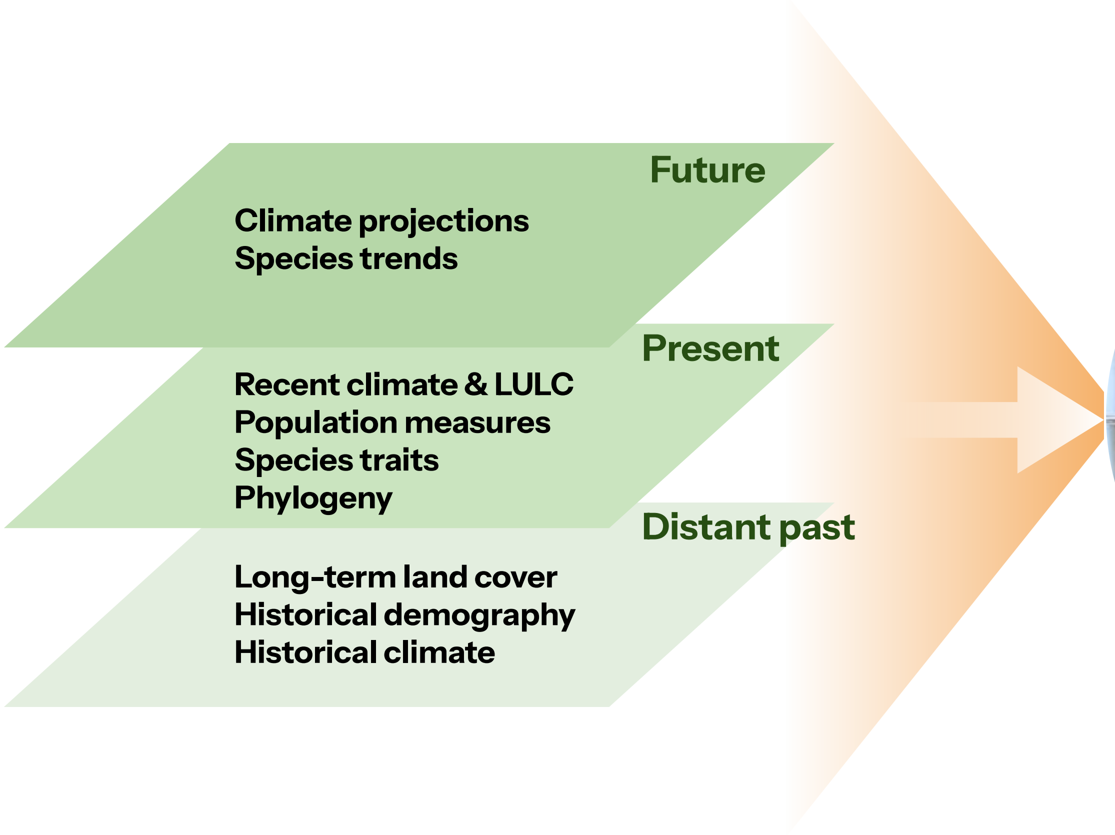


- Biodiversity models historically rely on land cover and climate data to predict species diversity at regional and global scales.
- Little, if any, long term ecological or evolutionary insight is included in predictions

Improving biodiversity models across scales: **layering over time**



Improving biodiversity models across scales: **layering over time**



Improving biodiversity models across scales: **applying lessons**

We are building a collaborative group to test whether integrating historical environmental contexts, evolutionary relationships and historical demographic inference increases the predictive power of species range models.

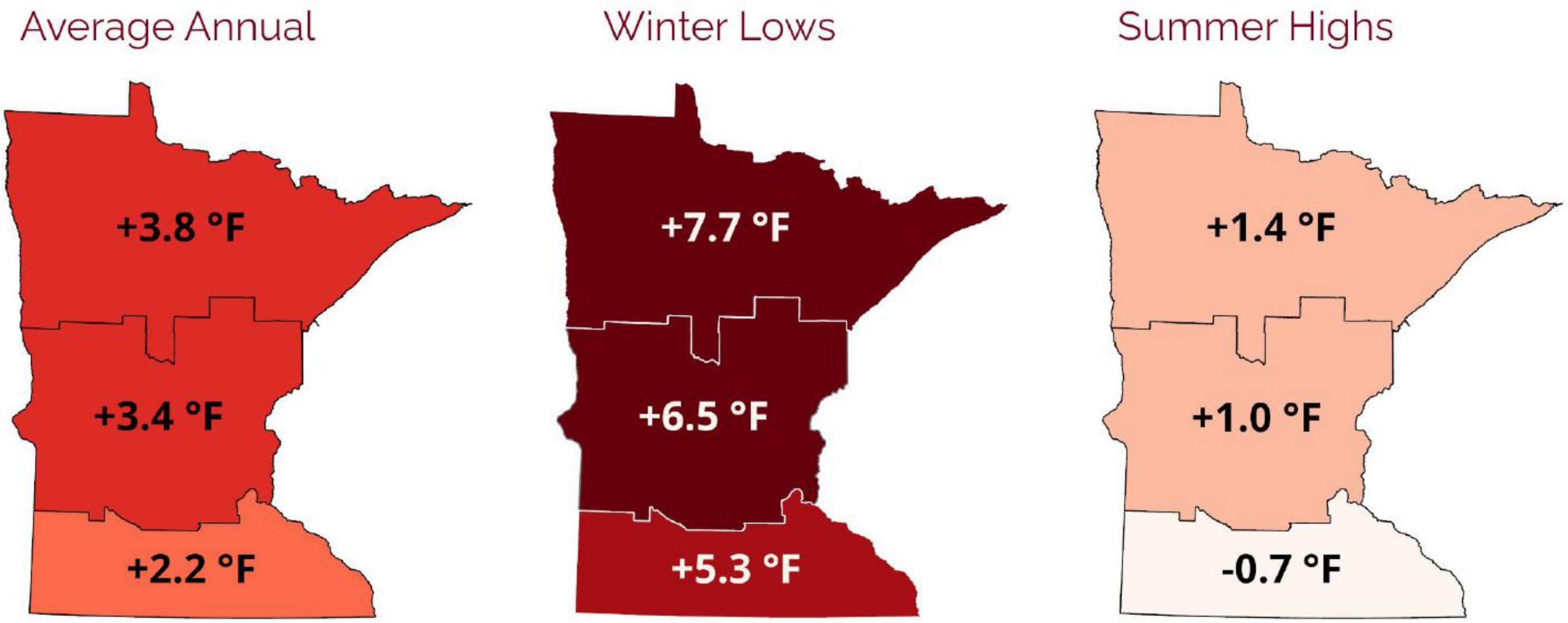
➔ Improving basic models will improve applied offerings as well, at a time when we are building new InVEST models, like a biodiversity suite

European corn borer pest

Evaluating Nature-Based Solutions for Climate Resilience in Minnesota

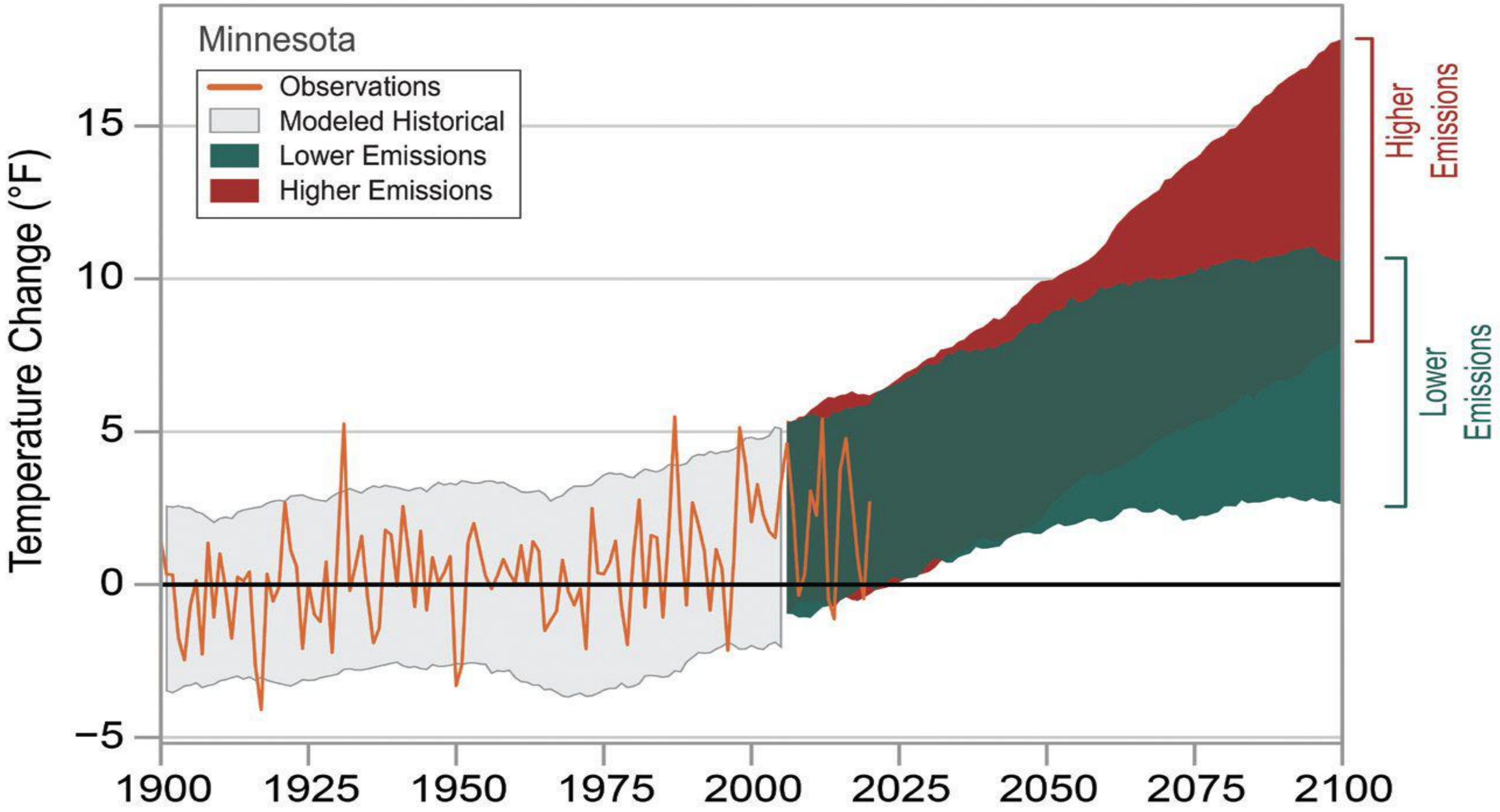
Heman Das Lohano

Observed Temperature Change in Minnesota, 1895 - 2024

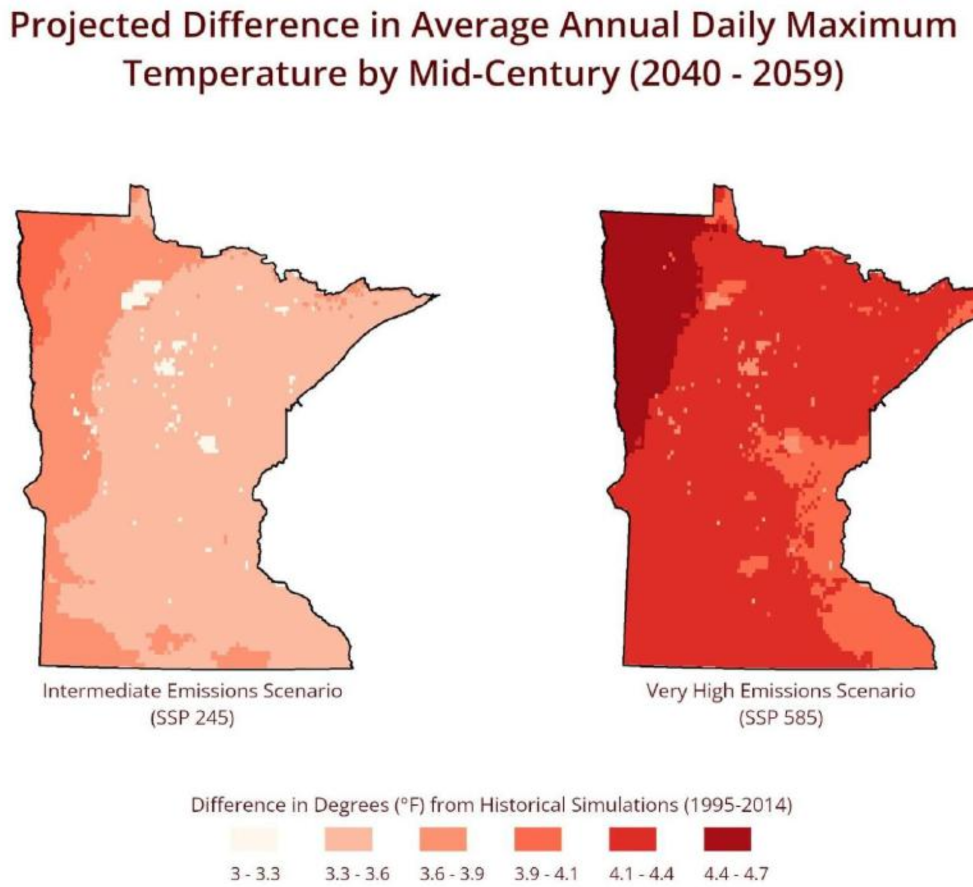


Source: https://climate.umn.edu/
UMN Climate Adaptation Partnership

Observed and Projected Temperature Change



Source: https://climate.umn.edu/



Source: https://climate.umn.edu/

Climate change trends in Minnesota through 2099

Hazard	Projections Through 2099	Confidence in Projected Changes
Warming Winters	Continued loss of cold extremes and dramatic warming of coldest conditions	Highest
Extreme Rainfall	Continued increase in frequency and magnitude; unprecedented flash-floods	
Heat Waves	More hot days with increases in severity, coverage, and duration of heat waves	High
Drought	More days between precipitation events, leading to increased drought severity, coverage, and duration	Moderately High
Heavy Snowfall	Large events less frequent as winter warms, but occasional very large snowfalls	Moderately Low
Severe Thunderstorms & Tornadoes	More "super events" possible, even if frequency decreases	

Source: Regional Climate Vulnerability Assessment
https://metrocouncil.org/

Prepare for addressing the climate change impacts

- Minnesota faces intensifying extreme rainfall, flash flooding, and heatwaves toward 2050 and beyond.
- Minnesota's regional planners and local governments recognize these risks and have planned for mitigating these risks
  - Metropolitan Council's Imagine 2050
- Nature-based solutions (NBS) and other measures for climate resilience

Nature-based solutions

- Nature-based solutions (NBS)
    - Enhancing and preserving our tree canopy
    - Urban and riparian tree planting
    - Green roofs, rainwater harvesting
    - Resilient and restorative landscapes:
        - wetland enhancements, rain gardens
- NBS can mitigate the hazards but also deliver many co-benefits
    - Water purification and Air purification
    - Enhance habitat and pollination, reduce noise, and deliver mental- and public-health benefits.
    - Carbon sequestration
- NBS achieves many objectives of Imagine 2050 and other plans

Benefit Distribution: Local, Transboundary, Global

Local:
Urban cooling
Energy saving
Flood risk reduction
Water quality
Air quality
Health

Transboundary:
Downstream flood risk reduction and water quality

Global:
Carbon sequestration
Biodiversity

Research objectives

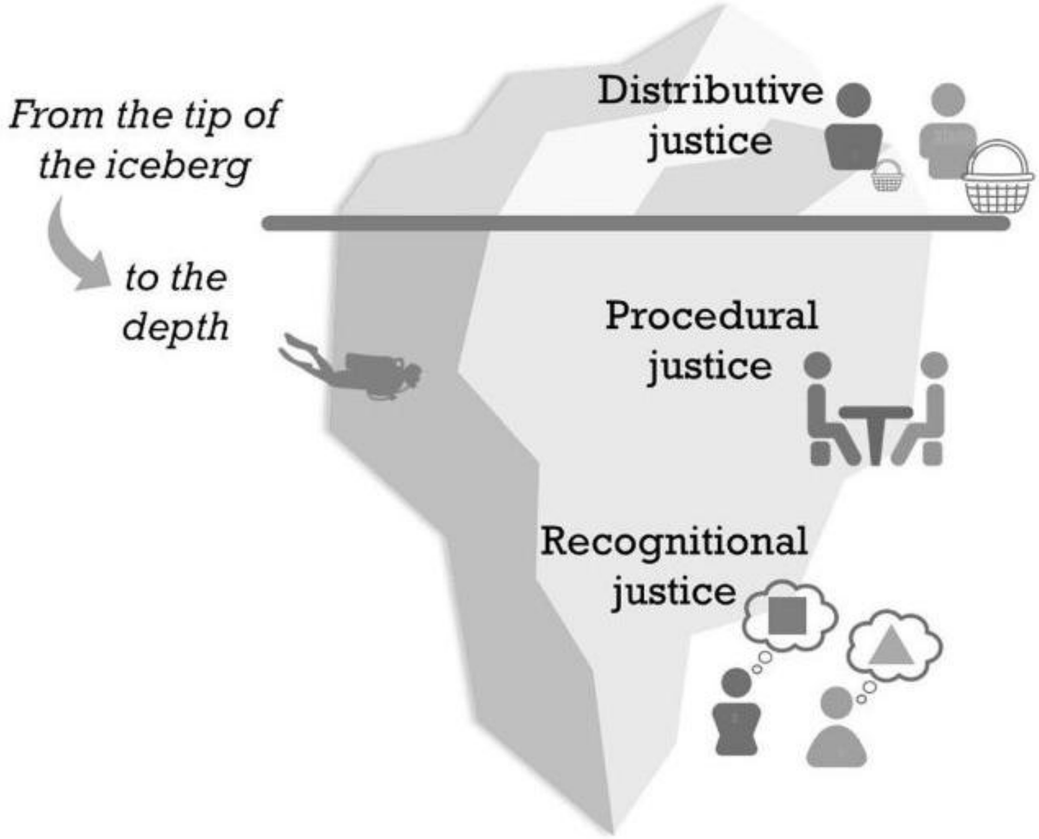
- Evaluate the existing role of nature in mitigating climate change impacts and providing many other ecosystem services (such as water purification, health) in Minnesota
  - Monetary value of ecosystem services
    - Local, Transboundary, and Global
- Evaluate the additional benefits of NBS options for enhancing these ecosystem services
- Conduct cost-benefit analysis for different NBS plans and provide recommendations

Investing in Environmental Justice within Earth-Economy Modeling

Libby Kula
9/25/2025

“Toward Procedural and Distributive Justice in Earth-Economy Modeling”

Johnson, J. A., Chaplin-Kramer, R., Chapman, M., Polasky, S., & Williams, B. (2025). *Earth-Economy Modeling: Advances in Linking Economic and Ecosystem Models*. https://doi.org/10.1146/annurev-resource-013024-033043



Loos et al. (2023) An environmental justice perspective on ecosystem services.

Procedural Justice in EE Modeling

- “Co-Creating Our Earth-Economy Future” requires procedural justice
- Working with local and diverse stakeholders to develop scenarios and priorities for model inputs/outputs
- Critical for ensuring model results are used in local decisions, but requires time and resources

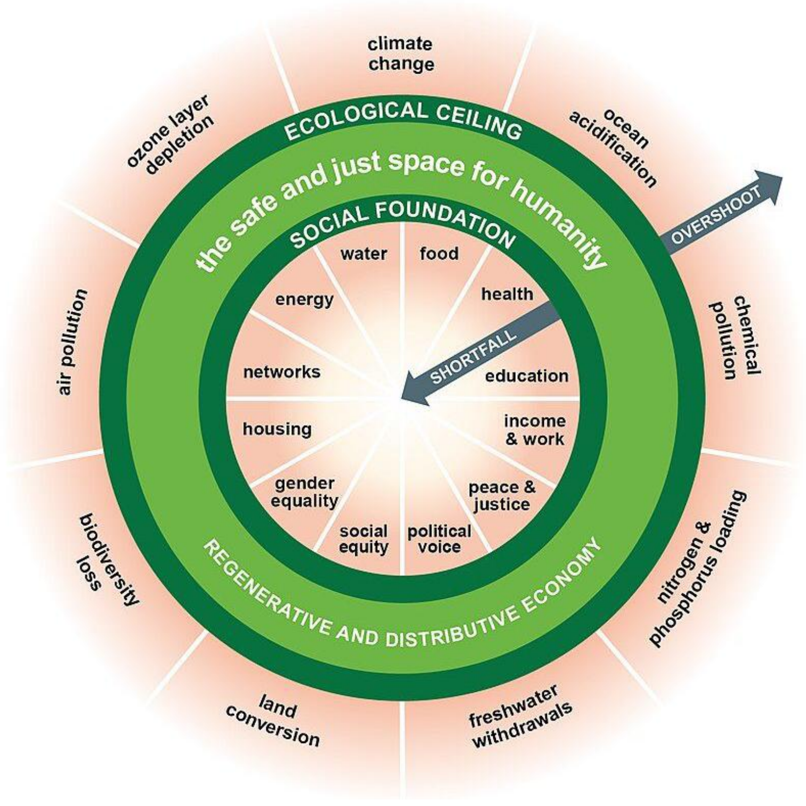
Distributive Justice in EE Modeling

- “Global models often sideline environmental justice concerns and instead focus on aggregate cost-benefit analyses without addressing how **vulnerable communities are disproportionately impacted** by environmental degradation and mitigation policies. However, this does not have to be the case.” (Johnson et al., 2025, p. 24)

- Ex. GTAP-InVEST can currently tell us the difference in effects for low-income vs. high-income countries, but not much about disaggregated effects within countries (Johnson et al., 2021)

Research questions and challenges

- How do policy and climate scenarios impact the well-being of different people/groups within a country?
  - **Measures of wellbeing:** income, locally-benefiting ecosystem services, health, happiness, etc.
  - **Socioeconomic groups:** race, ethnicity, tribe, religion, class, caste, gender, etc.
  - **Inequality measures:** distributions, differences in averages, % below thresholds (e.g., poverty), Lorenz curves, Gini/Theil coefficients, etc.
- High-income countries often have greater access to socioeconomic data. What data sources could we leverage in lower-income countries?
- How could we optimize land use to get to environmentally safe and just outcomes?



"Doughnut Economics" by Kate Raworth

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Bringing Ideas to Actionable Research

Funding the Future of Earth-Economy Science

Interactive Session

Closing Reflections

Thank You

Posters in the commons!