Metrics for Sustainable Development

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Why worry about metrics?

- Evaluation of performance (ex post)
- Policy advice: evaluation of alternatives (ex ante)

Metrics for sustainable development

- Task 1: define sustainable development
- Task 2: make definition operational (measurable outcomes in principle)
- Task 3: provide empirical measures (measurable outcomes in practice)

Two definitions of sustainable development

- World Commission on Environment and Development (WCED 1987):
  - "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Two definitions of sustainable development

- Inclusive Wealth (Arrow et al. 2004, 2010; Dasgupta Book Chapters)
  - "An economy follows a sustainable development path over a period of time if intergenerational well-being does not decline during it"
  - Non-declining well-being is equivalent to non-declining inclusive wealth

Task 2: Make definition operational

- WCED definition: hard to operationalize
  - What are “needs”?
  - Is meeting needs a yes/no answer?
  - How would we compare alternatives?

Task 2: Make definition operational

- Inclusive wealth defined (formally)

$$V(K(t),t) = \int_{t}^{\infty} U(C(s))e^{-d(s-t)}dt$$

$$\frac{dK(s)}{ds} = f(K(s),s) - C(s)$$

- V = inclusive wealth
- K = vector of capital stocks
- U = measure of well-being (“utility”)
- C = vector of flow of goods and services (“consumption”)
- δ = discount rate

Task 2: Make definition operational

- Sustainable development = non-declining inclusive wealth

$$\frac{dV(K(t),t)}{dt} \geq 0$$

Task 2: Make definition operational

- Take the time derivative of inclusive wealth:

$$\frac{dV(K(t),t)}{dt} = \frac{\partial V}{\partial t} + \sum_{i=1}^{N} \frac{\partial V}{\partial K_i} \frac{dK_i}{dt} \geq 0$$

- Redefine terms

$$\frac{dV(K(t),t)}{dt} = r_t + \sum_{i=1}^{N} p_i(t) I_i(t) \geq 0$$

Task 2: Make definition operational

- Things we need to know:

1. $p_i(t)$ = "shadow value" of capital stock *i*
2. $I_i(t)$ = net change in capital stock *i*
3. $r(t)$ = shadow value of time

Task 3: Can we measure change in inclusive wealth empirically?

- Inclusive wealth does a great job on tasks (1) & (2)
  - Succinct definition of sustainable development

$$\frac{dV(K(t),t)}{dt} \geq 0$$

- What we need to measure:
  - Changes in capital assets $\{I_i(t)\}$
  - Shadow values $\{p_i(t), r(t)\}$

Task 3: Can we measure change in inclusive wealth empirically?

- Task 3: can it be done?
- Short answer: NO
- Long answer:
  - We can estimate some elements relatively easily
  - With heroic assumptions we can approximate major elements of inclusive wealth

Measurement challenges

1. Putting the “inclusive” in inclusive wealth
   - Measuring change in all relevant stocks

2. Measuring shadow values
   - Market distortions
   - Measuring non-market values
   - Static approaches to dynamics problems
   - Treatment of uncertainty

Putting “inclusive” in inclusive wealth

- What capital stocks should be included?
  - Anything can affects human well-being either directly or indirectly
- Forms of “capital”
  - Manufactured capital: machinery, buildings, infrastructure (communication systems, roads, ports…)
  - Natural capital
  - Human capital
  - Social capital

Putting “inclusive” in inclusive wealth
Natural Capital

- Natural capital:
  - Land (including soil productivity)
  - Natural resources: mineral, energy, timber, species populations
  - Environmental quality: water, air, greenhouse gas concentrations
  - Ecosystem processes

Putting “inclusive” in inclusive wealth
Natural Capital

- Natural capital that can be tracked
  - Reserves of mineral and energy resources
  - Stocks of commercially harvested species
  - Volumes of timber
  - Some forms of environmental quality (e.g., GHG concentration)
- Caveats:
  - Definition of proven reserves dependent on prices and technology
  - Uncertainty on stock estimates
  - Unpredictable biological growth dependent on environmental conditions

Putting “inclusive” in inclusive wealth
Natural Capital

- Natural capital that is difficult to quantify
  - Some types of environmental quality (e.g., water quality)
  - Ecological processes
  - Resilience
- Lack of systematic data collection
- Lack of knowledge about what ecological processes to monitor

Putting “inclusive” in inclusive wealth
Human capital

- Human capital:
  - Education
  - Experience
- Health capital
  - Value to additional life years
  - “Value of statistical life” and “value of statistical life year”

Putting “inclusive” in inclusive wealth
Social capital

- How should we treat institutions
  - Good governance can improve outcomes
- How should we treat relationships among people
  - Trust can improve outcomes
- Difficult to measure trust and quality of institutions
- Inclusive wealth approach tends to lump political, cultural and social assets into exogenous time trend

Measuring shadow values: the ideal world

- Assuming we are in the “best of all possible worlds” (complete and competitive markets, full information, no externalities…)
- All capital stocks have market prices (no need for shadow prices)
- Market prices reflect the contribution of capital stocks to present and future well-being

Measuring shadow values: the real world case

- Incomplete markets: do not trade in most forms of environmental quality or ecosystem processes
  - Market prices do not exist for many forms of capital (especially natural capital)
- Imperfect competition, imperfect information and externalities (market failure)
  - Market prices may yield distorted signals of relative value

Measuring shadow values: two examples of market distortions

- Pollution externalities (value of coal)
  - Market price of coal reflects its value as energy source
  - Market price of coal DOES NOT fully reflect its contribution to GHG emissions, mercury emissions, acid rain, air pollution
- To correct the problem
  - Need to know impact of coal burning on stocks of environmental quality
  - Need to have shadow values on environmental quality

Measuring shadow values: two examples of market distortions

- Open-access fisheries
  - Rent dissipation: average cost of production equals price
  - Fish stock has little (or no) social value
- If fisheries were better managed then fish stock would have value
- What value should we use for fish stock?

Measuring shadow values: measuring non-market values

- Markets do not exist for most forms of natural capital
- How do we measure the value of non-market natural capital (shadow value)?
- Non-market valuation
  - Revealed preference methods
    - Hedonic property price method
    - Discrete choice random utility models
    - Averting behavior
  - Stated preference methods
    - Conjoint analysis
    - Contingent valuation


What is this view worth?

Measuring shadow values: static approach to a dynamic problem

- Non-market valuation typically measures values under current conditions
- Shadow values should represent the contribution of the stock to present ***and future*** well-being
  - Requires understanding of range of potential future conditions (environmental, cultural, technology…)
  - Requires measuring value under potentially different conditions

Measuring shadow values: treatment of uncertainty

- Value of capital stocks: present value of flow of services generated through time
  - Dependent on future values
  - Future values dependent on future conditions
  - Future conditions are uncertain
- Treatment of uncertainty (in principle…)
  - Specify all potential future conditions
  - Specify probabilities of each potential future
  - Estimate value under each potential future
  - Find expected value: sum over all potential future conditions of the value times the probability for each potential future

  (… and I want a pony for Christmas…)

Measuring shadow values:
treatment of uncertainty

- Example: social cost of carbon
- Accurately quantifying the benefits of reducing greenhouse gas emissions is a really hard problem (really, really hard!)
- What are the reductions in future expected damages from climate change?

Measuring shadow values: treatment of uncertainty

- Large uncertainties in the science:
  - Climate sensitivity
  - Role of feedbacks:
    - Cloud formation and water vapor
    - Melting of permafrost
    - Change in albedo
  - Regional climate prediction: how will changes affect precipitations patterns, storms,…
- Large uncertainties in the economics
  - What are the costs of damages associated with climate change? (Sea level rise, storm intensity, precipitation patterns and agricultural productivity, heat waves…)
  - Costs will be affected by adaptation
- Note: large uncertainty is not an excuse for ignoring the problem

Measuring shadow values: treatment of uncertainty

- Social cost of carbon: mean estimate (2005$): ~$50 per ton C or ~$14 per ton CO2
- 95% range:
  - Low estimate: $10 per ton C ($3 per ton CO2)
  - High estimate: $350 per ton C ($95 per ton CO2)
- Incorporation of realistic uncertainty tends to raise estimates of social cost of carbon (~$160 per ton; Anthoff et al. 2009)

Summary on Task 3

- Inclusive wealth is very useful for organizing what we need to know
- We are currently far from having accurate or complete measures of all that is needed to measure inclusive wealth

Measurement challenges Arrow et al. (2010)

- Ambitious attempt to measure change in inclusive wealth for five countries (US, China, India, Brazil, Venezuela)
- How well do they do on the measurement challenges?
- Note: the authors are quite candid about methodological shortcomings and data gaps

Putting “inclusive” in inclusive wealth Arrow et al. (2010)

- Natural capital measures
  - Value of energy and mineral resources
  - Value of timber stock
  - (Negative) Value of carbon emissions
- No ecological processes, no notion of resilience, and few ecosystem services

Measuring shadow values
Arrow et al. (2010)

- Other than carbon, all natural capital values are for market values of traded commodities
- Only shadow value estimate is the social cost of carbon
  - Take central estimate from literature for which there is a large range of values

Results: natural capital Arrow et al. (2010)

UNITED STATES

	Oil	Natural Gas	Bauxite	Copper	Iron	Gold	Lead	Nickel	Phosphate	Zinc	Timber	Forest Benefits	Land	TOTAL Natural Capital
Capital Stock 1995	54.91	10.22		0.10			0.02		4.20		26.105	0.300		
Capital Stock 2000	40.28	7.50		0.09			0.02		4.00		26.976	0.302		
Change in Stock	-14.63	-2.73		-0.01			0.00		-0.20		0.871	0.002		
Average Price	20.21	102		2,231			823		42		129			
Extraction Cost	17.73	88		1,513			634		35		30			
Accounting Price	2.48	14.55		718			189		7		99	3,149		
1995 Stock Value	136.15	148.69		70.89			4.23		30.83		2578.18	946.05	1779.70	**5694.73**
Value of Change	-36.27	-39.66		-6.29			-0.45		-1.47		86.07	5.74		**7.68**

CHINA

	Oil	Natural Gas	Bauxite	Copper	Iron	Gold	Lead	Nickel	Phosphate	Zinc	Timber	Forest Benefits	Land	TOTAL Natural Capital
Capital Stock 1995	27.88	2.48	2.04	0.04	15.39	0.00	0.03	0.01			11.753	0.167		
Capital Stock 2000	22.02	2.37	2.00	0.04	15.00	0.00	0.03	0.01			12.450	0.177		
Change in Stock	-5.87	-0.12	-0.04	0.00	-0.39	0.00	0.00	0.00			0.698	0.010		
Average Price	20.21	102	25	2,231	46	10.9m	823	7,394			61			
Extraction Cost	14.18	44	17	989	10	10.7m	696	7,038			19			
Accounting Price	6.03	58.28	8	1,242	35	.207m	126	356			42	2,432		
1995 Stock Value	168.02	144.67	16.64	49.08	545.9	1.03	4.19	2.90			487.97	406.31	2027.81	**3854.52**
alue of Change	-35.36	-6.76	-0.32	-3.14	-13.77	-0.18	-0.40	-0.09			28.96	24.15		**-6.90**

Results: sustainable development Arrow et al. (2010)

Table 3: Growth Rates (in Percent) of Per-Capita Comprehensive Wealth, Adjusted for Technological Change

	(1) Comprehensive Wealth Growth Rate	(2) Population Growth Rate	(3) Per Capita Comprehensive Wealth Growth Rate, Accounting for Population Growth *[(1) - (2)]*	(4) TFP Growth Rate	(5) Per Capita Comprehensive Wealth Growth Rate, Accounting for TFP Growth *[(3) + (4)]*	(6) Per Capita GDP Growth Rate
US	1.39	1.17	0.22	1.48	1.70	2.93
CHINA	3.86	0.94	2.92	2.71	5.63	7.60
BRAZIL	1.49	1.50	-0.01	0.15	0.14	0.50
INDIA	2.60	1.74	0.86	1.84	2.70	3.99
VENEZUELA	1.15	1.98	-0.79	-2.12	-2.94	-1.20

Results: inclusion of health capital

Health dominates!

Table 5: Per Capita Components of Comprehensive Investment Including Health

(in 2000 US dollars)

UNITED STATES (per capita)

	Natural Capital	Human Capital	Reproducible Capital	Health Capital	Oil Net Capital Gains	Carbon Damages	TOTAL
1995 Capital Stock	$21,386	$225,655	$50,438	$6,300,000			$6,597,480
2000 Capital Stock	$20,205	$229,614	$56,423	$6,356,761			$6,657,550
Change 1995-2000	-$1,181	$3,959	$5,984	$56,761	-$4,845	-$608	$60,071
Percentage Change	-5.52%	1.75%	11.86%	0.90%			0.91%
Growth Rate	-1.13%	0.35%	2.27%	0.18%			0.18%

CHINA (per capita)

	Natural Capital	Human Capital	Reproducible Capital	Health Capital	Oil Net Capital Gains	Carbon Damages	TOTAL
1995 Capital Stock	$3,199	$7,049	$3,076	$1,710,857			$1,724,181
2000 Capital Stock	$3,047	$7,440	$5,126	$1,719,892			$1,735,256
Change 1995-2000	-$152	$392	$2,049	$9,035	-$242	-$7	$11,075
Percentage Change	-4.75%	5.55%	66.62%	0.53%			0.64%
Growth Rate	-0.97%	1.09%	10.75%	0.11%			0.13%

Summary

- Exercise is informative
- But…
  - Large data gaps
  - Requires many assumptions that may not be accurate
- Stark contrast between elegance of theory and limited ability to measure

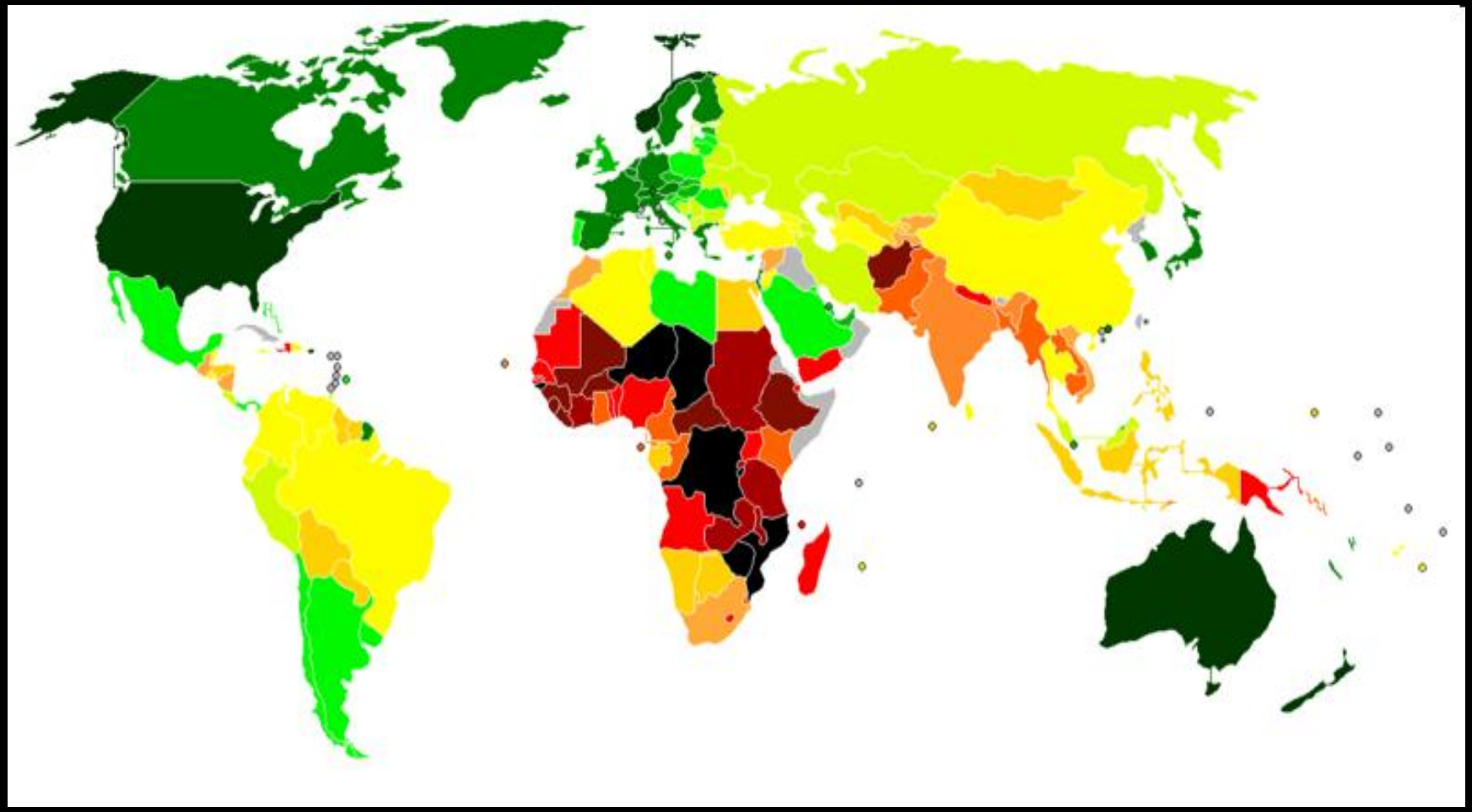
Other approaches

- Inclusive wealth: limited measurability
- What other approaches could yield useful information about sustainable development?
- Two examples:
  - Human Development Index (HDI)
  - Value of ecosystem services – Natural Capital Project: landscape level analysis

HDI

- HDI: geometric mean of
  - Life expectancy index
  - Education index
  - Per capita GDP index
- Easy to compute from readily available data
- No link to underlying theory

HDI



The Natural Capital Project:
Mainstreaming ecosystem services

Woods Institute for the Environment
Stanford University

WWF

The Nature Conservancy

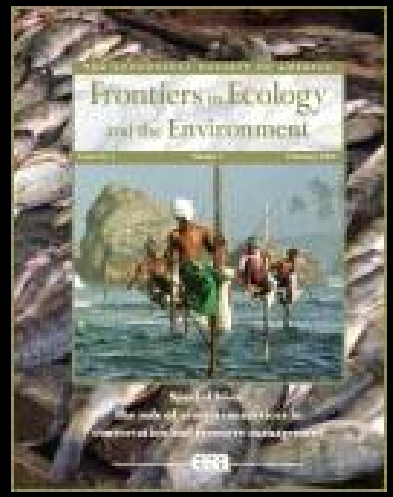
Institute on the Environment
University of Minnesota
Driven to Discover℠

natural capital PROJECT

ALIGNING ECONOMIC FORCES WITH CONSERVATION

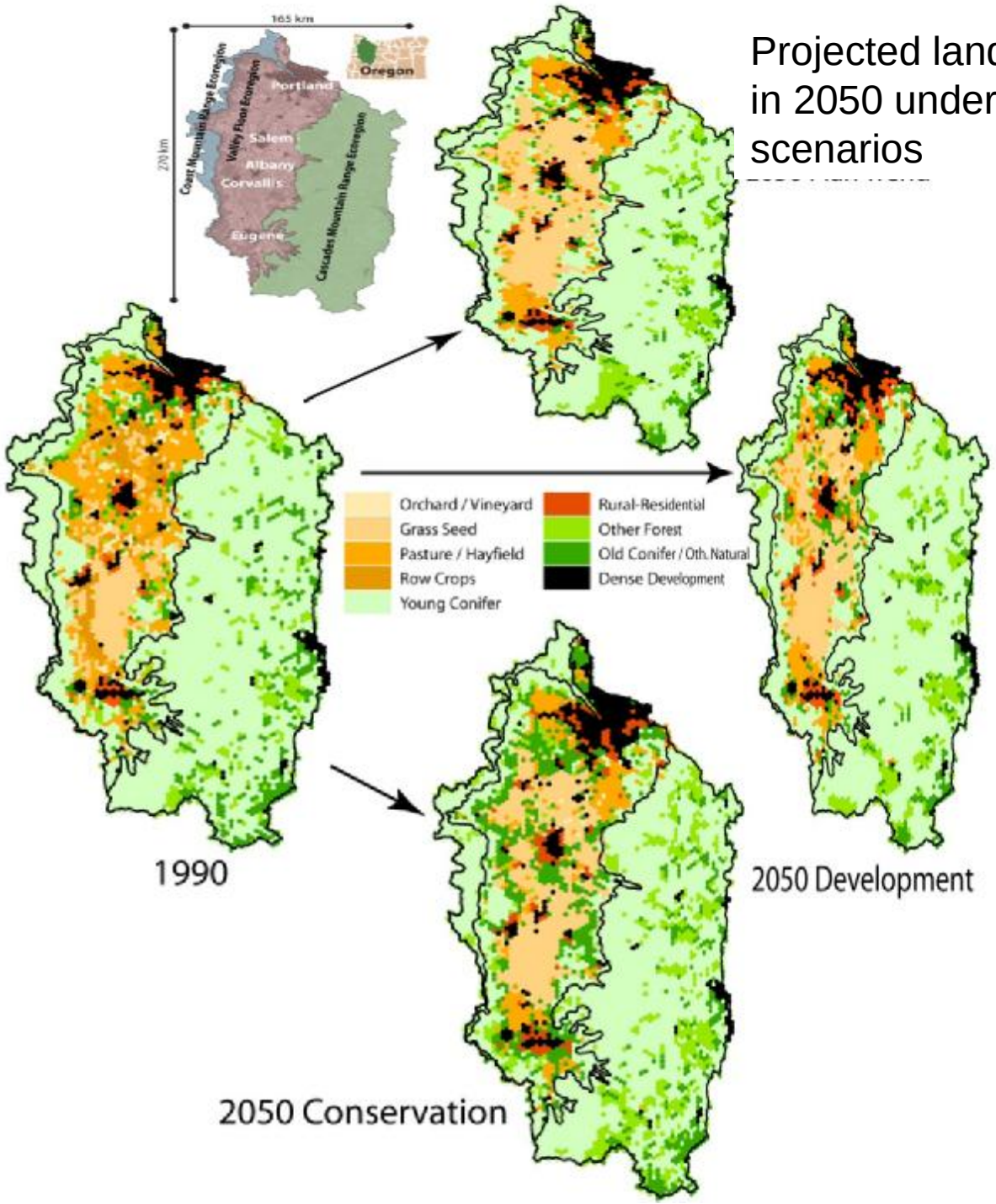
"InVEST"
Integrated **V**aluation of **E**cosystem **S**ervices and **T**radeoffs

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

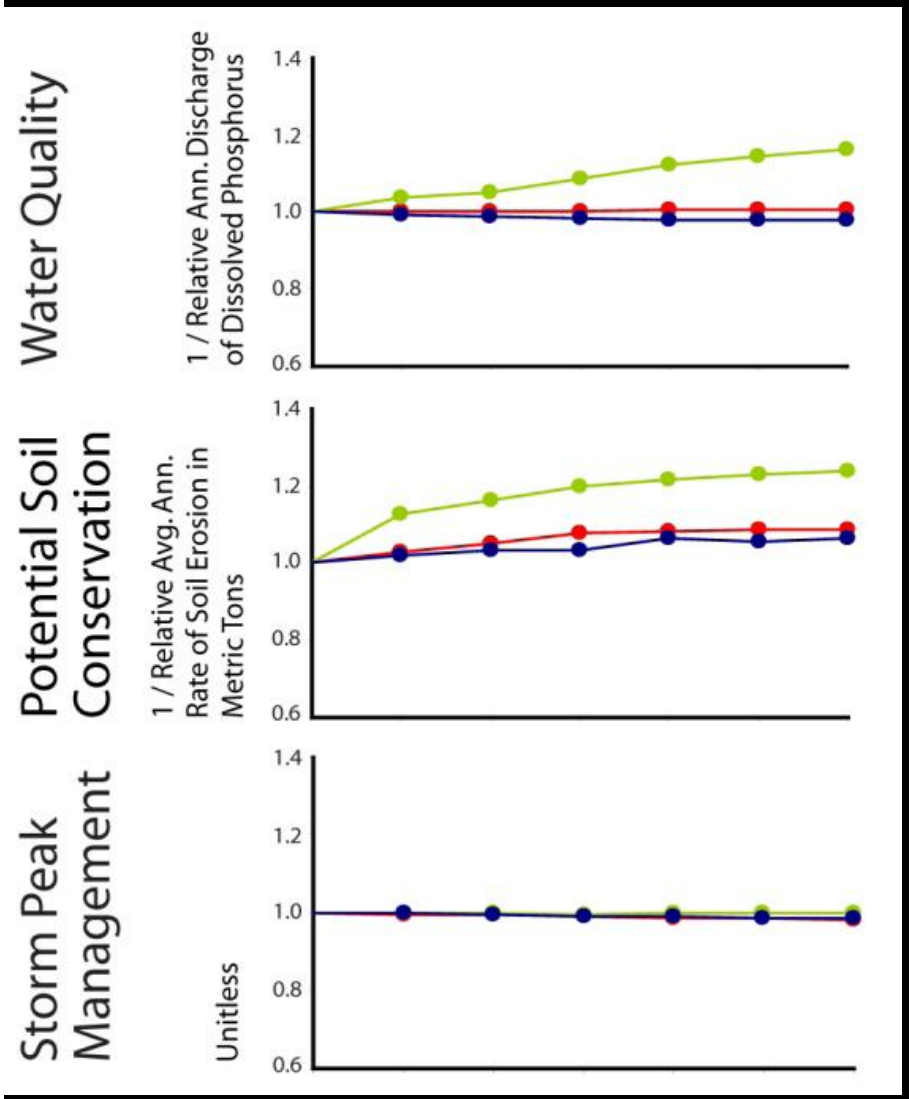


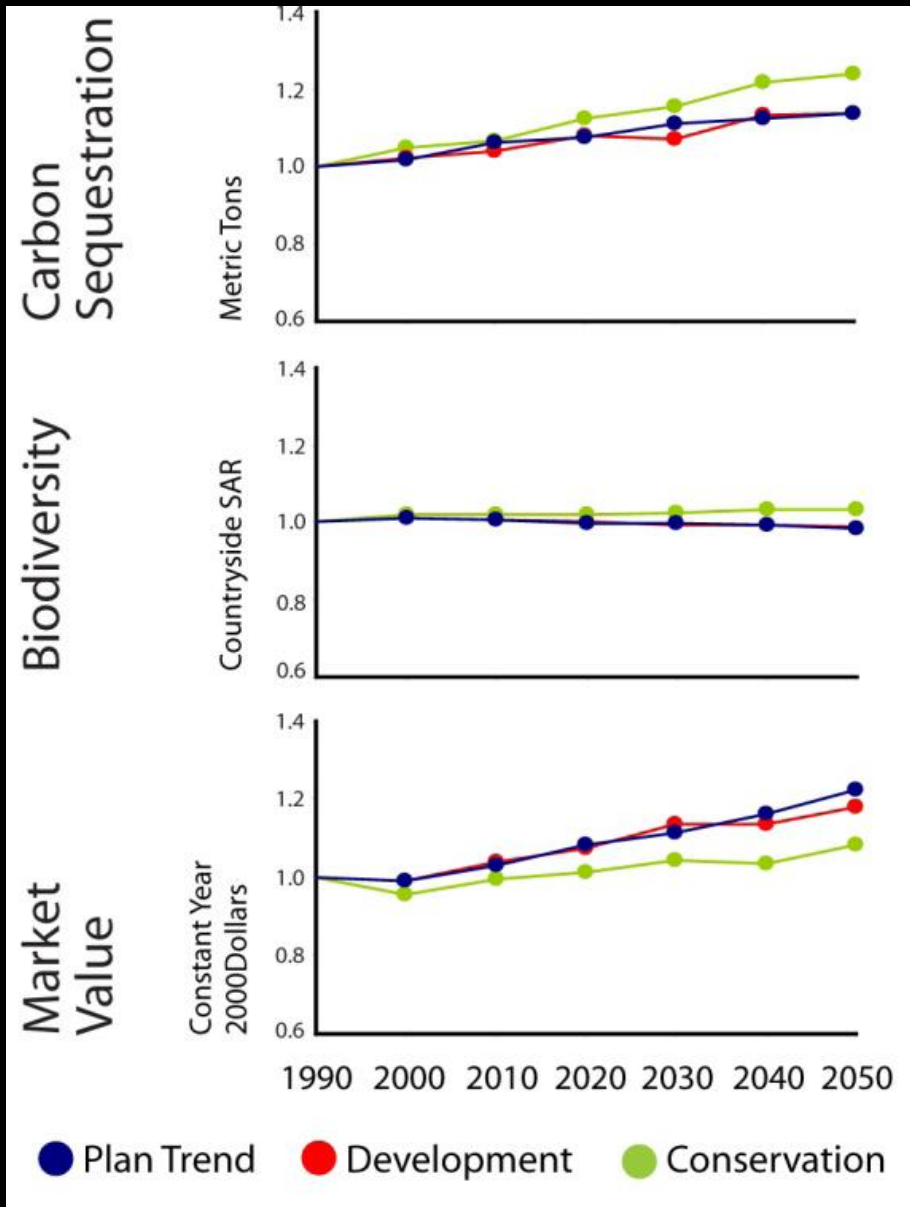
Frontiers of Ecology and Environment Feb 2009

Projected land use change in 2050 under the three scenarios



Ecosystem service outputs through time





Final note: equity

- Most measures are aggregate measures
- Is this sufficient – or do we need dis-aggregated measures that report on progress by individuals or groups?
- If we don't disaggregate, how do we know if we have development that meets the needs of all segments of society?